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Table of Contents

On the cover: Canada is the largest trading partner of the U.S. Junwook Chi analyzes the sensitivity of cross border freight volumes to income in the two countries and exchange rates. He disaggregates total freight flows into exports and imports by truck, rail, air, and pipeline in "Income and Exchange Rates Sensitivity of Cross Border Freight Flows: Evidence From U.S.-Canada Exports and Imports by Truck, Rail, Air, and Pipeline."

56TH Annual
Transportation Research Forum

CALL FOR PAPERS

The 2015 Transportation Research Forum will be held March 12-14th at The Georgia Tech Hotel and Conference Center in Atlanta, Georgia. The Forum's theme is transport logistics and innovative transportation technologies.

Papers in all areas of transportation and on all modes are welcome, with particular interest in:

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- Public-private partnerships in transportation
- Congestion and mobility
- Data innovations and transportation
- Transportation infrastructure and investment
- Green energy and transport
- Public transit innovations

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Paper and Poster Abstracts – October 31, 2014
Panel Session Proposals – November 30, 2014
Final Papers for Award Consideration – January 15, 2015

Abstracts and Proposals

Detailed instructions for submitting a paper or poster and proposals for Forum sessions and panels are available at www.trforum.org/forum. Authors may opt to present their papers in a poster session only. All presenters and panelists must register for the Forum by January 31, 2015.

TRF Paper Awards

Papers submitted by **January 15, 2015**, are eligible for the Forum's annual paper awards.

Papers authored by one or more graduate students are eligible for the Forum's *Best Graduate Student Paper Award*.

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TRF is dedicated to providing an interdisciplinary forum for the exchange of ideas among researchers, academics, practitioners and government officials for all modes of transportation, foreign and domestic.

ATLANTA

The capital of Georgia and one of the largest cities in Southeast U.S., Atlanta has a diverse economy with a global presence in logistics and transportation, professional and business services, media operations, and information technology.

QUESTIONS:

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A Message from the JTRF Co-General Editors

The Summer 2014 issue of *JTRF* contains the usual wide variety of contemporary transportation topics that is the distinguishing characteristic of *JTRF*. Topics in this issue include the following:

- Traffic speed at roundabouts
- Equity analysis of mileage-based user fees
- Visibility of overhead guide signs on highways
- Income and exchange rate sensitivities of cross border freight flow by mode
- Assessment of highway inventory data collection methods
- Effect of governance forms on North American airport efficiency
- State fiscal constraints and highway public-private partnerships

In "Modeling Through Traffic Speed at Roundabouts Along Urban and Suburban Street Arterials" Bashar H. Al-Omari, Khalid Ghuzlan, and Lina B. Al-Helo use a sample of 30 roundabouts in three cities in Jordan to analyze various characteristics of roundabouts. The authors collected data on the approaching street free flow speed, area type, entry width, circulating roadway width, exit width, and other dimensions and characteristics. They used the data to conduct a regression analysis with roundabout circulating speed as the dependent variable. The authors found that it is mainly dependent on the approaching free flow speed, internal circle diameter, entry deviation angle, entry width, and drive curve. Their average circulating speed model was found to be better than the 85th percentile speed model. The authors recommend that traffic engineers use the average circulating speed model to get more accurate estimates of the roundabouts' operating speeds.

Justin D. Carlton and Mark W. Burris using National Household Travel Survey (NHTS) data assigned transportation related taxation and expenditures to individual households in the Houston area in "Comprehensive Equity Analysis of Mileage-Based User Fees: Taxation and Expenditures for Roadways and Transit." The author found that using Gini coefficients and Theil Indices, the implementation of mileage-based user fees (MBUF) would not have a pronounced effect on the current distribution of what households pay vs. what they receive in transportation expenditures. They also found that MBUF would decrease the total number of miles traveled by 22.8% and increase transit ridership by as much as 10.2%. The relative winners from MBUF in the Houston metro area are rural and high income urban households while the relative losers are all other urban households.

In "Determining Cost-Effective Policy for Visibility of Overhead Guide Signs on Highways," Mohammed S. Obeidat, Margaret J. Rys, Eugene R. Russell, and Aditya Gund conduct two surveys to determine state policy for increasing overhead guide sign visibility. A lighting survey and a retroreflectivity survey were sent to all state departments of transportation. They found that 57% of the states currently illuminate guide signs, and the most used retroflective sheeting by states that don't illuminate signs is Diamond Grade for legend and High Intensity for background. The authors also conducted a cost analysis and they found that the LED light source and the high intensity types of retroflective sheeting are the most cost effective methods for increasing guide sign visibility.

Junwook Chi examines the long run impacts of Gross Domestic Product (GDP), real exchange rate, and the producer price index (PPI) on U.S.-Canada freight flows by mode in "Income and Exchange Rate Sensitivities of Cross-Border Freight Flows: Evidence from U.S.-Canada Exports and Imports by Truck, Rail, Air, and Pipeline." The author employs a Fully Modified Ordinary Least Squares (FM-OLS) approach to evaluate the long run impacts of economic growth, exchange rate and export price on U.S. freight exports and imports. The author finds that the GDP of the importing country is an important driver influencing U.S.-Canada cross-border trade, suggesting that economic growth of the country is a powerful factor in the relative intensity of bilateral freight flows. Chi found that the real exchange rate is positively related to U.S. imports, but negatively associated with U.S. exports, indicating that U.S. dollar appreciation against the Canadian dollar increases demand for U.S. commodities in Canada, but weakens demand for Canadian commodities in the U.S. The author also found that the Canadian GDP has a positive and significant effect on U.S. freight exports by all transportation modes, but U.S. exports by pipeline are more sensitive to a change in Canadian GDP than U.S. exports by truck and rail. Chi concluded that the findings in the paper provide important policy and managerial implications for cross-border transportation planning in the U.S. and Canada.

In "A Comprehensive Assessment of Highway Inventory Data Collection Methods," Mohammad Jalayer, Huoquo Zhou, Jie Gong, ShunFu Hu, and Mark Grinter evaluated existing highway inventory methods through a nationwide survey and a field trial of identified promising highway inventory collection (HIDC) methods on various types of highway segments. They conducted a comparative analysis to present an example on how to incorporate weights provided by state DOT stakeholders to select the most suitable (HIDC) method for the specific purpose. The purpose of the study was to identify cost-effective methods for collecting highway inventory data for implementing the Highway Safety Manuel (HSM). They evaluated several photo/video and satellite/aerial methods. Field trials for collecting HSM-related highway inventory data on four types of highway segments (rural two-lane two way roadways, rural multi-lane highways, urban and suburban arterials, and freeway) were performed to evaluate and compare various data collection methods.

Qi Zhao, Yap Yin Choo, and Tae H. Oum applied a stochastic cost frontier model to a panel of 54 major airports over the 2002-2008 period in "Effect of Governance Forms on North American Airport Efficiency: A Comparative Analysis of Airport Authority vs. Government Branch." The authors examine how the two dominant governance forms of publicly owned airports in the U.S. and Canada, namely, operation and governance by a government (city, county or state) branch or by an airport authority affect airport efficiency. The key findings are (a) the airports operated by an airport authority achieve higher cost efficiency (on average, 14% higher technical efficiency) than those operated by a government branch, (b) the airports operated by a government branch have lower labor share than those operated by an airport authority, and (c) there is no statistically significant difference in the efficiency performance between airports operated by a U.S. airport authorities and Canadian airport authorities. The authors also conclude that the stochastic frontier specification of their cost model significantly improved the accuracy of efficiency measurement, suggesting to future researchers that it is worth incorporating both the allocative efficiency and the technical inefficiency modules in stochastic frontier models for measuring our port efficiency.

In "Do State Fiscal Constraints Affect Implementation of Highway Public-Private Partnerships? A Panel Fixed Logit Assessment," Zhenhua Chen, Nobuhiko Daito, and Jonathon L. Gifford empirically test one of the claims often made regarding the motivation of states for employing public-private partnerships (P3s). The authors also empirically analyze how state P3 enabling legislation affects the behavior of both the public and private sectors. Chen and co-authors conduct the empirical analysis with a regular logit model and a fixed effects logit panel model. The authors find that after controlling for state economic conditions, legislative political affiliation and highway travel demand state fiscal constraints are not associated with the propensity to use highway P3 projects.

Michael W. Babcock
Co-General Editor

Kofi Obeng
Co-General Editor

Modeling Through Traffic Speed at Roundabouts Along Urban and Suburban Street Arterials

by Bashar H. Al-Omari, Khalid A. Ghuzlan, and Lina B. Al-Helo

A total of 30 roundabouts with different dimensions and characteristics were selected from three cities in Jordan. The collected data included the approaching road free flow speed (FFS), area type, entry width, circulating roadway width, exit width, roundabout internal and external circle diameters, circulating roadway super elevation, entry deviation angle, and drive curve. The regression analysis showed that the entry width, internal circulating diameter, entry deviation angle, approaching FFS, and drive curve were significant in determining the average and 85th percentile roundabout circulating speed. The developed model was compared with other international models developed in the United States and Italy.

INTRODUCTION

Roundabout is used worldwide for controlling at-grade intersection traffic due to its low cost and effectiveness in traffic control (FHWA 2000). The modern roundabout is a type of circular intersection with channelized approaches, yield control at entries, and geometric curvature that slow entering vehicles (FHWA 2000).

In recent years, and with the rising traffic safety problem, traffic agencies showed more interest in applying traffic calming measures as part of their strategies to improve traffic safety levels. Roundabouts are one of the major physical traffic calming measures being used worldwide and have recently received more attention in many countries like the United States (TRB 2007).

This research aimed at quantifying the role of the roundabout as a traffic calming measure in reducing traffic speeds along urban and suburban street arterials by modeling the roundabout through traffic speed as a function of the geometric and operational characteristics of the roundabout and its upstream approaches (entry road links before the roundabout).

LITERATURE REVIEW

Speed represents a fundamental issue for road design and traffic engineering studies, and it is considered as the most important variable in roundabout geometric design (FHWA 2000).

Roundabout configuration forces drivers to slow down from the speed along the upstream highway (entry road link before the roundabout), stop or yield at the roundabout area, then accelerate to the speed along the downstream highway (exit road link after the roundabout), producing different speed profiles as compared with other types of intersection control or traffic calming devices (Margarida et al. 2006).

Drivers approaching a roundabout usually reduce their speeds to safely enter the roundabout and interact with other roundabout users. Their speed choice depends on several factors, including the upstream approach width, circulating roadway curvature (curve radius of the circulatory roadway around the roundabout), and traffic volumes at the roundabout entry and circulatory roadway (FHWA 2000). Antov et al. (2009) found that the midblock speed (speed at the middle of the road link before the roundabout) and the inscribed circle diameter (diameter of the circle formed by the outer edge of the road around the roundabout) affect the roundabout speed, and noticed that roundabout speeds are up to half of the midblock speeds. Montella et al. (2012) have identified the entry path radius (the radius of the curve formed by the vehicle path at the roundabout entry), deflection radius (the radius of the curve formed by the gradual shift in the vehicle path while moving from the road link to the roundabout), and deviation angle (the angle between the straight vehicle path before entering the roundabout and the tangent line of the curve formed by the vehicle path while entering the roadway) as the main parameters that control the roundabout speeds.

Some studies have used the following AASHTO (2011) horizontal curve (a curve in the plan location which connects two straight lines to change direction gradually) design equation for estimating the roundabout circulating speed as a function of the super elevation (the vertical distance between the heights of inner and outer edges of the roadway pavement), side friction factor (coefficient of friction in the perpendicular direction to the vehicle's movement that prevents the vehicle from sliding), and vehicle path radius (radius of curve formed by a vehicle path along the horizontal curve):

The circulating speed was determined using the following AASHTO (2011) equation;

(1) $V = \sqrt{(127\ R\ (e + f\ ))}$

Where:

V = predicted speed for circulating traffic movements (km/h),

R = radius of vehicle path (m).

e = super-elevation (m/m) (inner edge of curve is lower than the outer when e is positive).

f = side friction factor.

However, its application showed an overestimation in the through movement circulating speed of around 3-5 km/h (TRB 2007).

Bassani and Sacchi (2011) have developed the following empirical model in Italy for estimating the roundabout circulating speed as a function of the internal circle diameter (diameter of inner edge of the circulatory roadway around the roundabout), circulatory roadway width (the width of the circular road around the roundabout), and roundabout entry width (the width of the road at the point where entering vehicle path crosses the external circle diameter) with $R^2_{adj.} = 0.91$ & SEE= 2.2:

(2) $V_{85} = 0.4433\ D_{INT} + 0.8367\ W_{CR} + 3.2272\ W_{EL}$

Where:

V_{85} = 85-percentile operating speed at circulating roadway (km/h).

D_{INT} = diameter of the internal circle (m).

W_{CR} = width of the circulatory roadway (m).

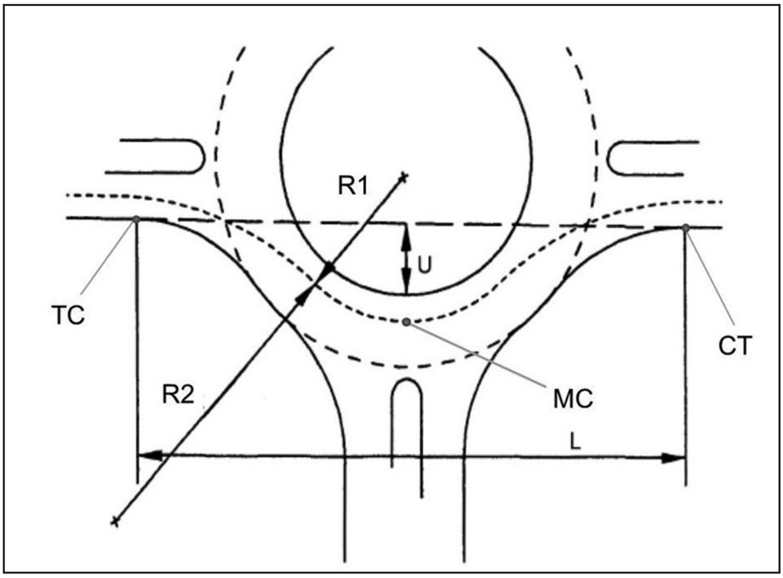
W_{EL} = width of the entry lane (m).

Chen et al. (2013) have evaluated roundabout safety utilizing the average approach speed (AAS), which was defined as the average of entry, circulating (moving around the roundabout), and exiting speeds. They estimated the AAS as a function of the average roundabout diameter (average of inscribed circle and central island diameters) and average roundabout roadway width (average of entry, circulating and exit widths). Hels and Orozova (2007) have noticed higher accident probabilities at roundabouts with larger drive curves that allow for higher driving speeds. They defined the drive curve (D) as a measure for through circulating path deflection (shift in the vehicle path while moving from the entry road link to the roundabout and then to the exit road link) over the length of the circulating path (road length inside the roundabout between points of entry and exit). It is calculated using the following equation:

(3) $$D = \frac{(0.25\ x\ L)^2 + (0.50\ x\ (U + 2))^2}{U + 2}$$

Where L, U, and other related parameters are shown in Figure 1 and defined as follows:

Figure 1: Definition of the Drive Curve



(Hels and Orozova 2007) with Modifications

D = the drive curve; which is a geometric characteristic that depends on the shift (U) and tangent distance (L)
U = the shift; which is the maximum horizontal distance between the imaginary line that represents the right side edge of the road assuming the roundabout does not exist to the left side edge of the circulating road around the roundabout at point MC
L = the tangent distance; which is the length of the straight imaginary line between points TC and CT
R1 = the internal radius of the assumed vehicle path along the circulating road
R2 = the external radius of the assumed vehicle path along the circulating road
TC = the point of transition from tangent to curve
CT = the point of transition from curve to tangent
MC = the middle point of the circulatory roadway along the vehicle path between the two points TC and CT

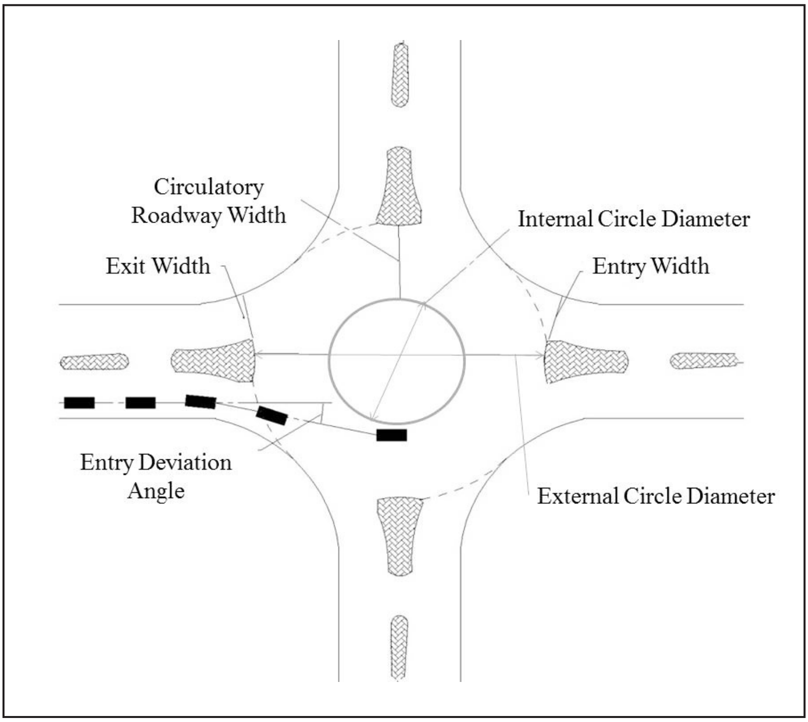
Daniels et al. (2011) found that the size of the central island does not affect the crash frequency, while the higher lateral deflection (lateral shift in the vehicle path while moving from the road link to the roundabout) at the roundabout entry tends to reduce the traffic speed, which is in agreement with Akçelik (2008).

DATA COLLECTION AND REDUCTION

A total of 30 roundabouts with different dimensions and characteristics were selected from the three major cities in Jordan: Amman, Zarqa, and Irbid (Al-Helo 2013). To avoid any bias in the collected data, the roundabouts were selected from locations with good pavement conditions, away from any upstream or downstream traffic calming measures or major traffic control devices, and with almost level and straight road alignments.

Geometric data were collected through field measurements during off peak periods, and included: roundabout external diameter (diameter of outer edge of the circulatory roadway around the roundabout), internal diameter, circulatory roadway width, entry width, exit width, entry deviation angle as shown in Figure 2, and the drive curve parameters (U, L, R) as shown in Figure 1.

Figure 2: Roundabout Geometric Elements



Also, field measurements were made for the circulatory roadway super-elevation (the vertical distance between the heights of inner and outer edges of the pavement for the circular road around the roundabout).

The speed data were collected using a laser radar gun during sunny days with dry pavement conditions and during times when there were no policemen in the area. Approaching street free flow speed (FFS) was measured at the midblock between the roundabout entry and the previous major traffic control device, or at 300m upstream of the entry, whichever is less. The roundabout circulating speed data were collected during off peak periods for the leading vehicles that have arrived at the roundabout entries when there were no conflicting vehicles present (free flow condition). The roundabout circulating speed data were measured for 100 through moving passenger cars at the middle of the circulatory roadway for each roundabout (point MC in Figure 1).

The sufficiency of the sample size was tested using equation (4) with acceptable errors (d) of 1, 3, and 5 km/h and confidence interval of 95% considering the actual speed standard deviation (S):

(4) $N = [\frac{ZS}{d}]^2$

Where:

N = Minimum sample size

Z = Number of standard deviations corresponding to the required confidence (1.96 for 95% confidence level)

S = Sample standard deviation (km/h)

d = limit of acceptable error in the average speed estimate (km/h)

It was found that the adopted sample size of 100 vehicles at each roundabout is higher than the required sample size for the three values of acceptable error (except for two roundabouts at 1 km/hour acceptable error). All roundabouts satisfied the required sample size at an acceptable error of 3 km/h, which is usually adopted in most traffic engineering studies. The terms used in this study are defined in Table 1 and a summary of the collected data characteristics are shown in Table 2.

Table 1: List of Variables Used in the Study

Variable	Symbol	Unit
Internal circle diameter[1]	D_i	m
External circle diameter[2]	D_e	m
Entry Width[3]	W_e	m
Circulatory roadway width[4]	W_c	m
Exit width[5]	W_x	m
Drive curve[6]	DC	m
Super Elevation[7]	SE	%
Entry deviation angle[8]	A_e	Radian
FFS of the upstream approach[9]	V_a	km/h
Area type[10]	AT	-

[1] Internal circle diameter = diameter of inner edge of the circulatory roadway around the roundabout.
[2] External circle diameter = diameter of the circle formed by the outer edge of the road around the roundabout.
[3] Entry Width = the width of the road at the point where arriving vehicles yield to circulating traffic then enter the roundabout.
[4] Circulatory roadway width = the width of the circular road around the roundabout.
[5] Exit width = the width of the road link after the roundabout at the point where vehicles exit the roundabout.
[6] Drive curve = geometric characteristic that depends on the shift, tangent distance, and vehicle path curve radius.
[7] Super Elevation = the vertical distance between the heights of inner and outer edges of the roadway pavement.
[8] Entry deviation angle = the angle between the straight vehicle path before entering the roundabout and the tangent line of the curve formed by the vehicle path while entering the roadway.
[9] FFS of the upstream approach = free flow speed of the entry road link before the roundabout.
[10] Area type = roundabout surrounding area type as urban or suburban.

Table 2: Characteristics of the Collected Data

Variable	W_e	W_c	W_x	D_e	D_i	DC	U	L	A_e	SE	V_a
Mean	6.6	6.73	7.33	47.4	34.37	42.1	10.6	76.5	0.31	0.25	52.0
Std. Dev	1.14	1.25	1.54	18.1	16.76	20.4	8.3	26.8	0.13	1.88	8.44
Min	4.0	4.50	5.00	18.7	9.67	18.3	00.0	35.0	0.10	-7.00	32.0
Max	9.7	10.00	11.50	87.0	70.00	95.0	29.0	151.0	0.54	4.32	67.0

ANALYSIS AND MODEL DEVELOPMENT

Regression analysis was used to estimate the roundabout circulating speed as a function of the main influencing geometric and operational factors, including upstream approach FFS, area type, entry width, entry deviation angle, circulatory roadway width, exit width, circulatory roadway super-elevation, drive curve, and external and internal diameters. Table 3 shows that the average and 85th percentile roundabout circulating speeds have high correlations (above $2/3^{rd}$) with the upstream approach FFS (0.79 and 0.75 respectively). Medium correlations (between $1/3^{rd}$ and $2/3^{rd}$) have occurred with the area type, entry width, internal diameter, external diameter, and drive curve, while low correlations (below 1/3rd) have occurred with the super elevation, circulatory roadway width, and deviation angle.

Table 3: Correlations of Variables with Average and 85th Percentile Circulating Speeds

Variable	Pearson Correlation	
	$V_{C,\ avg.}$	$V_{C,\ 85th}$
Upstream Approach FFS (V_a)	0.788	0.749
Area type (AT*)	0.570	0.543
Internal Diameter (D_i)	0.511	0.396
External Diameter (D_e)	0.491	0.372
Entry Width (W_e)	0.530	0.481
Drive curve (DC)	0.426	0.523
Super-elevation (SE)	0.286	0.332
Circulatory Roadway Width (W_c)	0.196	0.090
Exit Width (W_x)	0.070	0.033
Deviation Angle (A_e)	-0.284	-0.399

*AT = 0 (Urban), 1 (Suburban)

The Stepwise regression method (Using the IBM SPSS Statistics 19 computer package) was used to select the most significant variables for estimating the average and 85th percentile roundabout circulating speeds producing the following two models:

(5) $V_{c,85th} = 14.321 + 0.196\ V_a + 0.655\ W_e + 0.11\ D_i + 0.048\ DC - 11.96\ A_e$

With $R^2 = 0.89$, $R^2_{adj} = 0.87$, and standard error of the estimate (SSE) = 1.39.

(6) $V_{c,\ avg.} = 11.098 + 0.183\ V_a + 0.645\ W_e + 0.11\ D_i + 0.027\ DC - 9.27\ A_e$

With $R^2 = 0.93$, $R^2_{adj} = 0.92$, and SSE = 0.95

Where:
- $V_{c,85th}$ = 85th percentile circulating speed (km/h)
- $V_{c,\ avg.}$ = Average circulating speed (km/h)
- V_a = Upstream approach FFS (km/h)
- W_e = Entry width (meter)
- D_i = Internal circle diameter (meter)
- DC = Drive curve (meter)
- A_e = Entry angle (radian)

Tables 4 and 5 show that the intercept, the variables and the regression model are all significant with 95% confidence interval. The distribution of the standardized residuals for the two models showed that they satisfy the normality assumption and consistency of variance, leading to significant relationships between dependent and independent variables with no need for any transformation.

Although the two models are significant (high R^2_{adj} and low SSE values), the average roundabout circulating speed model (R^2_{adj} = 0.92, SSE = 0.95) is stronger than the 85th percentile roundabout circulating speed model (R^2_{adj} = 0.87, SSE = 1.39) as it has higher R^2_{adj} and lower SSE values. This is because the average speed is more representative of different vehicles speeds and more sensitive to the effects of the influencing factors than the 85th percentile speed.

Table 4: Statistical Characteristics of Model 5

Source	Sum of Squares	Df	Mean Square	F	Sig.
Regression	377.094	5	75.419	38.524	.000
Residual	46.985	24	1.958		
Total	424.078	29			
R^2 = 0.889, R^2_{adj} = 0.866, and SSE = 1.39					
Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	14.321	2.312		6.193	0.000
W_e	0.655	0.251	0.198	2.606	0.016
D_i	0.107	0.020	0.467	5.490	0.000
DC	0.048	0.016	0.238	2.963	0.007
V_a	0.196	0.037	0.434	5.322	0.000
A_e	-11.964	2.915	-0.400	-4.104	0.000

Table 5: Statistical Characteristic of Model 6

Source	Sum of Squares	Df	Mean Square	F	Sig.
Regression	297.347	5	59.469	61.067	.0000
Residual	23.372	24	.974		
Total	320.719	29			
R^2= 0.931 and R^2_{adj} = 0.917 and SSE=0.95					
Variable	Unstandardized Coefficients		Standardized Coef-ficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	11.098	1.631		6.805	0.000
W_e	.645	.177	.224	3.640	0.001
D_i	.110	.014	.548	7.941	0.000
DC	.027	.011	.155	2.374	0.026
V_a	.183	.026	.465	7.028	0.000
A_e	-9.268	2.056	-.356	-4.507	0.000

These models are consistent with the Bassani and Sacchi (2011) model in terms of estimating the roundabout circulating speed as a function of the internal circle diameter and entry width. However, the circulatory roadway width was included in the Bassani and Sacchi (2011) model, while it is replaced by the upstream approach free flow speed, drive curve, and entry angle in this study's models.

The average and 85th percentile roundabout circulating speeds are directly proportional to the upstream approach free flow speed, entry width, internal circle diameter, and drive curve, while they are inversely proportional with the entry angle.

The area type was not significant in the two models as its effect is already considered in the upstream approach free flow speed. Suburban streets usually have higher free flow speeds than urban streets.

As entry width increases, drivers can have more flexibility in choosing their path while entering the roundabout such that they can keep higher speeds, especially during low traffic volume and free flow conditions. Also, increasing the entry width reduces the deflection (horizontal deviation in the vehicle movement at entry due to entry curvature) imposed on vehicles at entry which allow for lower curvature that reduces the side friction with adjacent objects at the entry (Margarida et al. 2006). The exit width was not significant in the model because it is located downstream of the circulatory roadway midpoint, where speed measurements were conducted.

Increasing the drive curve reduces the curvature in the driver's path inside the roundabout, which results in an increase in the circulating speed. This is consistent with the Hels and Orozova (2007) study, which found that roundabouts with larger drive curves had higher driving speeds.

The entry deviation angle is inversely proportional with circulating speed, which is in agreement with Daniels et al. (2011). This is expected as increasing entry curvature increases entry angle and leads to a decrease in the entry speed (Montella et al. 2012).

The size of the internal circle diameter has a significant effect on the circulating speed, as it determines the curvature of the driver's path, which in turn determines the speed at which drivers can travel along the roundabout circulating roadway. This is consistent with the AASHTO (2011) horizontal curve design equation and the Bassani and Sacchi (2011) models. The roundabout external diameter was not significant in the models because drivers tend to move along the left side of the circulating roadway to reduce the curvature effect and keep relatively higher speeds; so the internal diameter was more important than the external diameter. The circulatory roadway width was also not significant in the models because it has more influence on the roundabout capacity rather than circulating speed. Furthermore, the circulatory roadway super-elevation was not significant in the models because not much variability was observed in this factor between the selected roundabouts for this study.

COMPARISON WITH OTHER MODELS

Comparisons were made between the proposed model in this study with the predictions based on Bassani & Sacchi (2011) and AASHTO (2011) models.

In order to estimate the circulating speed using the AASHTO (2011) equation (1), the vehicle path radius while circulating was assumed equal to the internal circle radius plus 1.5 m as recommended by TRB (2007). The super-elevation was measured from the field using the Level surveying instrument. The side friction factor was estimated as a function of speed using the AASHTO (2011) design charts. The estimated side friction values were in the range of (0.25-0.35) corresponding to speed values of (20 to 37) km/h.

In using the Bassani & Sacchi (2011) model, the required geometric parameters are the entry and circulatory roadway widths and the internal circle diameter that were collected from the field in this study for all roundabouts.

Both AASHTO (2011) and Bassani & Sacchi (2011) models were applied to this study's roundabouts based on the collected field data, and the predicted circulatory speed results were plotted against the observed data as shown in Figures 3 and 4. It can be seen that the roundabout circulating speed values are underestimated by the AASHTO (2011) equation and overestimated by the Bassani and Sacchi (2011) model. The developed models in this study have shown much better estimations for the measured roundabout circulating speed values as shown in Figures 5 and 6.

The paired t-test was used to check if the differences between the actual and predicted circulating speed are significantly far from zero. Table 6 shows that, with 95% confidence, there are significant statistical differences between the actual and predicted circulating speed by the AASHTO (2011) model (mean of 7.38 km/h, standard deviation of 5.41, t-ratio of 7.47, and P-value < 0.05) and Bassani & Sacchi (2011) model (mean of -10.52 km/h, standard deviation of 8.32, t-ratio of - 6.93, and P-value < 0.05). Thus, the hypothesis that the deviations are equal to zero is rejected for the two models.

Figure 3: AASHTO (2011) Equation Predictions vs Measured 85th Roundabout Circulating Speeds

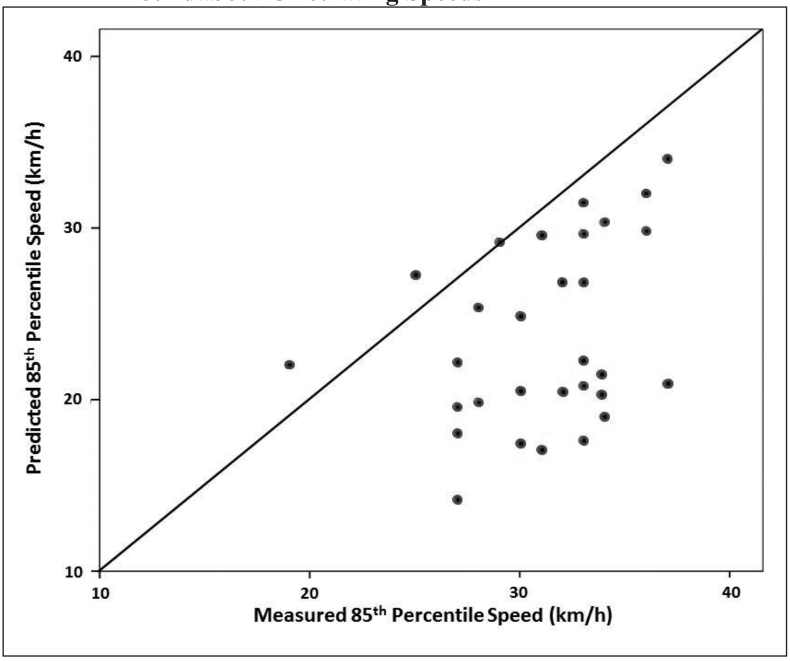


Figure 4: Bassani & Sacchi (2011) Model Predictions vs Measured 85th Roundabout Circulating Speeds

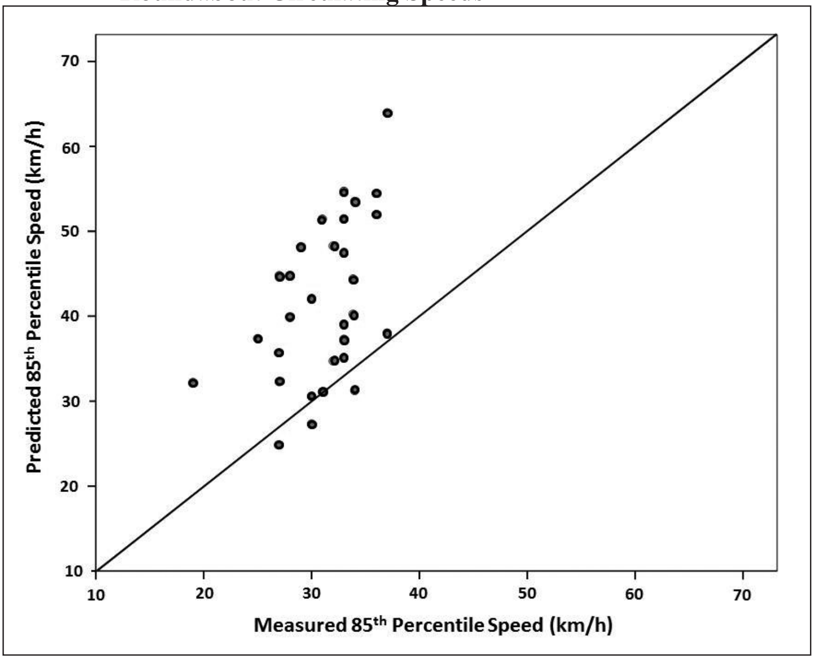


Figure 5: Proposed Model (Model 5) Predictions vs Measured 85th Roundabout Circulating Speeds

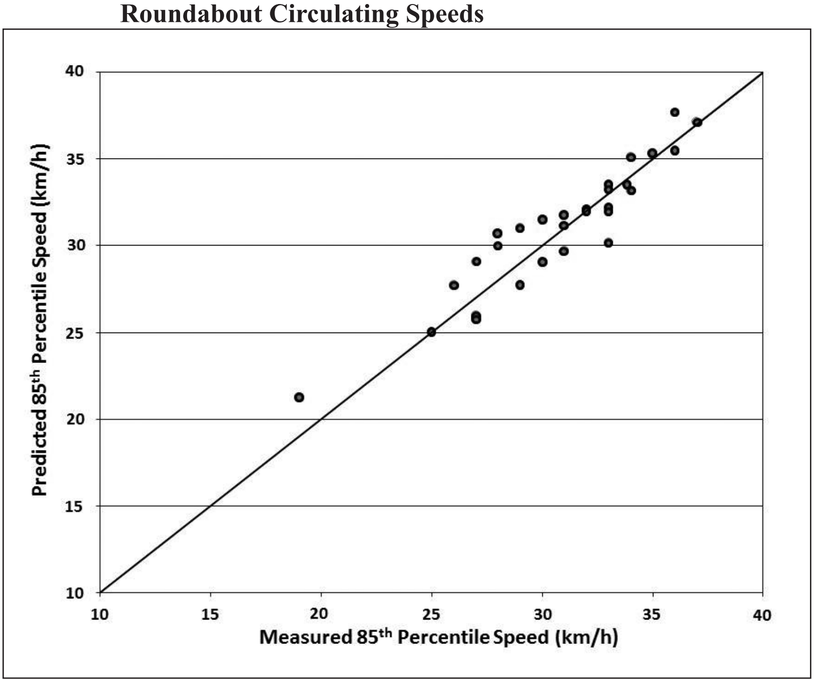


Figure 6: Proposed Model (Model 6) Predictions vs Measured Average Roundabout Circulating Speeds

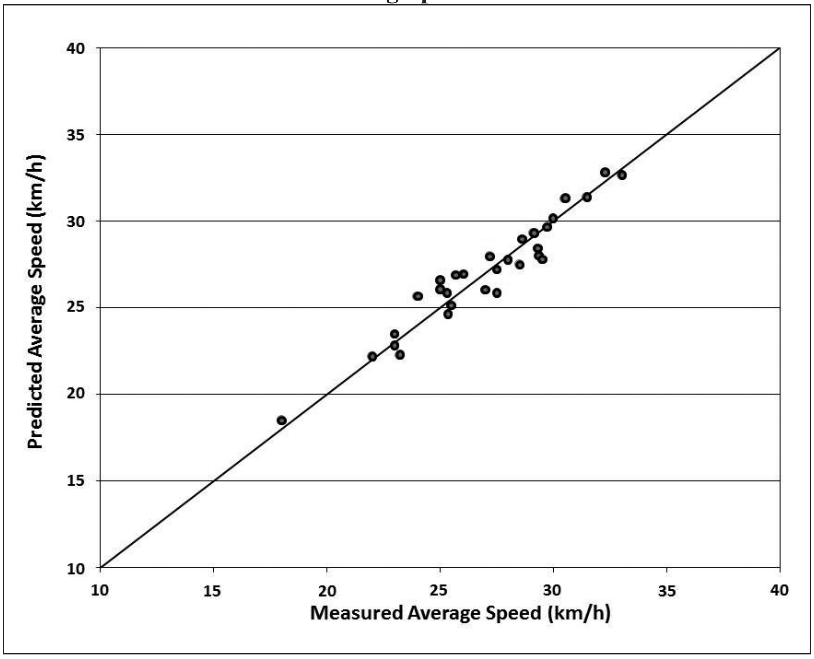


Table 6: Paired t-Test for Comparing the Developed Model with AASHTO (2011) and Bassani & Sacchi (2011) Models

Pairs	Mean	ST. DEV	SE. MEAN	T	P-value
Observed Vs. Predicted by AASHTO Model	7.38	5.41	0.99	7.47	0.000
Observed Vs. Predicted by Bassani & Sacchi Model	-10.52	8.32	1.52	-6.93	0.000

The measured circulating speeds were also regressed against the computed values using the AASHTO (2011) and Bassani & Sacchi (2011) models. The results showed R^2 of 13.5 % and SEE of 3.77 for the AASHTO (2011) model, and R^2 of 25.5 % and SEE of 3.50 for the Bassani & Sacchi (2011) model. The developed models in this study have much higher R^2_{adj} and lower SSE values; (R^2_{adj} = 0.866, SSE = 1.39) for model 5 and (R^2_{adj} = 0.917, SSE = 0.95) for model 6.

These differences may refer to the fact that these models did not consider all the influencing factors in addition to the differences in driver behavior between developed and developing countries.

SUMMARY AND CONCLUSIONS

This study aimed at quantifying the roundabout's role as a traffic calming measure in reducing traffic speeds along urban and suburban street arterials by modeling the through traffic speed at the middle points of the roundabout's circulatory roadways as a function of the geometric and operational characteristics of roundabouts and their upstream approaches.

Field data were collected from 30 roundabouts with different dimensions and characteristics, selected from three major cities in Jordan: Amman, Zarqa, and Irbid. The collected data included the approaching street free flow speed, area type, entry width, circulating roadway width, exit width, roundabout internal and external circle diameters, circulating roadway super elevation, entry deviation angle, and drive curve.

Based on the regression analysis, it was found that the roundabout circulating speed is mainly dependent on the approaching street free flow speed, internal circle diameter, entry deviation angle, entry width, and drive curve. The circulating speed is inversely proportional with the entry deviation angle, while it is directly proportional with all other variables. This implies that roundabouts' traffic operating speeds can be reduced by increasing the entry deviation angle or reducing the approaching street free flow speed, internal circle diameter, entry width, and drive curve. The average circulating speed model was found to be better than the 85^{th} percentile speed model. It is recommended that traffic engineers use the average circulating speed model to get more accurate estimates for the roundabouts' operating speeds.

Significant differences were found between the measured roundabout circulating speeds and their corresponding predicted values by the AASHTO (2011) equation and Bassani & Sacchi (2011) model. These differences may refer to the fact that these models did not consider all the influencing factors in addition to the differences in driver behavior between developed and developing countries.

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Comprehensive Equity Analysis of Mileage-Based User Fees: Taxation and Expenditures for Roadways and Transit

by Justin Carlton and Mark Burris

Using National Household Travel Survey data and information collected from over 100 agencies, transportation-related taxation and expenditures were assigned to individual households in the Houston Core Based Statistical Area (CBSA). Using Gini Coefficients and Theil Indices, the research demonstrated that implementation of a Mileage Based User Fee (MBUF) would not have a pronounced effect on the current distribution of what households pay versus what they receive in transportation expenditures. The relative winners are rural and high income urban households, while the relative losers are all other urban households.

INTRODUCTION

The fuel tax in the State of Texas, which consists of $0.20 applied to each gallon of gasoline purchased, has not increased since 1991. Both the Texas gasoline tax rate and the Texas diesel tax rate rank 40th in the country, with only 10 states having a lower tax rate (API 2013). From 1991 to 2013, the State of Texas fuel tax has lost 40% of its purchasing power due to inflation (BLS 2013). From 1980, the vehicle miles traveled in the Unites States increased by 95.5%, while the lane-miles have only increased by 8.8% (OHPI 2008). Even though mileage is increasing, experts estimate that average fuel consumption will drop by as much as 20% by 2025 due to increasing fuel efficiencies (TRB 2006). The Obama administration recently finalized regulations to increase the fuel efficiency of cars and light duty trucks to 55.4 mpg by 2025, which will only exacerbate the difficult financial situation (NHTSA 2012).

According to the Texas Transportation Needs 2030 Committee, it will take a total investment of $270 billion dollars by 2035 in order to maintain current conditions and avoid a devastating $1.7 trillion economic burden due to wasted fuel, time, and maintenance costs (Texas 2030 Committee 2011). While insufficient investment is a critical issue, it is not the only problem. The prices paid by users often do not reflect the true costs of that service nor do they reflect the true social costs in terms of delay and pollution. "This underpayment contributes to less efficient use of the system, increased pavement damage, capacity shortages, and congestion" (NSTIF 2009). An analysis of nine midwestern communities revealed that 80% of local funding was derived from mechanisms unrelated to road use (Forkenbrock 2004).

The issues presented demonstrate the primary weakness of the fuel tax as well as the issue with it going forward; it is not tied directly to roadway use. The lack of revenue sustainability has generated concern over the fuel tax's ability to meet infrastructure needs, and the potential drastic consequences have prompted extensive research into funding alternatives for our transportation related infrastructure. One such option is the Mileage-Based User Fee (MBUF), often called the Vehicle Miles Traveled (VMT) Fee. A mileage based user fee would charge road users according to the number of miles they drive, thus holding them accountable by directly tying the costs of road use to the benefits received. Over time it has become the consensus of transportation experts and economists that a MBUF system should be considered the leading alternative to the fuel tax (CBO 2011). Previous MBUF initiatives demonstrate how such a system could work and show how it could lead to a more equitable and efficient use of the roadway (GAO 2012). Additionally, MBUFs may reduce congestion simply because the true cost of driving is more visible to drivers (NSTIF 2009). These are among the reasons why an MBUF is an attractive alternative.

As with any method of taxation, equity becomes a primary concern. Transportation equity is defined as the actual and perceived "fairness" of how cost and benefit impacts are distributed (Litman 2002). While numerous studies have evaluated MBUF equity, none have addressed or included transportation spending, only revenue generation. This means that the big picture of how transportation taxation and expenditures interrelate is not well understood, i.e., how much does each household pay in transportation-related taxes and how much do they benefit from roadway and transit expenditures? Understanding the myriad of potential equity issues involved in both transportation taxation and spending is critical due to the widespread public mistrust of governmental agencies' ability to handle money (Cronin 2012; Grant Thornton 2010). This paper addresses these issues by focusing on the relation between transportation taxation and spending in the Houston Core Based Statistical Area (CBSA).

LITERATURE REVIEW

Mileage-Based User Fees

MBUFs have become one of the most attractive alternatives to the fuel tax (CBO 2011; Larsen et al. 2012). Some of the benefits of MBUFs include increased cost recovery for new facilities, congestion management and traffic reduction, the ability to privately finance roadways, possible incentives for fuel efficient vehicles through lower rates, and a greater wealth of data for use in improving planning models (Forkenbrock and Hanley 2006).

There are several options for MBUF implementation, and they vary in complexity. Several factors are key in MBUF implementation, though privacy is often the primary concern of the public. Drivers in one study almost exclusively preferred the high privacy option (Hanley and Kuhl 2011). The appropriate application of technology is a struggle between accountability, flexibility, and privacy. Implementation methods include odometer readings (Kavalec and Setiawan 1997; NCHRP 2009; Whittey 2007), use of cell phone technology (Battelle 2013; NCHRP 2009; Whittey 2007), and onboard units (OBUs) utilizing global positioning systems (GPS) and radio frequency (RF) technology (Forkenbrock 2005; Hanley and Kuhl 2011; Puget Sound Regional Council 2008; Whittey 2007).

One of the most notable studies took place in Portland, Oregon. In the study, an onboard GPS receiver calculated the fees (rush hour miles, in-state miles, out-of-state miles) and transmitted them via RF to the fuel pump, which then charged the driver the required fee (Whittey 2007). One of the primary benefits of this system is that it can be easily fit into existing infrastructure and would allow drivers to pay their fees with their preferred payment method. It also eliminates the issue of interstate travel. Should someone from another state drive through Oregon, they would pay the fuel tax when refueling as they would do normally. Additionally, there is little incentive for tampering, since users will be charged the regular gas tax if the onboard device is not functional. This also allows for the system to be phased in slowly (Whittey 2007). As the system develops, charges could be implanted for local communities as well, potentially reducing property and other local taxes (Forkenbrock 2005).

These initiatives and studies listed above have demonstrated that current technology is mature, reliable, and capable of handling a MBUF system, making it a very possible reality. Given that implementation is technically feasible, the potential impacts of such a fee will receive greater scrutiny.

Equity

Equity concerning transportation usually refers to the actual and perceived "fairness" of how cost and benefit impacts are distributed. As would be expected, fairness is subjective and difficult to define. One must consider several types of equity, impacts, measures, and categories of people (Litman 2002).

There are two primary classifications of equity. Vertical equity concerns the distribution of impacts between individuals or groups with different needs and abilities. A policy is *progressive* if it favors disadvantaged groups since it makes up for existing inequities. A policy is *regressive* if it excessively burdens the disadvantaged (Litman 2002). Typically, when the type of equity is not specified, it usually concerns vertical equity. The income tax is considered vertically equitable since those with higher incomes are subject to a higher tax bracket. This type of equity is based on the "ability to pay" principle, which states that "consumers of governmental goods and services should pay according their ability to pay, with lower income individuals paying less relative to those with higher income" (Baker, Russ, and Goodin 2011). Public transit and paratransit address this type of equity (NSTIF 2009).

Horizontal equity concerns the distribution of impacts between individuals or groups with equal ability and need. In other words, "equal individuals and groups should receive equal shares of resources, bear equal costs, and in other ways be treated the same" (Litman 2002). Therefore, no individuals or groups should be favored over others. The income tax is criticized in this area because there are various exemptions that allow households with the same income to pay different amounts. The "benefits" principle is the basis for this type of equity, which states that "those who pay a tax should be those that benefit from the public goods and/or services that are received" (Baker, Russ, and Goodin 2011). Geographic equity falls into this category and "refers to the extent to which users and beneficiaries bear the cost burden for the portions of the system they use or benefit from, based on their geographic proximity to those portions" (NSTIF 2009).

Studies show the fuel tax to be regressive when compared to driver income (CBO 2011; Larsen et al. 2012; Weatherford 2012). Additionally, those studies suggest that an increase in either fuel tax or MBUFs would be less regressive. One study indicated that low-income drivers pay more through a flat sales tax than they would through an MBUF (Schweitzer and Taylor 2008). A recent study by Larsen applied different MBUF rate structures for fuel efficiencies as well as for urban and rural driving for Texas travelers (Larsen et al. 2012). Results demonstrated that vertical equity changes were minor. These results were similar to a previous study of Oregon drivers by Zhang (Zhang et al. 2009). MBUF tax structures that take into account fuel efficiency, weight, and other measures may not be worth implementing simply because the differences are very small on a per-month basis for users (Whittey 2007). Another important finding is that increasing the revenue may make the tax more regressive (Larsen et al. 2012; NSTIF 2009). There is also evidence to suggest that rural households would pay less under a mileage fee system (CBO 2011, McMullen et al. 2010).

DATA

National Household Travel Survey

The 2009 National Household Travel Survey (NHTS) is a compilation of data collected from over 150,000 households across the United States and is available for download on its website (nhts.ornl.gov). The Texas Department of Transportation (TxDOT) paid for 20,000 add-on surveys, bringing the total for the State of Texas to 22,255 households and over 45,000 vehicles. Included in the survey data are variables for household income, vehicle type, vehicle fuel efficiency, annual vehicle miles traveled, average price of fuel, and other important data that allow for easy computations without relying heavily on estimation (NHTS 2011). Additionally, the NHTS data include weights so each household in the survey is representative of the population.

Missing values throughout the data set are perhaps the primary obstacle to its effective use. In order to perform an analysis, these missing values need to be addressed. Additionally, according to the NHTS weighting report, the Texas data were weighted to reflect the state as a whole, without any subareas. Since the analysis in this research concerned only the Houston CBSA, these existing weights may not properly reflect the demographics in the area (Rizzo et al. 2010). For this reason, the survey was filtered and re-weighted.

Filtering. The first step in the filtering procedure was to eliminate golf carts, jet skis, or other non-roadway vehicles. Consequently, this also means that households with zero vehicles were removed from the vehicle survey file, leaving 44,964 valid vehicle surveys.

Missing data were addressed using pairwise deletion, where only surveys with missing variables relevant to the analysis were removed. Following this, any surveys with negative values for the income, race, Hispanic status, urban/rural, best mile (VMT), fuel economy, or hybrid variables were eliminated. Several variables, such as household size, were not missing any values due to their having been hot deck imputed for the original NHTS weighting (Rizzo et al. 2010). When using hot deck imputation, a missing entry is randomly assigned a value from a non-missing donor entry. These donors are selected from a group based on eligible criteria that prevents unrealistic combinations (for example, no seven-year-old drivers). The "Other Trucks" vehicle type variable category was also filtered out, as it could include any number of vehicle types. Since the survey focused on households, it was not practical to include large trucks because they are more often associated with commercial businesses. Additionally, large trucks pay very different fees compared with regular vehicles. For these reasons, the survey would not be representative of the population, thus large trucks were not included. Finally, incomplete surveys (where not all eligible household residents filled out the survey) were filtered out in order to ensure that any unknown bias would not influence the analysis (for example, ensure public transit use was accurate to the household). Table 1 displays the surveys before and after filtering for each area. The percent of retained surveys suggests uniformity across the CBSAs, indicating that no area is substantially different in terms of survey completion.

Table 1: NHTS Surveys Before and After Filtering by Area

Area	Survey Households Before Filtering	Survey Households After Filtering	Surveys Retained	Survey Vehicles Before Filtering	Survey Vehicles After Filtering	Survey Vehicles Retained
State of Texas	22,255	16,978	76.3%	44,964	33,287	74.0%
Austin CBSA	1,543	1,211	78.5%	3,073	2,340	76.2%
Dallas/Fort Worth CBSA	5,875	4,521	77.0%	11,971	8,962	74.9%
Houston CBSA	4,043	3,004	74.3%	8,054	5,828	72.4%
San Antonio CBSA	2,054	1,590	77.4%	4,099	3,107	75.8%

Weighting. The filtered results (Table 1) needed to be re-weighted to better represent vehicle owning households in Texas. An iterative raking method was used for the weighting procedure, often called proportional fitting, where weights are iteratively adjusted to independent control totals for various demographic categories. Control totals are simply the total number of households in a given strata. For example, in 2008 there were 695,170 households in the Houston CBSA with one vehicle. The original NHTS weights for each household were used as the default starting values.

Due to the data filtering, the summation of these weights, broken down into their respective strata, don't equal the control totals. For each iteration, these weights were multiplied by the average fraction required to cause them to sum to their respective strata control totals. This in turn causes the required fraction to change. Over many iterations, the fractions converge to a value of 1, yielding a set of household survey weights representative of the general population. The final weights were accurately disaggregated by household size, family income, race, Hispanic status, vehicle count, worker count, urban/rural location, home ownership, and CBSA location. The average weights for each area are shown in Table 2.

Table 2: Average Survey Weight by Area

Area	Households in Area	Number of Surveyed Households (After Filtering)	Average Number of Households Each Survey Represents (Total Households / Surveyed Households)
State of Texas	8,527,938	16,978	502
Austin CBSA	637,229	1,211	526
Dallas/Fort Worth CBSA	2,201,105	4,521	487
Houston CBSA	2,004,427	3,004	667
San Antonio CBSA	738,162	1,590	464

The control totals utilized in the weighting procedure were obtained from the American Community Survey (ACS) through the American Fact Finder website of the United States Census Bureau (factfinder2.census.gov). Control totals for the number of urban and rural households were determined based on data from the 2000 and 2010 United States Census. Since census years (2000 and 2010) were different from the ACS year (2008), the number of urban and rural households in 2008 was interpolated from the 2000 and 2010 census numbers.

The NHTS variable categories were adjusted to match the ACS categories. For example, any NHTS entry with four or five plus workers per household was considered a three plus worker household, as the ACS survey only had groups for one, two, and three plus workers per household. This effort provided the control totals (actual number of households in each strata). Maximum and minimum weights were set in order to prevent over sensitivity to a specific strata (Battaglia et al. 2004). The values for the maximum and minimum weights were 3,500 and 70, respectively. A total of 2.0% of the households exceeded the maximum weight and were thus given a weight of 3,500. A total of 5.6% of the households were below the minimum weight and were thus given a weight of 70. The final weighted totals closely matched the ACS control totals. Dallas/Fort Worth, Houston, and San Antonio were within two households of their respective variable category control totals for all variables.

The NHTS data set includes a set of 100 replicate weights, which are used to calculate more accurate standard errors when doing statistical analysis of weighted survey data. These replicate weights were put through the same weighting procedure as the survey data. These revised replicate weights are used in this research whenever standard errors and confidence intervals of the survey results are reported. For further information on how to calculate standard errors using the NHTS dataset, consult chapter seven of the NHTS User Guide (NHTS 2011).

Based on the re-weighted data set, there was no statistical difference between the demographics of the four Texas CBSAs (Austin, Dallas/Fort Worth, Houston, and San Antonio). For example, the average fuel efficiency for low income households was the same in each of the four CBSAs. For this reason, the results of the analysis are likely applicable to the other CBSAs in Texas with public transit services.

Transportation Taxation and Spending in the Houston Area

In order to provide a complete perspective for a MBUF, the entire system in which it operates needs to be understood. To achieve this aim, transportation related taxation and spending information was collected from the sources listed in Table 3 and is presented in Table 4.

State Level. The State of Texas imposes a tax on motor fuel purchases of $0.20 per gallon. Additionally, the US Government imposes a $0.184 and $0.244 per gallon tax on gasoline and diesel, respectively. Fuel tax is reported directly to the state by individual businesses, thus no information is collected disaggregated at the county level (David Reed pers. comm.). As the NHTS data allow the fuel tax to be directly calculated, total fuel revenues were not required. In addition to this, Texas collects a 6.25% sales and use tax on motor vehicles as well as a tax on motor oil (Texas Comptroller of Public Accounts 2013). The State also collects a motor vehicle registration fee. In 2008 this fee was $40.80, $50.80, and $58.80 for 2002 and older models, 2003-2005 models, and 2006 and newer models, respectively. All of these are deposited into the State Highway Fund, 25% of which is then deposited into the school fund. The remaining amount is available for use by TxDOT.

Drivers license fees, vehicle inspection fees, driver record request fees, motor carrier penalties, state traffic fines, and proceeds from the driver responsibility program are deposited into the Texas Mobility Fund, which TxDOT uses to finance mobility related projects (Legislative Budget Board 2006). TxDOT also distributes grants for small transit related entireties (TxDOT 2008). The average inspection fee per vehicle was $4.62, which was determined by dividing the total Texas revenue from inspections ($86,166,829) by the total registered vehicles in Texas (18,647,093). This is just the fee collected by the state; actual inspection prices reflect the respective businesses' charge for the service and are not included. The average fee for drivers licenses and driver record requests was $11.69, which was determined by dividing the total Texas revenue from fees ($179,667,613) by the total number of registered drivers in the state (15,374,063). As drivers licenses are not a regular annual expense, an average is appropriate.

County Level. The Texas Constitution allows for local entities to collect up to a combined 2% sales tax (Texas Comptroller of Public Accounts 2013). Austin, Brazoria, Liberty, and San Jacinto counties collect a 0.5% sales tax while the municipalities collected an average sales tax of 1.43% (www.window.state.tx.us/ taxinfo/local/city.html). Texas also allows counties, which are often in charge of collections, to add an additional fee to their vehicle registrations (See Table 4). Property taxes ($/$100 of assessed value) are set by the local entity and stack on top of each other. For example, one household may pay property taxes to the county, the city, a school district, utility districts, and a special development district.

Some counties and cities have a designated fund or department devoted to transportation, though this does not always include all their transportation spending (overhead and grants are often not included). In order to obtain a reasonable estimate for county level transportation-related taxation, the total county tax rates were multiplied by the percent of total revenue spent on transportation. This information is also presented in Table 4. For example, the property tax for Brazoria County, not including school or other districts, was .39000$^{\$/\$100}$, and the county spent 18.79% of its total revenue on transportation. Multiplying the two yields .07329$^{\$/\$100}$, which is an estimate of the average tax paid toward transportation expenditures. Additionally, the county sales tax was multiplied by the 18.77% spent on transportation to get 0.094%, which is the average sales tax diverted to transportation.

Table 3: Data Sources

Data	Source	Web Address
Population	United States Census Bureau	factfinder2.census.gov
TxDOT Spending, Registered Vehicles	TxDOT's District and County Statistics (DISCOS)	www.txdot.gov/inside-txdot/division/finance/discos.html
Daily Vehicle Miles	Roadway Inventory Database (TxDOT Planning Department)	www.txdot.gov/inside-txdot/division/transportation-planning.html
Vehicle Registration Fee, Drivers License Fee Revenue, Vehicle Inspection Revenue	Texas Department of Motor Vehicles, Open Records Requests	www.txdmv.gov
Licensed Drivers	FHWA Highway Statistics	www.fhwa.dot.gov/policyinformation/statistics.cfm
Fuel Stations	County Business Patterns (GBP) (United States Census Bureau)	www.census.gov/econ/cbp
County and Local Property Tax	County Appraisal Districts, Personal Communication	www.austincad.net, www.brazoriacad.org, www.chamberscad.org, www.fbcad.org, www.galvestoncad.org, www.hcad.org, www.libertycad.com, www.mcad-tx.org, www.sjcad.org, www.waller-cad.org
County and Local Sales Tax	Texas Comptroller Window on State Government Website	www.window.state.tx.us/taxinfo/local/city.html
County Revenue, County Transportation Spending	County Websites, Personal Communication	www.austincounty.com, www.brazoria-county.com, www.co.chambers.tx.us, www.fortbendcountytx.gov, www.galvestoncountytx.gov, www.harriscountytx.gov, www.co.liberty.tx.us, www.co.montgomery.tx.us, www.co.san-jacinto.tx.us, www.wallercounty.org
Local Revenue, Local Transportation Spending	Municipal Websites, Personal Communication	See Texas Comptroller Link for List of Municipalities
Metro Sales Tax	Metropolitan Transit Authority of Harris County (Metro)	www.ridemetro.org
Transit Revenue Miles	National Transit Database	www.ntdprogram.gov/ntdprogram/

Local Level. For municipalities however, the method needed to be modified as only county level resolution was available for each entry in the NHTS survey. Certain issues were encountered when collecting the required information from the local level. Each city has different accounting standards, given they would provide any financial documents at all. Some have separate departments for transportation, while smaller cities only have line items, which required estimation for transportation spending. The earliest available data closest to the year 2008 were used. As revenues and expenditures tend not to change dramatically from year to year, the numbers are assumed to average to a reasonable estimate. Where information was not available, municipal revenue was estimated based on linear regression of revenues versus population of known cities (Using data from latest available census). Revenues and expenditures were only calculated if the municipality had a sales or property tax on record.

Weighted average sales and property taxes were calculated based on the population of all cities and towns in the county. The assumption for sales tax was that the majority of spending occurs in one of these locations, with relatively little spending occurring in completely rural areas. Weighted average property taxes were calculated the same way. However, they were only applied to urban households, as few rural municipalities impose property taxes. Additionally, these small municipalities are vastly outweighed by the larger cities. Next, the weighted averages were multiplied by the average percent of local transportation-related spending in order to obtain an estimate for the tax rate devoted to transportation. The results are listed in Table 4.

Transit. Information collected for transit agencies is presented in Table 5. Since 1978, METRO has imposed a 1% sales tax on its constituent service areas (METRO 2013). By voter mandate, METRO must appropriate 25% of this sales tax to its constituents for roadway-related improvements. The same weighting method used for local level taxes was used for the 1% METRO sales tax, as a few of its constituents were not wholly within Harris County. Colorado Valley Transit and The District serve a few counties inside the Houston CBSA, though most of their service counties are not. Their numbers in the table below are a weighted average based on population for the counties they service within the Houston CBSA. By looking at the numbers presented, it is clear that METRO dominates the totals. For this reason, an error in estimation for the smaller agencies will not have a substantial impact as most effort focused on obtaining accurate data for METRO. The average expenditure per unlinked trip was $5.39. Revenue miles per county are listed in Table 4.

Table 5: Transit Agency Data (Numbers are Restricted to Houston CBSA)

Agency	Total Fares Collected	Total Unlinked Trips	Total Expenditure	Total Revenue Miles
METRO	$56,701,736	125,080,144	$665,537,067	63,110,626
Galveston Island Transit	$208,726	499,920	$3,323,955	423,749
Fort Bend	$237,840	165,386	$3,086,912	767,725
Gulf Coast Center	$61,922	50,912	$2,357,046	514,883
Colorado Valley Transit	$40,000	30,500	$373,380	69,191
The District	$1,727,727	738,226	$6,879,468	1,593,112
Total	$58,977,951	126,565,088	681,557,828	66,479,286

For the purposes of this research, transit fares were considered a private cost, similar to how an individual's vehicle maintenance is a privately incurred cost. As the analysis focuses on taxation, fares were not included. However, they were used to determine the increase in transit expenditures due to increased ridership. This was included in case the analysis demonstrated a dramatic increase in transit usage.

Table 4: Taxation and Spending by County and Governmental Level

		Austin	Brazoria	Chambers	Fort Bend	Galveston	Harris	Liberty	Montgomery	San Jacinto	Waller
STATE	Daily Vehicle Miles	1,269,543	4,560,600	2,420,542	6,556,343	4,670,684	56,245,209	1,892,604	8,552,671	705,745	1,745,771
	TxDOT Spending	$10,200,209	$43,658,438	$59,083,813	$135,429,001	$109,429,821	$698,574,728	$46,308,786	$228,228,197	$21,671,778	$8,613,283
	Spending / Annual DVM	$0.02	$0.03	$0.07	$0.06	$0.06	$0.03	$0.07	$0.07	$0.08	$0.01
COUNTY	Population	26,610	294,233	28,771	509,822	283,987	3,935,855	75,434	412,638	24,818	35,933
	Registered Vehicles	37,076	279,616	38,468	429,422	259,329	3,076,623	76,252	385,240	26,042	42,665
	Fuel Stations	22	136	25	181	129	1,529	34	151	7	26
	Total Revenue	$16,224,143	$141,294,435	$72,422,527	$273,440,458	$164,577,238	$2,469,793,493	$42,291,838	$261,537,623	$16,628,937	$19,126,890
	Revenue per Person	$610	$480	$2,517	$536	$580	$628	$561	$634	$670	$532
	Daily Vehicle Miles	104,280	1,153,050	112,749	1,997,908	1,112,898	15,423,961	295,613	1,617,060	43,103	140,815
	Transportation Spending	$5,218,685	$26,550,726	$8,166,697	$19,208,682	$12,206,563	$373,484,374	$9,102,163	$76,212,732	$3,240,545	$3,937,295
	% Transportation Spending	32.17%	18.79%	11.28%	7.02%	7.42%	15.12%	21.52%	29.14%	19.49%	20.59%
	Spending / Annual DVM	$0.14	$0.06	$0.20	$0.03	$0.03	$0.09	$0.08	$0.13	$0.21	$0.08
	Sales Tax	0.50%	0.50%	–	–	–	–	0.50%	–	0.50%	–
	Adjusted Based on Transportation Spending	0.16%	0.09%	–	–	–	–	0.11%	–	0.10%	–
	Property Tax ($/$100)	0.4796	0.39	0.52214	0.55	0.5586	0.38923	0.56	0.4888	0.6287	0.64253
	Adjusted Based on Transportation Spending	0.15427	0.07329	0.05888	0.03864	0.04143	0.05886	0.12052	0.14244	0.12252	0.13227
	Vehicle Registration Fee	$10.00	$10.00	$10.00	$11.50	$10.00	$11.50	$10.00	$10.00	$11.50	$10.00
LOCAL	Municipal Urban Population with Taxation	10,116	204,510	15,787	243,421	245,364	2,773,932	21,347	170,581	0	17,329
	Municipal Rural Population with Taxation	2,468	10,007	2,210	5,230	3,488	6,619	3,385	11,020	2,029	2,327
	Town Population without Taxation	6,537	28,405	6,353	18,886	1,063	214,413	3,076	9,029	2,531	447
	Daily Vehicle Miles	113,326	1,931,851	162,073	2,239,243	2,241,053	25,089,105	222,726	1,635,423	18,272	177,005
	Transportation Spending	$882,075	$22,774,262	$2,606,164	$32,811,793	$37,134,394	$390,198,463	$3,714,527	$23,024,474	$179,074	$2,652,955
	% Transportation Spending	5.59%	7.73%	7.45%	9.71%	9.63%	8.66%	8.37%	11.72%	8.51%	10.16%
	Spending / Annual DVM	$0.02	$0.03	$0.04	$0.04	$0.05	$0.04	$0.05	$0.04	$0.03	$0.04
	Weighted Average Sales Tax Adjusted Based on Transportation Spending	0.06%	0.10%	0.09%	0.15%	0.17%	0.08%	0.11%	0.09%	0.07%	0.18%
	Weighted Average Property Tax Adjusted Based on Transportation Spending	0.01169	0.04394	0.03177	0.04322	0.05034	0.04939	0.04536	0.04213	0.01002	0.0533
	Metro Sales Tax	–	–	–	0.14%	–	0.62%	–	–	–	0.10%
	All Transit Revenue Miles	14,765	0	0	767,725	938,632	63,110,626	0	1,390,034	83,603	19,938

Daily Vehicle Miles

In order to assign roadway expenditures to individuals, the total use of the system needs to be determined. The daily vehicle miles (DVM) for a road segment is simply the annual average daily traffic (AADT) multiplied by the length of the segment, meaning it is an estimate of the total daily vehicle miles traveled (VMT). Information from the TxDOT Planning Department's roadway inventory database was used to create an estimate for the total DVM on state, county, and local roadways disaggregated by county. For details on the estimation, the full report may be accessed online (https://ceprofs.tamu.edu/mburris/ publications.htm).

The estimates created are presented in Table 6 and make intuitive sense. Counties with large urban populations like Brazoria, Fort Bend, Harris, and Montgomery have a large number of local miles driven, while rural counties such as San Jacinto have few. Estimates were also created for the percentage of DVM driven on urban and rural roadways, which are shown in Table 7. Note that San Jacinto has no urban areas, therefore no urban DVM. Based on the estimates, the total yearly mileage for the Houston CBSA was 51.1 billion. The total mileage according to the NHTS data was 42.7 billion, or 85% of the estimated total, which leaves 15% of total mileage driven by trucks and other commercial vehicles.

Table 6: Estimated DVM by Road Ownership

Owner	**Austin**	**Brazoria**	**Chambers**	**Fort Bend**	**Galveston**
State	1,269,543	4,560,600	2,420,542	6,556,343	4,670,684
County	104,280	1,153,050	112,749	1,997,908	1,112,898
Local	113,326	1,931,851	162,073	2,239,243	2,241,053
Owner	**Harris**	**Liberty**	**Montgomery**	**San Jacinto**	**Waller**
State	56,245,209	1,892,604	8,552,671	705,745	1,745,771
County	15,423,961	295,613	1,617,060	43,103	140,815
Local	25,089,105	222,726	1,635,423	18,272	177,005

Table 7: Percent DVM by Geographic Location

County	**Urban Area**			**Rural Area**		
	State Roads	**County Roads**	**Local Roads**	**State Roads**	**County Roads**	**Local Roads**
Austin	72%	8%	19%	91%	6%	2%
Brazoria	52%	15%	33%	79%	16%	4%
Chambers	61%	12%	27%	97%	2%	1%
Fort Bend	63%	11%	26%	54%	44%	2%
Galveston	58%	13%	29%	54%	38%	8%
Harris	60%	12%	28%	23%	76%	1%
Liberty	65%	11%	25%	85%	13%	2%
Montgomery	70%	9%	21%	77%	21%	2%
San Jacinto	0%	0%	0%	92%	6%	2%
Waller	4%	29%	67%	95%	4%	1%

Consumer Spending

In order to apply sales taxes to individual households, disaggregated consumer spending habits are required. Information from the Bureau of Labor and Statistic's 2008 Consumer Spending survey is presented in Table 8 (www.bls.gov/cex). The BLS consumer survey contains expenditures by line item disaggregated by income level. To estimate sales taxable expenditures, exempt line items were removed based on Subchapter H of the Texas Tax Code (www.statutes.legis.state.tx.us/ Docs/ TX/htm/TX.151.htm). The average taxable auto purchases were included as well. This information represents vehicle purchases only, not other related vehicle spending. Unfortunately, the survey combined motor oil purchases with fuel purchases. For this reason, motor oil was not included in the analysis, as the bulk of this line item (fuel expenditures) are calculated elsewhere in this research.

Table 8: Consumer Spending with Taxable Estimation

Household Income	Total Consumer Spending	Total Sales Taxable Consumer Spending	Total Taxable Auto Purchases
Less than $5,000	$23,036	$12,514	$430
$5,000 to $9,999	$19,125	$9,521	$810
$10,000 to $14,999	$21,120	$10,547	$606
$15,000 to 19,999	$25,536	$12,968	$1,346
$20,000 to $29,999	$30,367	$15,966	$1,770
$30,000 to $39,999	$35,778	$18,974	$2,069
$40,000 to $49,999	$40,527	$21,900	$2,098
$50,000 to $69,999	$50,465	$28,625	$3,093
$70,000 to $79,999	$58,742	$33,269	$3,114
$80,000 to $99,999	$67,180	$38,619	$3,916
$100,000 and more	$100,065	$59,140	$5,450

Household Property Values

In order to apply the property taxes previously calculated, property values are required. Home values broken down by income were available for the American Community Survey (factfinder2.census.gov). The average values are presented in Table 9. The Harris County Appraisal District determines replacement values (new value per square foot) for use in their appraisals (www.hcad.org/pdf/ Resources/ 2013_Mass_Appraisal_Report_final_20130620.pdf). The values per square foot (by quality class) for single family units, duplexes, townhomes, and apartments are similar (~10%). Therefore, the correlation between income and home values presented in Table 9 will likely be representative of other housing types as well. For mobile homes, however, the values are not comparable. Because they account for 0.01% of all households in the Houston CBSA, they were assumed to follow the correlation in Table 9 as well.

Table 9: Average Home Values by Household Income

Household Income	Average Home Value
Less than $10,000	134,460
$10,000 to $19,999	112,570
$20,000 to $34,999	131,140
$35,000 to $49,999	137,830
$50,000 to $74,999	155,150
$75,000 to $99,999	184,760
$100,000 or More	282,040

Elasticity

Table 10: Fuel Price Elasticity of Travel Demand (VMT)

Household Income Quintile	Urban	Rural
Lowest	-0.447	-0.254
Lower Middle	-0.280	-0.159
Middle	-0.259	-0.147
Upper Middle	-0.335	-0.191
Highest	-0.373	-0.212
Total (Weighted Average)	-0.339	-0.192

An elasticity is defined as the percent change in consumption resulting from a percent change in price (Litman 2013). For the purposes of this paper, elasticities will refer to the percent change in either miles traveled or transit ridership based on the percent change in the cost of travel. For example, using an elasticity of -0.15, a 6% increase in the cost of travel would result in a 0.9% reduction in miles traveled. Wadud et al. (2009) modeled disaggregated fuel price elasticities of travel demand for income quintiles via the Seemingly Unrelated Regression Feasible Generalized Least Squares Autoregressive (SUR-FGLS with AR (1)) model and for geographic distinction via Log-linear SUR-FGLS with AR (1) values (Wadud, Graham, and Noland 2009). Larsen combined these values into a cross classification table for urban and rural income quintiles, which are presented in Table 10 (Larsen et al. 2012).

Unfortunately, elasticities disaggregated by income and geographic location were not available for public transit ridership. Based on literature presented by the American Public Transportation Association, 0.185 was the average transit trip to fuel price elasticity (APTA 2011). As noted by APTA, this elasticity only represents areas where public transportation is available. The author of a recent thesis found a statistically significant elasticity of 0.096 specifically for the Houston CBSA (Lee 2012). While this may not be as reliable as other estimations, it shows that the Houston area may be less responsive compared with other areas. For this reason, the APTA elasticity will be considered to yield a high range number, while Lee's elasticity will be considered the lower range. We felt the elasticities obtained from the literature on fuel prices were better indicators of real world reaction to a change in fuel price than linear regression of Texas NHTS data. The disaggregated elasticities by income and location are consistent with average elasticities found in large scale studies (Goodwin, P.B. 1992).

METHODOLOGY

For the analysis, there were three different MBUF funding scenarios. The first was meant to be tax neutral, meaning that the MBUF would create the same gross revenue as the state fuel tax (it would ignore implementation costs). This scenario was meant to analyze any distributional impacts inherent in changing to an MBUF. The primary difference between the MBUF and the fuel tax when it comes to total taxes paid would be the fuel efficiency of each vehicle. This scenario would isolate that effect. The next scenario raises the MBUF based on the estimated increase in revenue required for implementation, including GPS unit purchases for vehicle tracking, installation costs, operational costs, and individuals misreporting miles. This scenario provides a more realistic look at the MBUF. The final scenario increases the net revenue in order to meet Texas 2030 needs. This scenario will demonstrate any distributional changes with an increase in fees. Additionally, it will provide a relatable visualization of the true required cost of transportation moving into the future. MATLAB software was utilized in order to perform the analysis.

Implementation Cost and Additional Revenue

An implementation similar to the Oregon study was assumed, where gas stations read on board GPS units in order to ensure that the user is charged the appropriate fee (Whittey 2007). The same process as described by Larsen et al. (2012) will be used in this research with a few changes. According to Battelle, units may be purchased for under \$100, though they may not have the accuracy and reliability needed for street level tracking (Battelle 2013). They list \$150 for units better equipped for the task at hand, which provides a more conservative estimate for their cost. As noted by several authors, all the costs associated with the MBUF will likely become cheaper if mass produced and as technology improves (Battelle 2013; Forkenbrock and Hanley 2006). With 3,547,500 vehicles in the Houston area, the total cost of outfitting all vehicles would be \$532.1 million. According to the 2008 County Business Patterns (CBP) series of the United States Census Bureau (www.census.gov/econ/cbp), there were 2,240 gasoline stations in the Houston CBSA. With an installation price of \$15,000 per station (Larsen et al. 2012), the total cost to outfit all gas stations in the Houston CBSA would be \$33.6 million. In order to be consistent with the revenue increase scenario (discussed below), 22 years was used for the total life span of the system, with the upfront cost paid for incrementally each year. With a 22-year yield of 4.5%, the total annual cost of installation would be \$41 million.

According to the Texas 2030 Committee, \$14.1 billion in additional revenue per year will be required for the State of Texas to maintain current traffic and roadway conditions. This figure includes pavement maintenance, bridge maintenance, urban mobility, rural mobility, and safety. Additionally, the figure was determined based on the period of time between 2008 and 2030 (22 years). The required revenue increase for the Houston area (\$3.29 billion) was determined based on its share of total NHTS miles driven. The additional revenue was assigned based on the breakdown of current state expenditures for each county. The assumption was that TxDOT will not dramatically alter their allocation process.

Taxation Calculations

The fuel taxes were calculated based on NHTS variables for vehicle miles traveled and each vehicle's fuel economy. Sales taxes were determined based on the consumer spending habits in Table 8 and the weighted average sales taxes listed in Table 4. Property taxes were determined based on property values listed in Table 9 and the weighted average property taxes listed in Table 4. The average vehicle inspection fee and drivers license fee was applied using the NHTS household vehicle count variable and the household driver count variable, respectively. Automobile registration fees were applied based on the vehicle age NHTS variable and the county of residence. After the all taxes were assigned for each vehicle, they were summed with the respective household taxes based on the HOUSEID variable. The result was a total for all transportation related taxes paid by each household.

MBUF Calculation

The required MBUF was determined iteratively, as a driver's fuel price travel demand elasticity will alter the number of miles they drive as the cost of fuel changes. First, the initial MBUF is calculated based on the target revenue, which is the sum of the state fuel tax it will be replacing. This included any revenue increases or implementation costs depending on the scenario.

$$(1)\quad MBUF = \frac{Target\ Revenue}{\Sigma\ (VMT * HH\ Weight)'}$$

Where:

VMT is the NHTS mileage driven by each individual vehicle

HH Weight is the final household survey weight (from the weighting procedure) for the household the vehicle belongs to.

The total annual MBUF paid by each vehicle was then added to the total annual fuel purchase (not including fuel tax) in order to obtain a new "cost of fuel" for each vehicle. The disaggregated fuel price elasticities from Table 10 were then used to determine the change in annual VMT for each vehicle. This in turn changes the required MBUF to meet revenue criteria, and the process repeats until the calculated total revenue is within $1 of the target revenue. Then, the change in transit ridership was calculated using the transit demand fuel price elasticities.

Expenditure Assignment

As both the fuel tax and the MBUF tie taxation to road use, then following the benefits principle, transportation spending should also reflect an individual's use of the roadway. Multiplying a household's VMT by the average expenditure per daily vehicle mile (DVM) provides a reasonable estimate of the benefit received. However, the NHTS survey does not provide the geographic location for household miles driven. As discussed previously, the breakdown of total miles driven on urban state, county, and local roads as well as rural state, county, and local roads was determined using TxDOT DVM data and some estimation. It is assumed that a generic urban or rural mile driven by a household would follow this average DVM distribution (See Table 7). However, urban and rural households do not have the same distribution of miles traveled on urban and rural roadways (Larsen et al. 2012). As the NHTS survey contains the urban and rural location of each household, these different distributions can be accounted for. The average urban roadway expenditure per DVM for a generic urban mile driven and the average rural roadway expenditure per DVM for a generic rural mile driven are calculated as follows:

(2) $$U_{Exp} = S_{Exp} * \%SU_{DVM} + C_{Exp} * \%CU_{DVM} + L_{Exp} * \%LU_{DVM}$$

(3) $$R_{Exp} = S_{Exp} * \%SR_{DVM} + C_{Exp} * \%CR_{DVM} + L_{Exp} * \%LR_{DVM}$$

Where:

S = state, C = county, L = local, U = urban, R = rural

Exp = expenditures per mile, *DVM* = Daily Vehicle Miles

For example, $\%SU_{DMV}$ = the percentage of miles traveled on state-owned urban roadways

The previous two equations are calculated for each county separately. A mileage split for urban and rural locations was used by Larsen et al. (2012) based on GPS tracking in the Waco area (Larsen et al. 2012). The number of miles driven by urban households on urban roadways was 78%, while the number of miles driven by rural households on urban roadways was 41%. For the purposes of this research, 80% and 40% were used for urban and rural household miles driven on urban roadways, respectively. The city of Waco may not be representative of the city of Houston, but should be a reasonable estimate as no other data is available. Using these percentages, the miles driven by each vehicle can be broken down into urban and rural miles. The average urban and rural expenditure can then be tied to the vehicle. The total benefit received by each vehicle from all levels of governmental expenditure is calculated as follows:

(4) $$\text{User Benefit} = \left[(VMT * U_{Split}) * \frac{U_{Exp}}{1 + \%VMT}\right] + \left[(VMT * R_{Split}) * \frac{R_{Exp}}{1 + \%VMT}\right]$$

Where:

VMT is the annual VMT for each individual vehicle (Adjusted based on MBUF elasticity impact)

U_{split} / R_{split} is the percentage of miles traveled on urban/rural roadways (80%/20% for urban households or 40%/60% for rural households)

U_{Exp} and R_{Exp} are the urban and rural expenditures per mile (for the vehicle's respective county) calculated in Equations (2) and (3)

%VMT is the percent change in total annual mileage for all vehicles under a MBUF

If the total mileage driven by all vehicles under a MBUF system were to decrease *(%VMT* is negative) while spending remains the same, the average expenditure per DVM (U_{Exp} and R_{Exp}) should increase.

In order to determine how much a household receives from public transit expenditures, the average expenditure per trip was used. In 2008, the total expenditures for all transit agencies in the Houston BCSA was $681.6 million and the total number of recorded unlinked trips was 126.6 million. There are several ways an MBUF would impact transit expenditures. First, transit agencies benefit from roadway expenditures, as bus service comprises the majority of total unlinked trips (84%). Next, transit agencies do not receive reimbursements for what they pay in fuel tax. As this is the case, they were not be exempted from the MBUF in this analysis. Finally, an increase in transit usage will increase the total revenue from fares. As this analysis attempts to estimate the total user benefit received from all transportation taxation and expenditure, all of these factors were included.

RESULTS AND DISCUSSION

Demographic variations from the average calculated with the filtered and weighted NHTS data set are presented in Table 11. Low and high income represent the bottom and top quintiles, respectively. These geographic and income relationships will aid in the interpretation of the equity analysis.

Table 11: Variations from the Average for Select Demographics

	Low Income	High Income	Urban	Rural
Fuel Efficiency	-4.3%	+1.8%	+0.7%	-3.1%
VMT by Vehicle	-11.7%	+5.6%	-2.4%	+10.5%
VMT by HH	-50.5%	+43.1%	-5.3%	+27.7%
% Hybrids	-1.1%	+1.0%	Not Significant	Not Significant

Displayed in Table 12 are the fees ($/mile) required to meet the target revenue. In their respective tables, *Lower* indicates the lower 95% confidence bound while *Upper* indicates the upper 95% confidence bound for testing statistical significance. These bounds were obtained using standard errors derived from the NHTS replicate weights. With reasonable costs for implementation, operation, maintenance, and leakage included, the fee would be 1.3 cents per mile, which shows that the overhead required for implementing a VMT scenario upfront is quite costly, especially considering that one cent per mile would completely replace the state fuel tax. In order to meet the Texas 2030 Committee's goals, which would prevent worsening roadway and traffic conditions, the total fee required would be 13.9 cents per mile. The dramatic increase in the fee for this scenario helps visualize how underfunded the current system is based on the 2030 Committee.

The decrease in total mileage under the first two scenarios was negligible. However, the revenue increase scenario would decrease total miles traveled by 22.8%. This reduction closely matches finding from the Oregon study, where congestion pricing (10 cents per mile) reduced miles traveled by 22% (Whittey 2007). Additionally, the visibility of the MBUF may further reduce the total miles driven. When considering vehicle miles traveled disaggregated into income quintiles and geographic distinction, the results were as expected based on the elasticities. Low income households reduced their mileage by the greatest amount, while high income households reduced their mileage slightly more than medium income households. Again, as expected, urban households decreased their mileage to a greater degree than rural households. Considering that rural households already drive more miles than urban households, the MBUF may further increase the gap between the two. This should be kept in mind for equity comparisons.

Table 12: Mileage-Based User Fee by Scenario (cents/mile)

Scenario	MBUF	Lower 95%	Upper 95%
Gross Revenue	0.970	0.960	0.981
Net Revenue	1.342	1.328	1.356
Revenue Increase	13.922	13.506	14.337

A 1.3 cent/mile MBUF would increase transit ridership 0.2% to 0.4%. This would result in an increase of 170,000 to 320,000 total annual trips. More substantial is the increase to a 13.9 cent/mile MBUF, which would result in a 5.3% to 10.3% increase in transit ridership. This would mean 3.9 to 7.5 million additional annual trips. Such a large increase in the mileage-based user fee for the revenue increase scenario may be high enough to encourage a very large increase in transit ridership, increasing the number of transit vehicles and making the mode more attractive. For this reason, the low end estimate (Lee 2012) is likely more accurate for the net revenue scenario, while the high end estimate (APTA 2011) may be more accurate for the revenue increases scenario.

An important finding was the average benefit (or expenditure) to taxation ratio for all households. The results are displayed in Table 13. Even though NHTS vehicle miles traveled accounted for roughly 85% of the total estimated DVM, more was spent on the transportation households used than what households paid in taxes for all scenarios except the revenue increase scenario. This suggests that other groups such as businesses, most likely through property and sales tax, finance more than their share of the transportation network. The confidence interval for the revenue increase scenario does not overlap any of the other scenarios, indicating that the scenario statistically decreases the benefit to taxation ratio. This means that increasing an MBUF while the other taxes and fees remain in place may cause households to receive less than the pay in taxes (less is spent on transportation compared with what they paid in taxes).

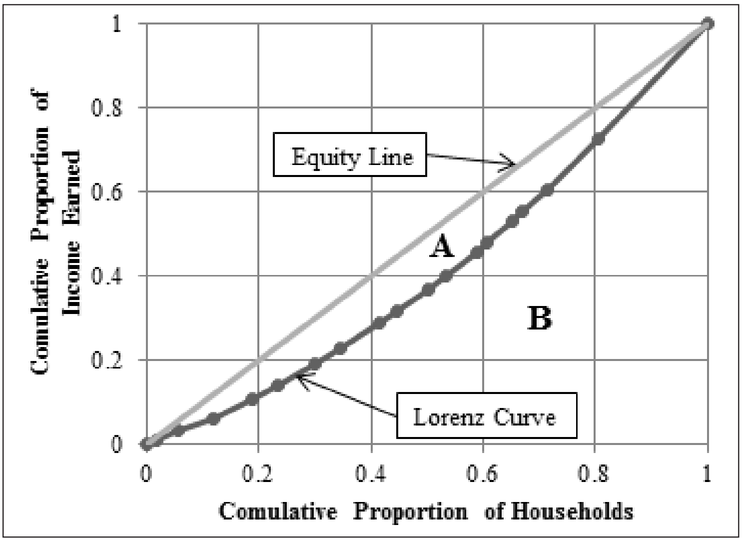
Table 13: Average Benefit/Taxation Ratio

Scenario	Average Ratio	Lower 95%	Upper 95%
Fuel Tax	1.1424	1.012	1.272
Gross Revenue	1.1407	1.011	1.271
Net Revenue	1.0568	0.936	1.177
Revenue Increase	0.8015	0.709	0.894

The Gini Coefficient

In order to analyze equity, one needs to apply objective measures that are directly comparable. The most commonly used measure, the Gini coefficient, is often considered to be the gold standard for vertical equity (De Maio 2007). The Gini coefficient is calculated based on the Lorenz curve, which is a plot of the cumulative proportion of benefits received versus the cumulative proportion of households, with absolute equality represented by a line bound by the points (0,0) and (1,1). An example Lorenz curve is shown in Figure 1.

Figure 1: Example Lorenz Curve



The Gini coefficient, which ranges from zero to one, is a measure of inequity used to determine benefits distribution, shown mathematically in Equation 5. If each member of a society receives the same share of wealth, then the Gini coefficient will be equal to zero, indicating complete equality. If one individual holds all the wealth, then the coefficient would be equal to one, indicating complete inequality (Drezner, Drezner, and Guyse 2009).

$$(5) \quad G = \frac{A}{A+B} \; or \; 2 * A$$

Three different Gini Coefficients are presented for each revenue scenario in Table 14. The first is for taxation, the second for benefits received (expenditures), and the third for the ratio between the two. The taxation Gini coefficients are similar to the ones obtained by Larsen, who also used NHTS data (Larsen et. al. 2012). The ratio coefficients are negative due to the lower two quintiles receiving a greater percentage of the distribution than higher quintiles. Notably, there was no statistical difference between any of the coefficients, which suggests that an MBUF would not have a pronounced effect on the current distribution of what households pay versus what they receive in transportation expenditures. This is similar to results from the literature (McMullen et al. 2010, Zhang et al. 2009). Additionally, it suggests that fuel efficiencies do not play a dramatic role in equity when considering the system as a whole. The revenue increase ratio was close to being statistically significant, which suggests that low income households would receive less than they do under the fuel tax.

Despite the lack of a statistical difference between scenarios, there appears to be a trend. For the revenue increase scenario, the lower taxation coefficient and the higher benefit and ratio coefficients are less desirable from a vertical equity standpoint, though expected since a user fee would inherently move the Lorenz curve closer to the equity line. When public transit expenditures were excluded from the analysis, the ratio Gini coefficient for the fuel tax was -0.033, which is statistically different than the -.089 coefficient in the table below, indicating that public transit has a progressive effect on equity. While this result is not surprising, it is good to see it reflected in the numbers.

Table 14: Gini Coefficients

Scenario	Taxation			Benefit			Ratio (Benefit/Tax)		
	Gini	Lower 95%	Upper 95%	Gini	Lower 95%	Upper 95%	Gini	Lower 95%	Upper 95%
Fuel Tax	0.179	0.170	0.188	0.137	0.113	0.160	-0.089	-0.109	-0.069
Gross Revenue	0.177	0.169	0.186	0.137	0.113	0.160	-0.088	-0.108	-0.068
Net Revenue	0.177	0.167	0.186	0.137	0.113	0.160	-0.089	-0.109	-0.069
Revenue Increase	0.170	0.155	0.185	0.162	0.142	0.182	-0.054	-0.070	-0.039

The Theil Index

An important drawback of the Gini coefficient is that it is not decomposable, meaning that Gini coefficients for groups within the population do not combine to form a coefficient for the total population, which is an attribute of the Theil Index (De Maio 2007). The Theil index can be broken down into two parts, the within group components and the between group components. When summed together, they equal the Theil index of the entire population. The within group components are simply the Theil Indices of each of the subgroups. The between group components are a measure of the relative income of each subgroup compared to all other subgroups (Conceicao, Galbraith, and Bradford 2001). The within group component and the between group component are calculated as follows:

$$(6)\quad T'_g = \sum_{i=1}^{m} \left(\frac{Y_i}{Y}\right) * \ln\left(\frac{Y_i}{Y} / \frac{n_i}{n}\right)$$

Where:

Y is the population's total income

Y_i is the total income for the i^{th} group in the population

n is the number of individuals in the population

n_i is the number of individuals in the i^{th} group of the population

$$(7)\quad T_g^w = \sum_{i=1}^{m} \left[\left(\frac{Y_i}{Y}\right) * \sum_{p=1}^{n}\left(\frac{y_p}{Y_i}\right) * \ln\left(\frac{y_p}{Y_i} / \frac{1}{n_i}\right)\right]$$

Where:

y_p is the income of the p^{th} member of the group

According to the Theil Indices for the entire population, the lack of a statistical difference between scenarios indicated that whatever disparity exists will not be changed by an MBUF. Additionally, there was no statistical difference between the MBUF alternatives for the within group components, further reinforcing that a MBUF would not alter existing inequalities. The between group components revealed that the relative winners are rural and high income urban households, while the relative losers are all other urban households. Keep in mind that each household still receives more in benefits than they pay into the system (except for the revenue increase scenario). For this reason, all households can be considered winners, with some receiving a greater share than others. The greater number of miles driven by rural and higher income urban households may be the reason why they are the relative winners. Driving more miles decreases the effective average tax per mile due to fixed rate costs such as vehicle registration and property taxes, which must be paid regardless of the number of miles driven. It should be noted that all of the between group indices were very close to zero, indicating that the relative winners and losers are determined by a narrow margin. The detailed indices are available in the full report, which may be accessed online (https://ceprofs.tamu.edu/mburris/publications.htm).

While nearing the end of this research effort, there were a couple times that we received updated data from cities or counties after we had run the analysis. This meant replacing our estimated values with true values, which were quite close to our estimates. This caused almost no change in the results. Through further experimentation with input data, it became clear that the results do not change substantially without major changes in assumptions, such as excluding public transit entirely.

SUMMARY AND CONCLUSIONS

Lack of sustainable revenue generation for transportation infrastructure has created a need to examine potential alternative funding sources. The most prominent of which is the Mileage-Based User Fee (MBUF), where drivers would be charged based on the number of miles they drive, thus holding them accountable for their use of the roadway. While numerous equity-related issues have been addressed, the interrelation of transportation taxation and expenditures on all levels of government (state, county, and local) is not well understood.

Using National Household Travel Survey data and information collected from over 100 agencies, roadway taxation and expenditures were assigned to individual households in the Houston core based statistical area (CBSA). Using Gini Coefficients and Theil Indices, the research demonstrated that implementation of an MBUF would not have a pronounced effect on the current distribution of what households pay versus what they receive in transportation expenditures. Increasing the MBUF to meet the Texas 2030 Committee recommendations would decrease the average benefit to taxation ratio, causing households to receive less than they pay into the system. Additionally, it would decrease the total number of miles traveled by 22.8% and increase transit ridership by as much as 10.2%. Even with the drastic impact, the relative distribution of transportation taxation and expenditures did not change significantly compared to the other scenarios. However, this is purely for taxation and spending, which does not reflect the true total cost (including external costs) of using the transportation system (vehicle maintenance, transit fares, pollution, congestion). Excluding public transit expenditures resulted in a statistically significant and undesirable (regressive) change in the Gini Coefficient, indicating that public transit has a positive impact on equity when considering the transportation system as a whole.

Due to relatively fixed rate taxes (vehicle registration, property tax, and sales tax), the higher the miles driven, the lower the effective tax is per mile. When miles traveled are decreased by 22.8%, the effective tax per mile increases, which is the reason why the average benefit to taxation ratio was reduced. Therefore, increasing the MBUF (or the fuel tax) while other methods of taxation remain the same may disadvantage most households (less is spent on transportation than they paid in taxes). If transportation-related taxation were to shift toward user-based methods, then the benefit to taxation ratio should tend towards a value of one, indicating that all users receive exactly the value they pay for.

Research Limitation

The research did not include trucks or commercial vehicles. However, based on NHTS data and the daily vehicle mile estimate, they only account for roughly 15% of total miles driven. Due to the lack of available information, several other estimations needed to be made, most of which are believed to have yielded reasonable results. However, there was little confidence in the total daily vehicle miles driven on county roads. The state reported DVM was accurate and the local DVM could be reasonably estimated, but the county DVM estimation resulted in some deviation between the 10 counties when it came to county expenditure per DVM. However, when combining the numbers into urban and rural expenditures, the county variations were no longer pronounced.

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Determining Cost-Effective Policy for Visibility of Overhead Guide Signs on Highways

by Mohammed Said Obeidat, Malgorzata J. Rys, Eugene R. Russell, and Aditya Gund

Overhead guide sign visibility on highway, can be achieved either by illumination or by using retroreflective sheeting. Two surveys were sent to all U.S. departments of transportation, to determine the states' policies for increasing overhead guide sign visibility. Results showed that 57% of states currently illuminate guide signs, and the most used retroreflective sheeting by states that do not illuminate signs is Diamond Grade for legend and High Intensity for background. Based on cost analysis, the LED light source and the High Intensity (types III and IV) retroreflective sheeting are the most cost-effective methods for increasing guide signs visibility.

INTRODUCTION

Drivers of all ages often experience more difficulty driving at night as compared with daytime driving. Different issues related to driver visibility of the road include a driver's visual acuity, contrast sensitivity, distance judgment, and color discrimination (Lagergren 1987). Guide signs are typically green signs located along a roadway to notify drivers of destinations and exit information. Overhead guide signs are important for improving driver guidance. The objective of these signs is to provide drivers with information regarding destinations and necessary instructions for reaching specific destinations. As stated by Bullough et al. (2008) "overhead highway signs must be highly visible and legible so that drivers can detect, read and interpret the information contained on the signs in time to respond appropriately" (Bullough, Skinner, and O'Rourke 2008).

As required in the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD), overhead guide signs must either be illuminated or retroreflective (FHWA 2009). Many departments of transportation (DOTs) in the United States are considering whether to illuminate the current overhead guide signs or replace these signs by brighter retroreflective sheeting to improve their visibility to drivers, especially elderly drivers, during nighttime. The 2009 MUTCD specifies minimum levels of retroreflectivity for signs. Retroreflectivity is an optical phenomenon in which the reflected light rays returned in an opposite direction that is close to the direction from which the rays came (Austin and Schultz 2009). The objective of the minimum retroreflectivity requirement is to improve safety on U.S. roadways by ensuring that roadway users, especially the elderly, are able to detect and react completely to traffic signs in order to facilitate safe, uniform, and efficient travel (Jonathan and Carlson 2012). Roadway lighting also contributes to highway safety by increasing drivers' visual comfort and reducing driver fatigue (IDOT 2002).

Energy conservation is essential in the midst of a worldwide energy crisis. As of 2007, in the United States, the estimated street and area light sources number was 131.356 million with a total annual consumption of 178.3 billion kWh (Navigant Consulting Inc. 2008). In addition, U.S. road lighting is estimated to be 14 billion kWh of the annual energy, which represents approximately 3% of total electricity consumption in the United States (Li et al. 2009).

Problems directly related to the energy crisis force DOTs to study the use of energy-efficient lighting technology used for street lighting, including overhead guide sign lighting. This paper presents the results of two surveys, a lighting survey and a retroreflectivity survey, related to overhead guide sign visibility. In addition, a detailed cost analysis is conducted among six types of light sources used by state DOTs, in order to find the most cost effective source. Similarly, a cost analysis of three retroreflective sheeting used by states DOTs is provided to find the most cost-effective retroreflective sign sheeting.

LITERATURE REVIEW

Traveling on U.S. roadways can be confusing and challenging for all drivers if driving routes are not easily understood or clearly marked, especially when the driver is unfamiliar with the driving location (Amparano and Morena 2006). This issue can be enormous for older drivers, especially those who have cognitive or physical disabilities (Amparano and Morena 2006). However, various engineering opportunities such as sign placement, legibility of sign lettering, retroreflectivity, and sign size can enhance a driver's ability to detect signs and comprehend sign messages.

The American Society for Testing and Materials (ASTM) details sheeting material components that can be used in constructing retroreflective guide signs. ASTM D4956 –11a is a standard that describes the different types of retroreflective sheeting material that can be used on traffic signs (ASTM 2011). According to ASTM D4956 - 11a standard, there are 11 types of retroreflective sheeting with a variety of applications (ASTM 2011).

The 2009 MUTCD minimum retroreflectivity requirements refer to sheeting types as defined in ASTM D4956. A common problem associated with retroreflective sheeting, however, is that even though a particular type of sheeting may initially meet minimum retroreflectivity levels, it may quickly degrade below minimum retroreflectivity levels because of weather or other environmental causes. The MUTCD has no instructions about the longevity of sheeting materials used for overhead guide signs. Agencies may overcome this problem by using higher performance sheeting, which may have a higher initial cost but remain above the minimum retroreflective requirement longer and provide a more efficient life-cycle cost.

Guide signs must be visible and clear for intended drivers in order to allow for proper driving response time. Desirable attributes for guide signs include high visibility and legibility during daytime and nighttime. Legibility is defined as adequately sized letters, symbols, or arrows, and a short legend for quick comprehension by a road user approaching a sign (Gowda 2010).

The use of retroreflective sheeting materials for signs is beneficial in making them more conspicuous, especially in high visual "noise" locations (Amparano and Morena 2006). Research performed at the University of South Dakota shows that the time required by senior drivers to detect signs in complex backgrounds can be reduced significantly by using super-high-intensity sheeting materials (Amparano and Morena 2006). Also, detection distance for fluorescent signs is significantly greater than non-fluorescent signs for both younger and older drivers, though older drivers benefited the most.

McGee and Paniati (1998) performed a study, in which they created an implementation guide for determining minimum retroreflectivity requirements for traffic signs, to assist governmental and private agencies in the establishment of a cost-effective program for the replacement of ineffective traffic signs (McGee and Paniati 1998). The researchers provided a description of different types of retroreflective sheeting materials and the difference among them according to the coefficient of retroreflection at different entrance and observation angles. The observation angle can be defined as the angle between a retroreflected beam toward an observer's eye and the line formed by the light beam striking a surface, and the entrance angle is the angle between a headlamp ray to the sign and a line perpendicular to the sign face. The researchers also quoted minimum retroreflectivity values for four groups of signs based on earlier research. In addition, the report presented the concept of Sign Management System that was defined by a coordinated program of policies and procedures, ensuring that highway agencies provide a sign system that meets drivers' needs according to budget constraints (McGee and Paniati 1998). In their research, McGee and Paniati (1998) suggest planning and developing an effective sign inventory process, including the involvement of key personnel, selecting a location as a reference system, selecting data elements, selecting inventory software, preparing for data collection, starting initial data collection, and maintaining inventory.

In a study performed by Bullough et al. (2008), researchers concluded that the measured luminance values, the resulting calculated luminance contrasts, and the visual response values indicated that in terms of visual performance, unlighted highway signs and new signs constructed from four types of retroreflective materials are similar to externally illuminated signs meeting the American Association of State Highway and Transportation Officials (AASHTO 2005) recommendations for guide sign illumination from a 328.083 ft (or 100 meters) viewing distance (Bullough, Skinner, and O'Rourke 2008). The important factors in their study include location of the signs relative to vehicles, headlight condition, ambient illumination, and other factors affecting actual luminance of sign background and characters.

Jonathan and Carlson (2012) performed a study in which four states (New York, Minnesota, Arizona, and Missouri) were selected to provide examples of effective and beneficial practices demonstrating how various agencies meet the MUTCD roadway sign retroreflectivity requirements. Researchers used three sources to gather information: (1) existing published research, (2) existing guidance and policies, and (3) a telephone survey. The survey included 14 questions, and 48 public agencies participated. Survey findings identified several strategies and techniques that were considered effective practices among the states. Among participating states and local agencies, the decision to replace a sign was based on four methods: (1) The expected sign life method was the most selected method for replacing signs (approximately 37.5%), (2) the most popular practice among participating states was nighttime visual inspection, involving training programs to ensure inspector proficiency (32.5%); (3) about 20% of agencies performed the blanket replacement method; and (4) 5% of agencies used the process of measuring retroreflectivity. However, the process of measuring retroreflectivity and control sign methods is associated with high cost due to the expensive retroreflectometer used and time spent taking measurements. Cost and time are crucial deciding factors in whether to use these methods or not. Purchasing a retroreflectometer can be expensive; however, resulting measurements could be valuable enough to justify the extension of sign replacement periods. Replacing signs based on retroreflectivity measurements can be time-consuming, though. If an agency has a retroreflectometer, maximum benefit is derived when used in conjunction with daily routine maintenance.

BASICS OF ILLUMINATION AND RETROREFLECTIVITY

Roadway lighting is a basic public amenity that contributes to a safer environment for drivers and pedestrians. Personal security, traffic flow operations, and safety can be improved by efficient roadway lighting (Medina, Avrenli, and Benekohal 2013). Drivers can easily recognize street conditions and geometry of the roadway with proper roadway lighting.

Overhead guide signs can be illuminated from the back, or back-illuminated, by using external light sources that illuminate the sign face (Bullough, Skinner, and O'Rourke 2008). External light sources are light fixtures designed to illuminate overhead guide signs by transforming electrical power into a visible light. Retroreflective sheeting materials can also be used to enhance overhead guide sign visibility for drivers.

Signs manufactured with retroreflective sheeting materials are commonly used on U.S. highways (Bullough, Skinner, and O'Rourke 2008). One important advantage of using retroreflective sheeting materials is that they do not require electrical power because they rely on efficient retroreflection of illuminance from oncoming vehicle headlamps which is reflected back toward the vehicle.

It is important to distinguish between two important terms: "efficiency" and "efficacy." Efficiency is used when both input and output units are equal. The term efficacy is used when input and output have two different units, i.e., for measuring luminous efficacy, the input unit is "watt" and the output is "lumen" (USDOE 2009).

A light source is a device that actually converts electrical energy to visible light in a specific manner based on the source type. Because of human eyes' shift response to light levels at nighttime, light sources that produce greater short-wavelength (blue) light are relatively more effective for vision than those associated with little short-wavelength light, even if the level of measured light is the same (Bullough 2012a). One wavelength is the distance between two consecutive corresponding points of the same wave. Light sources used for roadway illuminating devices can be categorized into conventional lighting including incandescent lamps and electric discharge lamps, and into new light source generation, including Light Emitting Diode (LED) and induction lighting.

In incandescent lamps, an electrical current passes through a wire causing it to heat up to a certain level, which allows the wire to glow and emits light (Lopez 2003). According to Lopez (2003), two important types of incandescent lamps exist: common incandescent and tungsten halogen. Both types are low in cost, but they have low efficacy (lumen per watt). Electric discharge light sources produce light through the passage of an electric current through a vapor or gas instead of through a tungsten wire as in incandescent lamps (Lopez 2003). According to Lopez (2003), five common types of electric discharge light sources exist: fluorescent, induction fluorescent, mercury vapor (MV), high pressure sodium (HPS), low pressure sodium (LPS), and metal halide (MH). Two types of MV light sources are available in the market: clear light and phosphor-coated light. MV light sources include a phosphor-coated light source primarily used for sign lighting (Lopez 2003). In the HPS, light is produced by an arc in a ceramic tube containing sodium and other elements (Lopez 2003). In the LPS, light is produced by an arc in a long tubular glass envelope (bulb) containing sodium only (Lopez 2003). The MH light source is similar to the mercury light source, but in addition to mercury it contains various metal halides, which provide excellent color rendering and result in a white light (Lopez 2003). Metal halides are compounds between metals and halogens. Induction lighting is a modern fluorescent lamp that uses radio frequencies to stimulate lamp material to produce light, unlike conventional fluorescent lamps that use electrodes at either end of the lamp tube (Bullough 2012b). Induction lighting is a new lighting technology with some advantages over conventional lighting in the areas of efficacy and lifespan (Deco Lighting 2012). LEDs are "semiconductors that emit light when electrical current runs through them" (Avrenli, Benekohal, and Medina 2012).

SURVEY AND SURVEY ANALYSIS

Two surveys were sent to each of the 50 DOTs in the United States via e-mail. The first survey will be referred to as the "retroreflectivity survey." This survey was collected between February and March 2011. The motivation behind this survey was to obtain information from DOTs related to overhead guide signs, including type of sheeting material used, sign maintenance and inventory, and retroreflectivity measurement. The other survey will be referred to as the "lighting survey." This survey was collected between August 9 and September 15, 2012. The motivation behind the lighting survey was to obtain information from DOTs related to overhead guide signs, including current usage of overhead guide sign lighting, light source types and optical packages used in overhead guide signs illumination, policy and/or procedures used in designing and installing overhead guide signs, and any new types of guide sign illumination used or planned to be used in the future.

Analysis of the Retroreflectivity Survey

Responses to the retroreflectivity survey were received from 28 DOTs (56%). A discussion of each question in the retroreflectivity survey follows.

1. *Does your agency have a usage policy or policies for the type of sheeting material used for overhead guide signs?* (*Yes or No*)

A total of 19 states (68%) responded "Yes," seven states (25%) responded "No," and two states (7%) did not give any response.

2. *What materials does your agency use for overhead guide signs (for legend and background)? If more than one material is used please mention the primary material.*
   The legend of a sign represents the information part on the sign. For a sign's legend and background, some states use two or more types of sheeting material. For sign legend, the majority of states are using Diamond Grade (types IX and XI), followed by High Intensity (types III and IV). For sign background, the majority of states are using High Intensity (types III and IV), followed by Diamond Grade (types IX, and XI).

3. *What type of font does your agency use for overhead guide signs?*
   Some states use more than one font on signs. The majority of states are using Series E (Modified) font, Clearview 5W font, and Clearview 5WR font.

4. *What minimum value of retroreflectivity does your agency use for overhead guide signs? Please mention the values used for legend and background separately.*
   A total of 11 states use the MUTCD minimum values for retroreflectivity values of overhead guide signs. Other states have minimum retroreflectivity values, as shown in Table 1.

Table 1: Specific Values of Retroreflectivity Used by DOTs for Overhead Guide Signs

Retroreflectivity Value for Background ($cd/lux/m^2$)*	Retroreflectivity Value for Legend ($cd/lux/m^2$)*
Lighted - 30, Unlighted - 35	Lighted - 250, Unlighted - 380
25	250
38	380
45	250

* The unit of retroreflectivity is ($cd/lux/m^2$), where cd is candela, which is the SI unit of luminous intensity, lux is the SI unit of illuminance, and m is meter.

5. *Does your agency keep inventory of in-service traffic signs?* (*Yes or No*)
   A total of 15 states (54%) responded "Yes," 11 states (39%) responded "No," and two states (7%) did not respond.

6. *Does your agency use computerized databases to keep track of inventory?* (*Yes or No*). *If your answer was 'Yes,' how often does your agency update sign inventory?*
   A total of 16 states (57%) responded "Yes," nine states (32%) responded "No," and three states (11%) did not respond. Updating the sign inventory schedule by states is performed as follows: Eight states (53.3%) update the schedule daily, three states (20%) update the schedule annually, one state (6.7%) updates the schedule weekly, one state (6.7%) uses other schedules, and two states (13.3%) did not respond.

7. *Does your agency perform any activities for sign maintenance?* (*Yes or No*). *If your answer is 'Yes,' please specify the maintenance activity.*
   A total of 20 states (71%) responded "Yes," five states (18%) responded "No," and three states (11%) did not respond. Sign maintenance activities performed by states DOTs include replacing signs based on states' replacement policies (10 to 12-year cycle), repairing damaged signs, sign cleaning, and annual daytime and nighttime sign inspection.

8. *How often does your agency perform the inspection of traffic signs? Please specify.*
   A total of 13 states (46.4%) perform annual inspection, 10 states (35.7%) perform inspection without specific schedule, one state (3.6%) performs monthly inspection, one state (3.6%) did not respond, and three states (10.7%) perform inspection biannually.

9. *What type of inspection activity does your agency perform? Please specify.*
   Some states perform more than one activity (because the states are using more than one procedure, percentage addition will not match 100%): 10 states (30.3%) perform daytime and nighttime visual inspection, eight states (24.2%) perform nighttime visual inspection, five states (15.2%) perform visual inspection, two states (6.1%) did not respond, and eight states (24.2%) responded with additional inspection types such as taking retroreflectivity readings of suspect signs, replacing signs on a 12-year cycle, having no inspection program, performing random nighttime and daytime inspection, or using a combination of expected sign life and blanket replacement methods to maintain retroreflectivity.

10. *Does your agency use any instrument for measuring retroreflectivity?* (*Yes or No*).
    A total of 15 states (53.5%) responded "No," eight states (28.5%) responded "Yes," and five states (18%) did not respond.

11. *If your agency does not use any instrument for measuring retroreflectivity, what method do you follow to measure retroreflectivity of traffic signs?*
    A majority of state DOTs that do not use any instrument for measuring retroreflectivity use alternative methods to measure traffic sign retroreflectivity, including nighttime visual inspection. Some states perform sign replacement before retroreflectivity falls below the minimum required levels by the MUTCD.

12. *How frequently does your agency perform the measurement of retroreflectivity?*
    A total of six states (21.4%) measure retroreflectivity annually, one state (3.55%) measures biannually, two states (7.15%) do not measure retroreflectivity, seven states (25%) did not respond, and 12 states (42.9%) responded that they measure in other ways, meaning no specific schedule is available.

13. *Does your agency use external illumination for overhead guide signs?* (*Yes or No*). *If your answer to the above question is 'Yes,' what light source does your agency use for external illumination of the overhead guide signs?*
    A total of 10 states (36%) responded "Yes," 14 states (50%) responded "No," and four states (14%) did not respond. Major sources used for overhead guide sign illumination include MV, MH, HPS, induction lighting, and LED.

14. *Does your agency follow the replacement policy for overhead guide signs?* (*Yes or No*)
    A total of 13 states (46%) responded "Yes," nine states (32%) responded "No," and six states (22%) did not respond.

Analysis of the Lighting Survey

Responses to the lighting survey were received from 31 DOTs (62%). A discussion of each question in the lighting survey follows.

1. *Does your state currently use lighting for some overhead guide signs?*
   Among the 31 states that responded, responses were divided into two scenarios for analysis. Scenario 1: 12 states (38.7%) responded "Yes," 14 states (45.2%) responded "No," and five states (16.1%) responded that they had used sign lighting in the past but were currently phasing

it out. Scenario 2: States that currently illuminate guide signs but are phasing out illumination are counted as illuminating overhead guide signs. As a result, 17 states (54.8%) responded "Yes," and 14 states (45.2%) responded "No."

In the retroreflectivity survey shown previously, question 13 related to question one in the lighting survey. Answers to this question resulted in the inclusion of three additional states to the lighting survey. In another survey conducted by AASHTO Joint Technical Committee in December 2010, (AASHTO Survey), data were found for one additional state, and this state does not illuminate highway signs (AASHTO 2011).

The following are the updated scenarios after combining the results of the three surveys (involving 35 states). Scenario 1: In regard to whether states are using overhead guide sign lighting, 14 states (40%) responded "Yes," 15 states (42.9%) responded "No," and six states (17.1%) responded that they used overhead guide sign lighting in the past but are currently phasing it out. Scenario 2: States that currently illuminate guide signs but are phasing out illumination are counted as illuminating overhead guide signs. As a result, 20 states (57.15%) responded "Yes," and 15 states (42.85%) responded "No."

2. *What lamp type is currently used in the illumination of overhead guide signs in your state? (e.g., Metal Halide, High Pressure Sodium, Induction Lighting, LED, or others)*
   For the 17 states (54.8%) that responded to the lighting survey and answered that they light overhead guide signs, the lamp types used for illumination are MH, HPS, MV, Induction lighting, and LED. Results for question 13 in the retroreflectivity survey for the three additional states that are illuminating their overhead guide signs were also included. Among the 20 states that use lighting for overhead guide signs, including states in the retroreflectivity survey, five states (25%) (Alabama, Missouri, Oregon, West Virginia, and Wyoming) use MH lighting only. Six states (30%) (Alaska, Idaho, Illinois, Iowa, Nebraska, and Virginia) use HPS. Two states (10%) (Wisconsin and Texas) use MV. One state (5%), Florida, uses Induction lighting, and South Dakota (5%) uses LED lighting. Combining the remaining states (25%), they use two types of lighting. Kansas and North Carolina use MV and HPS, South Carolina uses MV for greater light clarity, and Utah uses HPS and some Induction lighting. One state, New Mexico, did not disclose what type of lighting they use.

3. *Which optical package is typically used for the lighting in your state? (e.g., reflector/clear flat glass, refractor, stippled flat glass, or others)*
   Two types of glass related to overhead guide sign lighting are used by DOTs: clear glass and prismatic glass. Prismatic glass has one smooth side and the other formed into sharp-edged ridges to reflect the light that passes through.

4. *Are AASHTO or Illuminating Engineering Society (IES) sign lighting levels used in the design of your overhead guide sign lighting or are installations based on historical practice and/or experience?*

   Among the 17 states that responded that they are lighting their overhead guide signs, three states (17.65%) (Idaho, South Carolina, and South Dakota) use AASHTO standards, four states (23.53%) (Alabama, Illinois, West Virginia, and Wyoming) use IES standards, three states (17.65%) (Florida, North Carolina, and Utah) use both AASHTO and IES standards, three states (17.65%) (Alaska, Oregon, and Texas) use historical practice and experience, one state (5.87%), Virginia, has its own standards and policies, and three states (17.65%) (Iowa, Nebraska, and New Mexico) have or use no standards or specifications.

5. *Are you looking at other emerging sources for your overhead guide signs lighting? (e.g., Ceramic Metal Halide, Induction lighting, LED, Plasma, or other)*
   Among the 17 states that answered "Yes" to question one in the lighting survey, 11 states (64.7%) answered "Yes," and six states (35.3%) answered "No." The states that answered "Yes" are divided into four groups according to their reported future plans. The first group of six states (54.55%) (Florida, Idaho, South Dakota, South Carolina, Virginia, and West Virginia) includes those looking to switch to LED lighting. The second group includes two states (18.18%) (Oregon and Wyoming) that are transitioning to induction lighting. The third group, comprising two states (18.18%) (North Carolina and Utah), includes those hoping to use or upgrade retroreflective sheeting on overhead guide signs. The last group comprises one state (9.09%), Illinois, which is trying to eliminate overhead guide sign lighting. States that answered "No," including Alabama, Alaska, Iowa, Nebraska, Texas, and North Carolina, are attempting to eliminate guide sign lighting with retroreflective sheeting on guide signs.

SURVEYS SUMMARY

In summary, some states are moving toward discontinuation of overhead guide sign illumination and transitioning to brighter retroreflective sheeting material. Other states are modifying lighting and moving toward new energy efficient light source types such as LEDs and induction lighting.

From the retroreflectivity survey, 68% of the states responded that they have policies for the types of sheeting material used for overhead guide signs. For legend, the most used sheeting material by state DOTs is Diamond Grade (types IX and XI) followed by High Intensity (types III and IV). For background, the most used sheeting material by state DOTs is High Intensity (types III and IV) followed by Diamond Grade (types IX and XI). The popular font size selected by state DOTs is Series E (Modified), followed by Clearview 5W and Clearview 5WR.

Regarding minimum retroreflectivity values of the guide signs, most states follow MUTCD minimum values, while other states have their own minimum values, as shown in Table 1. Approximately 71% of state DOTs perform activities related to sign maintenance, while 18% do not. Approximately 46% of the states perform annual inspection of traffic signs, and 35% perform unscheduled inspection. 46% of state DOTs have policies to replace overhead guide signs, while 32% do not.

From the lighting survey analysis, including analysis of the two other surveys (retroreflectivity and AASHTO), states have two procedures or future plans for improving overhead guide sign visibility during nighttime: (1) illuminating signs, usually with newer, more efficient light sources, or (2) using newer, brighter retroreflective sheeting material. The main objective is to provide adequate sign visibility while saving energy and reducing cost. Among states surveyed, 57% illuminate overhead guide signs and 43% do not. According to states that responded to the lighting survey and illuminate their signs, the most common light sources currently used in illuminating overhead guide signs are MH, MV, HPS, induction lighting, and LED.

In designing overhead guide sign lighting, states may refer to AASHTO standards, IES standards, both AASHTO and IES standards, historical practices and experiences, or to a state's own standards. States' future plans for overhead guide signs are distributed between modifying existing overhead guide sign lighting into new, more efficient methods of illumination, which save energy and cost, or using guide signs with using new, brighter retroreflective sheeting.

LIGHT SOURCES COST ANALYSIS

Various companies were contacted regarding the cost of six light sources. Four companies sent us valuable information about the cost and the lifespan of the light sources. The information obtained regarded light sources that have a 250W high intensity discharge equivalent: the 70W Cool White

LED, the 81W LED, the 62W LED, the 75.4W LED, the 85W induction lighting, and the 250W MH.

Cost calculations were based on using the light source for an average of 11-hour per night (average daily operating hours), and the price of electricity is assumed to be \$0.08 per kW. Labor and equipment costs were not included.

In this section, a detailed comparison between the six light sources is presented. As shown in Table 2, the least common value for the lifespan of the six light source types is 75 years. Actually, none of the six light sources will be utilized for this entire period of time, thus 50 years was selected for the sake of comparison. The reason for selecting this period is to include the maintenance effect of the different light sources over time.

The actual information we obtained about the lifespan of the 81W LED and the 85W induction is different than that shown in Table 2. The manufacturers of these two types of light sources claim that the lifespan for each light source is 100,000 hours. Other manufacturers doubt that these light sources will have a lifespan of 100,000 hours. Generally, in the case of the LED, the threshold of lumen output will not be 70% of initial lumens based on information from a study by Neary and Quijano (2009). Because of this concern, the 81W LED and the 85W induction lighting lifespan will be considered to be 50,000 hours instead of 100,000 hours in the comparison, which will increase the lifespan safety margin.

The cost analysis shown in Table 2 includes the following cost components of each light source: initial, operating, and maintenance. Based on the average annual cost of each light source as shown in Table 2, the 85W induction light source is the most cost-effective, followed by the 62W LED, the 81W LED, the 75.4W LED, the 70W LED, and the 250W MH. Considering the annual power consumption, the 62W LED is the most effective in power consumption.

Considering Table 2, the data of initial light source cost and lifespan in hours for each source were obtained from the manufacturers. Life in years is calculated by dividing the life in hours by the average daily operating hours (11-hours) and dividing the result by 365 (days per year). i.e., the 70W LED life is approximately 15 years (60,000 hours/ [11-hour per day × 365 days per year]). The daily power consumption is calculated by multiplying the wattage consumed per hour for each light source by the average daily operating hours, i.e., the daily operating hours of the 70W LED is 0.77 kW (0.07 kW × 11-hour). The annual power consumption is calculated by multiplying the daily power consumption by 365 (days per year), i.e., for the 70W LED, the yearly power consumption is 281kW (0.77 kW per night × 365 days per year). The power consumption per life is calculated by multiplying the yearly power consumption for each light source by the hours per life and then dividing by the average operating hours per day and then dividing by 365 days per year, i.e., for the 70W LED, the power consumption during life is 4,199 kW (281 kW × 60,000 hours / [11-hour × 365-day]). Number of required maintenance during a 50-year period is calculated by dividing the 50-year period by the lifespan in years for each light source and subtracting one. One is subtracted because it is assumed that at the first-time installation no maintenance is required, and the light source is ready to be used, i.e., in the case of the 70W LED, the number of maintenance during the 50-year period is 2.33 times ([50-year/15-year]-1). Total power consumption in the 50-year period is calculated by multiplying the power consumption per year times 50, i.e., in the case of the 70W LED, the power consumption during the 50-year period is 14,050 kW (281kW × 50-year). The daily operating cost of each source is calculated by multiplying the daily power consumption by the electricity price (\$0.08 per kW). i.e., for the 70W LED, the daily operating cost is \$0.0616 (0.77 kW × \$0.08). The annual operating cost is calculated by multiplying the daily operating cost by 365 days per year, i.e., for the 70W LED, the annual operating cost is \$22.48 (\$0.0616 × 365-day). The life operating cost is calculated by multiplying the annual operating cost by the light source lifespan in hours, then dividing by the daily operating hours and then dividing by 365 days per year, i.e., for the 70W LED, the life operating cost is \$336 (\$22.48 × 60,000 hours/ [11-hour × 365-day]).

Table 2: Lighting Sources Cost Comparison

			81W LED					
	Details	**70W LED**	**No Defrost**	**With Defrost**	**62W LED**	**75.4W LED**	**85W Induction**	**250W MH**
1	Initial cost ($)	1195.74	550.8	730.8	600	675.75	678.3	678.3
2	Life (hours)	60,000	50,000	50,000	50,000	50,000	50,000	30,000
3	Life (years)	≅ 15	≅ 12.5	≅ 12.5	≅ 12.5	≅ 12.5	≅ 12.5	≅ 7.5
4	Daily power consumption (kW)	0.77	0.891	1.463	0.682	0.8294	0.935	2.75
5	Annual power consumption (kW/ year)	281	325.2	393.86[1]	248.93	302.73	341.3	1,003.75
6	Life power consumption (kW)	4,199	4,049.8	4,904.8	3,100	3,770	4,250.31	7,500
7	Number of maintenance in 50-year	2.33	3	3	3	3	3	5.66
8	Total power consumption (kW/50-year)	14,050	16,260	19,693	12,446.5	15,136.5	17,065	50,187.5
9	Daily operating cost ($)	0.0616	0.07128	0.11704[2]	0.05456	0.06635	0.0748	0.22
10	Annual operating cost ($)	22.48	26.02	31.51	19.91	24.22	27.30	80.30
11	Life operating cost ($)	336	324	392.4	248	301.6	340	600
12	Maintenance required	Replace fixture	Replace fixture	Replace fixture	Replace fixture	Replace fixture	Replace lamp	Replace lamp
13	Maintenance cost($/ each time required)	1,195.74	550.80	730.8	600	675.75	75.00	30.00
14	Total maintenance cost ($/50-year)	2,786.07	1652.4	2192.4	1,800	2,027.25	225.00	169.8
15	Total operating cost ($/50-year)	1,124	1,301	1,575.5	995.72	1,211	1,365	4,015
16	Total Cost ($/50-year)	5,105.8	3,504.2	4,498.7	3,395.72	3,914	2,268.3	4,863.1
17	Average annual cost ($)	102.12	70.08	89.97	67.91	78.28	45.37	97.26

[1]Considering the operating time for the defrost option is only four months.

[2]This number is calculated considering the defrost option is being used.

The required maintenance is related to the light source type. For all LED types, the required maintenance is replacing the entire light source fixture. For the other light source types, replacing the lamp is the main required maintenance. The LED maintenance cost will be equal to the initial installation cost at each time required; and here an assumption is used in that the cost will be the same over time, i.e., in the case of the 70W LED, 2.33 maintenance times required during 50 years for a total maintenance cost of $2,786.07 (2.33 times × $1,195.74).

The total cost for each light source during the 50-year period is calculated by adding the initial cost of the light source, the operating cost during 50 years, and the maintenance cost during 50 years, i.e., for the 70W LED, the total cost is $5,105.8 ($1195.74 + $1124 + $2,786.07). The average annual cost is calculated by dividing the total cost by 50, i.e., for the 70W LED, the average annual cost is $102.12 ($5,105.8/50-year).

For the LED light source, a defrost option may be required for the 81W LED if it is used in areas that experience a lot of snow and frost during the winter. The initial cost of the defrost option is approximately $180. If the 81W LED light source is equipped with the defrost option and the unit is energized, it consumes an additional 52W per hour if the ambient temperature falls below 0^{o} C. The defrost option automatically turns off when the ambient temperature rises above freezing. The period of defrost option usage is assumed to be four months during winter (about 120 days) and it is energized similarly to LED for 11 hours per day, an additional 0.572 kW will be used per day, for a daily cost of $0.04576. During the four months of winter, the operating cost of the defrost option is $5.49 per year (0.572 kW × $0.08 × 120 days). The defrost option associated with the 81W LED consumes 68.64 kW during the winter period each year, and 1,709.6 kW during its lifespan, with a total operating cost of $136.8 (1,709.6 kW × $0.08). Based on the manufacturer, the lifespan of the defrost option of LED is the same as the life of LED.

RETROREFLECTIVE SHEETING MATERIALS COST ANALYSIS

Various companies were contacted regarding the cost of three types of retroreflective sheeting materials used on overhead guide signs. Three companies returned valuable information about the cost and the lifespan of the three retroreflective sheeting materials: Engineering Grade, High Intensity, and Diamond Grade. Only the cost of the retroreflective sheeting material is considered in the following sections; other costs related to overhead guide signs are ignored, i.e., the sign sheet metal and the other sign fixture component costs.

In this section, a detailed comparison between the three retroreflective sheeting materials is presented. Labor costs and equipment are identical for the three types of retroreflective sheeting material during first-time installation and replacement. Labor and equipment costs are assumed to be $200 each time of replacement per each sign sheeting type. This assumption is based on using two workers and one bucket truck to replace or install the sign sheeting. A 50-year life cycle is considered to obtain the replacement effect for the three retroreflective sheeting based on lifespan. Table 3 compares the retroreflective sheeting costs in details. The cost analysis include initial and maintenance or replacement cost components of each retroreflective sheeting for a 15 ft × by 9 ft sign size per lifespan of each sheeting type. A sign of 15 ft × by 9 ft is used for comparison purposes.

Table 3: Retroreflective Sheeting Material Cost Comparison of a 15 ft × 9 ft Sign

	Details	Engineering Grade	Diamond Grade	High Intensity
1	Initial cost ($/ft²)	0.8	3.93	1.45
2	Life (years)	7	12	10
3	Cost of (15 ft × 9 ft) sign sheeting ($)	108	530.55	195.75
4	Labor cost per each installation/replacement ($)	200	200	200
5	Number of sign installation/replacement in 50-year	7.14	4.17	5
6	Required sign sheeting cost ($/50 years)	771.12	2,212.40	957.5
7	Required labor cost ($/50 years)	1,428	834	1000
8	Total cost ($/50 years)	2,199.12	3,046.40	1,957.50
10	Average cost per year ($)	43.98	60.93	39.15

In explaining the calculations in Table 3, the initial cost and lifespan information were obtained from the manufacturers. The sheeting material cost for the 15 ft × 9 ft sign size is calculated. The number of sign sheeting replacement/installation in a 50-year cycle is calculated by dividing 50 by the sheeting material lifespan for each sheeting type. The material cost during a 50-year cycle is calculated by multiplying the number of sign sheeting replacement/installation by the cost of the 15ft × 9ft sign. The required labor cost in a 50-year cycle is calculated by multiplying labor cost by the number of sign sheeting replacement/installation. The total cost for each sheeting during a 50-year cycle is calculated by adding the material cost in a 50-year cycle to the labor cost in a 50-year cycle. The average annual cost is calculated by dividing the total cost during the 50-year cycle by 50. Based on cost analysis results shown in Table 3, The High Intensity is the most cost-effective sign sheeting, followed by Engineering Grade, and then by the Diamond Grade.

CONCLUSIONS

The most commonly used sheeting material by states for overhead guide sign legend is the Diamond Grade (type IX followed by type XI). For sign background, High Intensity (types III and IV) are the most commonly used. Most states use Series E (Modified) font, followed by Clearview 5W and 5WR for guide signs.

States have two options or future plans for increasing overhead guide sign visibility during nighttime: either by illuminating signs, usually with newer, more efficient light sources, or using newer, brighter retroreflective sheeting materials. Approximately 57% of state DOTs illuminate their overhead guide signs, while 43% do not. The most common light sources used currently to illuminate overhead guide signs are MH, MV, HPS, induction lighting, and LEDs.

Based on the cost comparison of the six light sources, the 85W induction lighting is the most cost-effective, followed by the 62W LED, the 81W LED, the 75.4W LED, the 250W MH, and the 70W Cool White LED. New light source generations (LED and induction lighting), are much better based on the life cycle cost than the conventional light sources (MH, MV, and HPS). In general, induction lighting is the most cost-effective light source followed by LEDs. Considering environmental issues and power consumption, LEDs are more environmental friendly than induction light sources because LEDs are free from mercury and lead materials and have lower energy consumption. This will result in making LEDs much better than induction, and in our case, the 62W LED will be the best choice among the six light sources. Based on the cost analysis of the three retroreflective sheeting materials, the High Intensity is the most cost-effective retroreflective sheeting.

Overall, comparing the best options used to increase sign visibility, sign illumination and sign retroreflectivity, it is found that using retroreflective sheeting is more cost-effective than sign illuminating. This means the High Intensity retroreflective sheeting is the best option, based on the cost analysis, to increase overhead guide sign visibility to drivers during nighttime.

One of the limitations of this paper is the unavailability of labor and equipment costs when installing or performing maintenance to the different light sources.

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Income and Exchange Rate Sensitivities of Cross-Border Freight Flows: Evidence from U.S.-Canada Exports and Imports by Truck, Rail, Air, and Pipeline

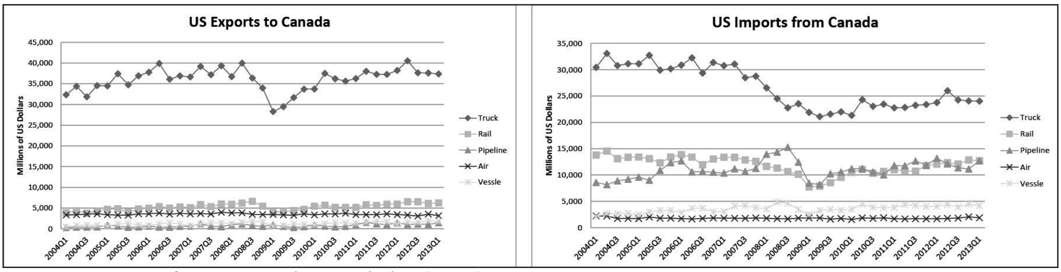
by Junwook Chi

This paper aims to improve understanding of the long-run impacts of the gross domestic product (GDP), real exchange rate, and the producer price index (PPI) on U.S.-Canada bilateral freight flows in a dynamic framework. Special attention is given to cross-border exports and imports by truck, rail, pipeline, and air. Using the fully modified ordinary least squares (FM-OLS) approach, the paper finds that the GDP of the importing country is a pronounced factor influencing U.S.-Canada cross-border trade, suggesting that economic growth of the country is a powerful driver in the relative intensity of bilateral freight flows. The real exchange rate tends to be positively associated with U.S. imports, but negatively associated with U.S. exports, indicating that the U.S. dollar depreciation against the Canadian dollar increases demand for U.S. commodities in Canada, but weakens demand for Canadian commodities in the United States. The long-run effects of the selected economic variables on cross-border exports and imports are found to vary by mode of transportation. The Canadian GDP has a positive and significant effect on U.S. freight exports by all transportation modes, but U.S. exports by pipeline are more sensitive to a change in Canadian GDP than U.S. exports by truck and rail. The findings in this paper provide important policy and managerial implications for cross-border transportation planning in the United States and Canada.

INTRODUCTION

Canada is the largest trading partner of the United States with cross-border exports and imports playing an important role in determining the trade balance between the two countries. Since the North American Free Trade Agreement (NAFTA) was implemented, cross-border exports of freight from the U.S. to Canada have substantially increased. For example, U.S. exports of freight to Canada have risen from $44.6 billion to $54.5 billion during 2004:Q1 to 2013:Q1 (Bureau of Transportation Statistics 2013). Trucking is the dominant transport mode compared to other modes (i.e., air, rail, vessel, and pipeline), accounting for approximately 70% of total U.S. exports in 2012. However, there are different patterns of exports and imports between the United States and Canada, and the intensity of freight trade flows appears to vary by mode of transportation (Figure 1). For example, U.S. exports to Canada by truck show an upward trend from 2004:Q1 to 2013:Q1, while U.S. imports from Canada by truck are in a downward trend over the same period. In addition, U.S. imports from Canada by rail and pipeline fluctuate more over time compared with U.S. exports to Canada by those same modes. These patterns suggest that key determinants of freight flows can differ between exports and imports, and the impacts of the determinants on bilateral freight flows may vary by modes of transportation.

Figure 1: US Exports to Canada and US Imports from Canada by Transportation Modes (Indexed Exports and Imports Adjusted for Inflation)



Source: Bureau of Transportation Statistics (2013).

Several studies have investigated bilateral international trade (Srivastava and Green 1986; Bahmani-Oskooee and Brooks 1999; McKenzie 1999; Bahmani-Oskooee and Ardalani 2006; Bahmani-Oskooee and Bolhassani 2014). These papers tend to focus on the impacts of income and exchange rate on bilateral trade. For example, Srivastava and Green (1986) examined the determinants of bilateral trade flows between 45 exporting countries and 82 importing countries and found that GDP of the exporting country is a pronounced factor affecting bilateral trade. Using cointegration technique, Bahmani-Oskooee and Brooks (1999) investigated the bilateral trade elasticities between the United States and its six largest trading partners. Their results showed that a cointegration relationship exists in the variables in the U.S. import and export demand functions, and a depreciation of the U.S. dollar improves the U.S. bilateral trade balance. In addition, Bahmani-Oskooee and Bolhassani (2014) examined the impact of exchange rate uncertainty on trade flows of 152 industries between the United States and Canada. Their paper suggested that an increase in exchange rate uncertainty has a little long-run impact on industries. McKenzie (1999) provided a comprehensive literature review and found mixed results of the impact of exchange rate volatility on trade flows.

A group of studies focused more on cross-border trade and transportation policy issues (Baier and Bergstrand 2001; Taylor et al. 2004; Globerman and Storer 2009; Bradbury 2013). Baier and Bergstrand (2001) assessed the impacts of income, tariff liberalization, and transport-cost on the growth of world trade among the selected OECD countries. Their results showed that income growth, tariff-rate declines, and transport-cost reductions explain about 67%, 25%, and 8% of the average world trade growth, respectively. Taylor et al. (2004) also explored the cost effects of border and trade policies on U.S.-Canada cross-border trade and transportation. They found that border and trade policies have a negative impact on the economies of two countries of $10.3 billion annually. Globerman and Storer (2009) examined the effects of border security-related costs and delays on Canadian exports to the United States and concluded that post-9/11 border security developments had a significant negative impact on Canadian exports to the United States.

Although previous studies have improved the understanding of the characteristics of cross-border trade flows, the determinants of the U.S.-Canada bilateral trade flows by transportation modes have not been investigated in existing literature. The impacts of the economic factors on freight flows may differ among transportation modes because of different shipment characteristics of trading commodities. For example, machinery and parts are main U.S. export commodities shipped by trucks to Canada, while petroleum products are mostly exported by pipeline. The income and exchange rate elasticities of demand for these commodities can vary for Canadian consumers and producers, which lead to a different magnitude of impacts of these factors on the trade flows by truck and pipeline. Bahmani-Oskooee and Ardalani (2006) also supported the proposition that income and exchange rate elasticities vary by commodity groups between the United States and its major trading partners.[1] This is likely to influence trade flows among transportation modes. Furthermore, it is essential for policymakers and logistics managers to understand the long-run determinants of bilateral freight flows to develop long-term transportation infrastructure and service plans.

The purpose of this paper is to advance understanding of the cross-border freight flows between the United States and Canada by examining the long-run determinants of bilateral freight flows *by transport modes*. Special attention is paid to the assessment of dynamic impacts of economic growth, exchange rate, and export price on U.S. freight exports and imports among transportation modes (i.e., truck, rail, pipeline, and air). To the best of my knowledge, this paper is the first to examine the dynamic effects of these economic variables on bilateral freight flows by transport modes between the United States and Canada. This paper adopts a fully modified ordinary least squares (FM-OLS) approach, developed by Phillips and Hansen (1990). The FM-OLS model is widely used to provide unbiased estimates of the dynamic relationship between variables of interest if variables are non-stationary $I(1)$ processes. Another advantage of the FM-OLS is that it is less sensitive to changes in lag length and superior to other cointegration techniques when a small number of observations are used (Engle and Granger 1987; Chi and Baek 2011). The sample size can be a major concern for validation of time-series techniques because limited data are available for the cross-border trade analysis at an aggregate level. The information derived from this paper can be used to improve understanding of the driving forces of the increasing cross-border freight flows between the United States and Canada. Further, this information may help build appropriate investment planning for transportation infrastructure based on the projection of long-term economic growth and exchange rate trends.

The remainder of the paper is organized as follows. The second section presents the FM-OLS model, variable description, and data sources. The third section provides the empirical findings of FM-OLS model, the results of unit root and cointegration tests, and long-run coefficients of freight exports and imports between the United States and Canada. Policy implications and concluding remarks are provided in the final section.

THE MODEL

The FM-OLS Approach

In examining the cross-border freight flows, this paper follows a theoretical framework of the bilateral trade model developed by Bahmani-Oskooee and Goswami (2004) and examines the long-run relationship between economic growth, exchange rate, export price, and trade flows between the United States and Canada. The reduced-form equations for U.S. freight exports (EX_{it}) and imports (IM_{it}) by transportation mode i are specified as follows:

(1) $EX_{it} = f(GDP_t^{ca}, ER_t, P_t^{us}),$

(2) $IM_{it} = f(GDP_t^{us}, ER_t, P_t^{ca}),$

where GDP_t^{us} (GDP_t^{ca})is the real Gross Domestic Production of the United States (Canada); ER_t is the real exchange rate of the Canadian dollar against the U.S. dollar; and is the export price of commodities including transportation costs in the United States (Canada). P_t^{us} (P_t^{ca}) The freight transportation mode i includes truck, rail, pipeline, vessel, and air ($i = t, r, p, v,$ and a).

To conduct the FM-OLS approach, Equations (1) and (2) are expressed in a log linear form as follows.

(3) $\ln EX_{it} = \alpha_0 + \alpha_1 \ln GDP_t^{ca} + \alpha_2 \ln ER_t + \alpha_3 \ln P_t^{us} + \varepsilon_t,$

(4) $\ln IM_{it} = \beta_0 + \beta_1 \ln GDP_t^{us} + \beta_2 \ln ER_t + \beta_3 \ln P_t^{ca} + \mu_t,$

where ε_t and μ_t are error terms and all the variables are hypothesized to be integrated of order one $I(1)$. With regard to the expected signs of coefficients, it is assumed that $a_1 > 0$ and $\beta_1 > 0$, because economic growth in Canada (the United States) is positively associated with demand for imported goods from the United States (Canada). For the real exchange rate, a decrease in the value of the U.S. dollar against the Canadian dollar leads to a price reduction of imported U.S. goods in Canada, which causes an increase in demand for U.S. goods ($a_2 < 0$). However, the U.S. dollar depreciation increases the price of imported goods in the United States and weakens demand for Canadian goods ($\beta_2 > 0$). A price increase in exporting goods in the United States (Canada) has a negative effect on demand for United States (Canadian) products in an international market; therefore, it is expected that $a_3 < 0$ and $\beta_3 < 0$.

Data

This paper uses quarterly data from 2004:Q1 to 2013:Q1. Freight exports and imports by mode of transportation are taken from the indexed trade data from the Bureau of Transportation Statistics (2013). The data are adjusted for inflation and exchange rate fluctuations. The paper uses the real GDP index (2005=100) collected from International Financial Statistics data, the International Monetary Fund (IMF 2013a). The GDP is used as a proxy for economic growth in the country. In addition, the real exchange rate is calculated by multiplying the nominal exchange rate by the ratio of the consumer price indices (CPI) of the two countries. The real exchange rate data are obtained from Economic Research Service (ERS), the United States Department of Agriculture (ERS 2013). This paper employs the producer price index (PPI) as a proxy for the export price of commodities and the PPIs for all commodities (2005=100) are collected from the International Financial Statistics data (IMF 2013a). It should be noted that the 2004:Q1 to 2013:Q1 period is the best available export and import data for all transportation modes from the Bureau of Transportation Statistics when the analysis is conducted. Table 1 presents the summary statistics of the data used in the models. All variables are expressed in natural logarithms.

EMPIRICAL RESULTS

The first step of the FM-OLS procedure is to test the non-stationarity of data. To apply the FM-OLS approach, the variables in Equations (3) and (4) must be non-stationary. This paper uses the Phillips-Perron (PP) test for unit root (Perron 1989); the main advantage of the PP test over the Augment Dickey-Fuller (ADF) test is that it can be more robust to general forms of heteroskedasticity. The optimal lag length is determined by the Newey-West estimator. The results of the PP test show that for all the variables, the null hypothesis of non-stationarity cannot be rejected at the 5% significance level for the level series, while it is rejected for the first-differenced series (Table 2). It is concluded that all the variables are non-stationary and $I(1)$, and therefore, all the selected variables can be used in the FM-OLS procedure.

Table 1: Summary Statistics (Quarterly Data from 2004:Q1 to 2013:Q1)

Variable	Unit	Mean	Median	Minimum	Maximum	Standard Deviation
GDP_t^{us}	Index	103.07	103.29	96.00	108.74	3.23
P_t^{us}	Index	111.37	110.91	95.66	125.97	9.81
EX_{tt}	US$ (mil.)	36,034.29	36,731.21	28,304.47	40,514.34	2,779.25
EX_{rt}	US$ (mil.)	5,254.53	5,295.52	3,772.10	6,627.57	799.38
EX_{pt}	US$ (mil.)	756.17	628.53	304.36	1,541.14	347.98
EX_{at}	US$ (mil.)	3,504.20	3,518.88	3,053.50	3,984.46	200.99
EX_{vt}	US$ (mil.)	1,226.48	1,203.13	453.57	1,953.34	379.20
GDP_t^{ca}	Index	104.67	105.06	95.40	112.29	4.2
P_t^{ca}	Index	102.62	101.10	93.70	117.80	5.47
IM_{tt}	US$ (mil.)	26,556.62	24,506.19	21,100.70	33,087.18	3,954.60
IM_{rt}	US$ (mil.)	11,834.26	12,094.88	7,708.89	14,535.06	1,669.46
IM_{pt}	US$ (mil.)	11,070.02	11,151.38	8,147.13	15,273.93	1,698.34
IM_{at}	US$ (mil.)	1,795.20	1,777.38	1,555.38	2,217.55	139.96
IM_{vt}	US$ (mil.)	3,580.03	3,691.83	2,097.46	4,840.41	673.77
ER_t	CA$/US$	1.12	1.09	1.00	1.36	0.10

Table 2: Results of Phillips-Perron (PP) Test for Unit Root

Variable	Level	First Difference	Decision	Variable	Level	First Difference	Decision
ln GDP_t^{us}	1.99	-2.65**	I(1)	ln GDP_t^{ca}	2.81	-2.81**	I(1)
ln P_t^{us}	1.89	-3.83**	I(1)	ln P_t^{ca}	1.76	-4.65**	I(1)
ln EX_{tt}	0.44	-7.68**	I(1)	ln IM_{tt}	-0.87	-7.84**	I(1)
ln EX_{rt}	0.91	-6.86**	I(1)	ln IM_{rt}	-0.20	-5.18**	I(1)
ln EX_{pt}	1.05	-7.68**	I(1)	ln IM_{pt}	0.56	-4.74**	I(1)
ln EX_{at}	-0.33	-10.62**	I(1)	ln IM_{at}	-0.57	-9.09**	I(1)
ln EX_{vt}	1.23	-9.33**	I(1)	ln IM_{vt}	1.25	-8.31**	I(1)
ln ER_t	-1.94	-4.71**	I(1)				

Notes: ** denotes rejection of the null hypothesis of a unit root at the 5% level. The 5% critical value for the PP test is -1.95. The Newey-West lag length is used to compute the standard error for the PP test.

Before estimating the U.S. export and import models, the optimal lag length and cointegration rank should be chosen. Trace statistics and eigenvalues are widely used to determine the number of cointegrating vectors in the Johansen Likelihood Ratio (LR) Test for Cointegration.[2] However, the Johansen LR Test (Johansen 1988) is derived from asymptotic results and critical values may be misleading for small sample size (Cheung and Lai 1993; Toda 1995). To avoid the small-sample bias, this paper adopts a model selection method based on information criteria suggested by Yu et al. (2007) and Park et al. (2008). Table 3 shows Schwarz's Bayesian (SIC) and Hannan and Quinn (HQ) information criteria on alternative lag lengths of zero through four. The test results show that the optimal lag lengths are not consistent between SIC and HQ measures for seven models. This paper employs HQ information criterion to select the optimal lag length because of the over-penalization problem of SIC (Park et al. 2008).

Table 3: Results of Optimal Lag Length of U.S. Export and Import Models

U.S. Exports										
	ln EX_{tt}		ln EX_{rt}		ln EX_{pt}		ln EX_{at}		ln EX_{vt}	
Lag	HQ	SIC	HQ	SIC	HQ	SIC	HQ	SIC	HQ	SIC
0	-25.18	-25.18	-25.18	-25.18	-22.55	-22.55	-26.28	-26.28	-23.29	-23.29
1	-30.86	-30.13*	-30.04*	-29.38*	-26.97	-26.24*	-30.52	-30.03*	-27.54	-27.06*
2	-31.51	-30.06	-29.87	-29.09	-26.99*	-25.54	-30.71*	-29.75	-27.94*	-26.98
3	-31.37	-29.19	-29.51	-28.07	-26.91	-24.73	-30.51	-29.06	-27.70	-26.25
4	-31.56*	-28.66	-29.16	-27.23	-26.89	-23.99	-30.41	-28.48	-27.70	-25.78
U.S. Imports										
	ln IM_{tt}		ln IM_{rt}		ln IM_{pt}		ln IM_{at}		ln IM_{vt}	
Lag	HQ	SIC	HQ	SIC	HQ	SIC	HQ	SIC	HQ	SIC
0	-26.40	-26.40	-25.93	-25.93	-25.77	-25.77	-27.45	-27.45	-26.11	-26.11
1	-31.46	-30.97*	-31.40	-30.92*	-30.24*	-29.76*	-31.09	-30.60*	-30.22	-29.74
2	-31.41	-30.44	-31.49	-30.52	-30.22	-29.26	-30.99	-30.03	-31.08*	-30.11*
3	-31.65*	-30.21	-31.69*	-30.26	-30.20	-28.75	-31.438	-29.99	-30.99	-29.55
4	-39.93	-29.01	-31.67	-29.74	-30.00	-28.07	-30.98	-29.05	-30.71	-28.78

Note: * indicates the optimal lag length; Schwarz's Bayesian information criterion (SIC) = $\ln(|\sum u|) + \frac{\ln(T)}{T} pK^2$; Hannan and Quinn information criterion (HQ) = $\ln(|\sum u|) + \frac{2\ln\{\ln(T)\}}{T} pK^2$.

One important requirement for application of the FM-OLS model is that a single cointegration vector[3] must exist in Equations (3) and (4). This paper uses HQ information criterion to identify the number of cointegration vectors (Table 4). The results show that one cointegration vector is present for the U.S. exports by truck, rail, pipeline, and air. This indicates that a long-run cointegration relationship exists among the variables in these cases. In other words, there is a statistically significant linear combination of U.S. exports, GDP, exchange rate, and PPI. However, there is no cointegrating vector found for U.S. exports by vessel. Since the FM-OLS model is a single-equation cointegration technique, the vessel models must be dropped. Thus, the paper proceeds with four transportation modes for the analysis. For U.S. imports, the test results support the hypothesis that a unique steady state relationship is present in the models for truck, rail, pipeline, and air.

Table 4: Results of Johansen Test for Cointegration

U.S. Exports					
Maximum Rank	ln EX_{tt}	ln EX_{rt}	ln EX_{pt}	ln EX_{at}	ln EX_{vt}
r = 0	-18.64	-17.55	-14.36	-17.09	-15.13*
r = 1	-18.79*	-17.75*	-14.76*	-17.63*	-15.09
r = 2	-18.73	-17.71	-14.67	-17.62	-14.87
r = 3	-18.66	-17.57	-14.58	-17.46	-14.66
r = 4	-18.60	-17.50	-14.51	-17.37	-14.60
U.S. Imports					
Maximum Rank	ln IM_{tt}	ln IM_{rt}	ln IM_{pt}	ln IM_{at}	ln IM_{vt}
r = 0	-18.39	-18.92	-17.98	-17.74	-18.26
r = 1	-18.61*	-18.95*	-18.16*	-17.82*	-18.80
r = 2	-18.45	-18.86	-18.12	-17.55	-19.33*
r = 3	-18.48	-18.79	-17.94	-17.34	-19.23
r = 4	-18.43	-18.73	-17.88	-17.28	-19.19

Note: * indicates the rank of the cointegration vector determined by Hannan and Quinn Information Criteria (HQ).

The results of long-run coefficient estimates of U.S. freight exports show that Canadian GDP has a positive effect on U.S. freight exports by all transportation modes and is statistically significant at the 5% level for truck, rail, and pipeline (Table 5). This result indicates that economic growth in Canada is an important long-run determinant of U.S. freight exports. Among transportation modes, U.S. exports by pipeline are more sensitive to a change in Canadian GDP than U.S. exports by truck and rail, while exports by air are non-significant. This finding can be explained by the unique shipment characteristics of natural gas and petroleum products by pipeline. Unlike other commodities demanded by either consumers or producers, the quantity demanded for imported natural gas and petroleum products can be derived by both domestic consumers and producers. That is, an increase in Canadian GDP, causing a rise in Canadian personal consumption as well as private investment, can increase the consumption of energy and petroleum products substantially.

Table 5: Results of Estimated Long-run Coefficients of U.S. Freight Exports to Canada

		U.S. Exports			
Dependent variable		ln EX_{tt}	ln EX_{rt}	ln EX_{pt}	ln EX_{at}
Independent variable	ln GDP_t^{ca}	6.99** (1.06)	4.70** (1.32)	9.83** (4.59)	0.22 (0.77)
	ln ER_t	-0.20 (0.26)	-0.68** (0.33)	2.37** (1.15)	-0.66** (0.19)
	ln P_t^{us}	-2.74** (0.43)	-1.24** (0.54)	0.90 (1.87)	-0.70** (0.31)
	Constant	-9.05** (3.31)	-7.33* (4.13)	-43.72** (14.33)	10.51** (2.42)

Note: ** and * denote rejection of the null hypothesis at the 5% and 10% significance levels, respectively. Standard errors are given in parentheses.

The real exchange rate has a negative long-run impact on U.S. freight exports by truck (-0.20), rail (-0.68) and air transportation (-0.66). However, the effect of the exchange rate is found to be statistically significant only for rail and air. Since a depreciation of the U.S. dollar against the Canadian dollar reduces the price of U.S. commodities in Canada, it can increase demand for U.S. commodities in Canada; thus, the exchange rate is negatively associated with U.S. freight exports by truck, rail, and air. Interestingly, only for pipeline, the results reveal that the exchange rate has a positive effect on U.S. freight exports, indicating that a depreciation of the U.S. dollar against the Canadian dollar reduces U.S. exports by pipeline. A plausible explanation for this finding is that if the U.S. dollar depreciates against the Canadian dollar, then the domestic consumption of U.S. energy products may increase due to cheaper U.S. products relative to imported Canadian energy products. This is likely to reduce U.S. energy exports by pipeline. Further, improved price competitiveness of U.S. products in foreign markets due to the U.S. dollar depreciation may increase energy consumption of export industries in the United States, which can reduce the exports of U.S. energy products to Canada.

In addition, U.S. PPI has a significant negative influence on U.S. exports by truck, rail, and air, suggesting that in the long run, an increase in export price and transportation rates in the United States leads to a drop in demand for imported U.S. commodities in Canada. In particular, U.S. freight exports by truck (-2.74) and rail (-1.24) are highly responsive to a change in U.S. PPI. One reasonable explanation for this finding is that these transportation modes are relatively competitive and more inter- and intra-modal competition exists for the commodities shipped by truck. For example, if a rail rate increases, a truck can be substituted for a railroad to ship exporting products such as machinery and parts, vehicles, and plastics, which can lead to a reduction in U.S. freight exports by rail. A positive and non-significant coefficient for pipeline can be explained by limited accessibility of pipeline in Canadian markets. Pipeline access is limited from oil-producing regions in western Canada to eastern refineries (Williams 2014), which is likely to reduce a substitute effect between imported U.S. and domestic Canadian crude oil in western Canadian markets. This may result in U.S. exports by pipeline being insensitive to changes in the export price of U.S. energy products in Canada.

Table 6 provides the results of estimated coefficients of U.S. freight imports from Canada. U.S. GDP has a positive long-run effect on U.S. freight imports and it is significant at least at the 5% significance level for all modes. The results show that the impacts of U.S. GDP on U.S. freight imports are greater for truck, rail, and pipeline than air. As shown in the U.S. freight exports to Canada (Table 5), the GDP of the importing country is found to be a pronounced factor influencing

U.S.-Canada cross-border trade. Coupled with the findings of Srivastava and Green (1986), this paper finds evidence supporting the idea that economic growth of the country is a powerful driver in the relative intensity of bilateral trade flows.

The real exchange rate is positively associated with U.S. freight imports from Canada by all transportation modes although pipeline is non-significant, indicating that the U.S. dollar depreciation relative to the Canadian dollar decreases demand for Canadian commodities in the United States. Compared with other modes of transportation, U.S. imports by truck (2.27) are shown to be more sensitive to an exchange rate change. This finding may reflect the shipment characteristics by truck. Trucking is the dominant mode of importing consumer goods rather than raw materials, and U.S. consumption of imported consumer goods can be more sensitive than other imported raw materials to an exchange rate change.

Canadian PPI is found to have a negative effect on U.S. imports by truck (-4.38) and rail (-3.52), indicating that a decline in export price and transportation rates in Canada increases freight imports from Canada to the United States. The impact of Canadian PPI is statistically insignificant on U.S. imports by pipeline and air. One possible explanation for the non-significant effect is that there is a small substitution effect between these modes and other transportation modes. For example, pipeline is generally the most economical mode to ship oil and natural gas, which substantially reduces a substitution effect between pipeline and other transportation modes. This effect may lead to an insignificant or little impact of exporting price on trade flows by pipeline. Similarly, many commodities shipped by air are time-sensitive and have high values per unit and, therefore, rail or truck may not be a viable substitute for air, especially long-haul services.

Table 6: Results of Estimated Long-run Coefficients of U.S. Freight Imports from Canada

		U.S. Imports			
Dependent variable		ln IM_{tt}	ln IM_{rt}	ln IM_{pt}	ln IM_{at}
Independent variable	ln GDP_t^{us}	7.65** (1.34)	7.21** (1.59)	4.14** (1.66)	1.72** (0.77)
	ln ER_t	2.27** (0.37)	1.49** (0.44)	0.27 (0.46)	0.86** (0.21)
	ln P_t^{ca}	-4.38** (0.67)	-3.52** (0.80)	-0.82 (0.83)	0.01 (0.39)
	Constant	-5.15 (4.93)	-7.85 (5.85)	-6.11 (6.11)	-0.68 (2.85)

Note: ** and * denote rejection of the null hypothesis at the 5% and 10% significance levels, respectively. Standard errors are given in parentheses.

One area of concern in using a single equation model of the bilateral cross border freight flows is that the residuals of Equations (3) and (4) (i.e., ε_t and μ_t) could be correlated. For example, a trade dispute between the United States or Canada on commodities (e.g., softwood lumber, beef, and agricultural products) can influence both inbound and outbound freight flows. Because of this effect, a simultaneous equations model may perform more efficiently than a single equation estimator. This paper employs a seemingly unrelated regression (SUR) model to address a potential of correlated residuals of the export and import equations. The results show that the signs of coefficients tend to be consistent between the two approaches, but more variables are found to be statistically significant in the FMOLS (Table 7 in Appendix).

CONCLUSION

The contribution of this paper is to investigate the determinants of U.S.-Canada bilateral freight flows by mode of transportation in a dynamic framework. Using an FM-OLS model, the paper evaluates the long-run impacts of economic growth, exchange rate, and export price on U.S. freight exports and imports. The empirical results show that a dynamic effect of the selected variables on cross-border freight exports and imports varies by mode of transportation. For example, the Canadian GDP is a primary determinant of U.S. freight exports by all transportation modes, but U.S. exports by pipeline are found to be more sensitive to a change in Canadian GDP than U.S. exports by truck and rail.

Several policy implications can be drawn from the findings of this study. First, this paper provides empirical evidence that U.S.-Canada cross-border freight flows are highly responsive to the economic growth in the importing country in the long run. An important implication from this finding is that the relative growth of Canadian and U.S. economies can be a crucial factor in determining the balance of trade in the United States and Canada. The International Monetary Fund (IMF 2013b) reports that U.S. GDP (3.06%) is forecasted to grow faster than Canadian GDP (2.20%) for the period 2013-2018. This growth could increase freight inflows from Canada to the United States and lead to the bilateral U.S. trade deficit with Canada. More specifically, Canada is the largest energy exporter to the United States and a growing U.S. economy is likely to increase energy expenditures and imports of petroleum from Canada. This likelihood further increases the need for improvement in transport capacity for energy exports by rail and pipeline.[4]

Second, the real exchange rate has a significant impact on both U.S. freight exports and imports. This finding implies that U.S. dollar depreciation can be used to improve U.S. exports and reduce imports from Canada, since U.S. dollar depreciation against the Canadian dollar increases demand for U.S. commodities in Canada, but weakens demand for Canadian commodities in the United States. Canada's healthy fiscal and economic position is likely to continue to maintain its strength against the U.S. dollar,[5] causing strong demand for imported U.S. products (e.g., motor vehicles and parts, machinery, electronics, chemicals, and durable consumer goods). For example, Statistics Canada (2013) reports that imports from the United States to Canada grew by 1.0 %, while exports to the United States increased by only 0.2% in October, 2013. This recent trend of U.S. dollar depreciation would help improve the U.S. trade balance and increase demand for transportation services for exporting commodities in the United States.

Finally, both exports and imports by truck and rail are negatively influenced by the producer price index (PPI), suggesting that a rise in export price and transportation cost can reduce the trade flows between the United States and Canada. This finding further implies that improved productivity and cost-efficient transportation services could positively affect cross-border freight flows in the long run. Nelder (2012) found that fuel efficiency in the rail industry improved by 20% from 1990 to 2006, and some of the efficiency gains are due to technological improvements. For example, lightweight, high-capacity railcars and stronger motors have reduced the number of locomotives required to pull a train. New technology, such as global positioning systems (GPS), radio frequency identification (RFID), and maintenance and safety monitoring systems, is evolving to realize further technological and efficiency improvements. In the long-run, the bilateral trade flows and cross-border markets in the United States and Canada may be affected by these improvements.

This paper was intended to examine the impacts of income and exchange rate changes on trade flows by using aggregate freight data among transportation modes. It is worth mentioning that this macro demand approach does not capture the dynamic relationships between these variables and trade flows at an industry or commodity level. Future research could extend to a bilateral freight flow model at the regional or city level to provide various policy implications on cross-border freight infrastructure and investment.

Endnotes

1. Bahmani-Oskooee and Ardalani (2006) found that the long-run coefficients of the rest of world income on U.S. exports are 3.89 and 0.43 for electrical machinery and petroleum preparations, respectively. The coefficients of the real exchange rate are -0.37 and 1.44, respectively, for these commodity groups.
2. The null hypothesis of the trace test is that the number of cointegrating vectors is less than or equal to *r*. If the trace statistic for given *r*=0 exceeds its critical value, then it is concluded that at least one cointegrating vector is present. The distribution of the trace statistic proposed by Johansen (1995) is -), where *T* is the number of observations and are the estimated eigenvalues.
3. If two or more variables are individually integrated (i.e., I(1)) but a certain linear combination of them to be I(0), then the variables are said to be cointegrated. A stationary equilibrium relationship between variables is present if a cointegrating vector of coefficients exists (Engle and Granger 1987).
4. To meet a strong need for transport improvement, Canada is currently enhancing its rail export capacity to transport oil across the border. It was almost zero capacity in 2011, but will reach 200,000 and 300,000 barrels per day by the end of 2013 and 2014, respectively (Crooks 2013).
5. The currency exchange rate decreased from 1.44 to 1.07 Canadian dollar per U.S. dollar from January 3, 2000, to December 28, 2013 (Bank of Canada 2013).

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APPENDIX

Table 7: Results of Seemingly Unrelated Regression (SUR) Model

		U.S. Exports			
Dependent variable		ln EX_{tt}	ln EX_{rt}	ln EX_{pt}	ln EX_{at}
Independent variable	ln GDP_t^{ca}	1.06* (0.57)	1.52 (1.12)	1.08 (4.85)	0.08 (0.76)
	ln ER_t	-0.80** (0.25)	-0.51 (0.35)	1.21 (1.29)	-0.70** (0.20)
	ln P_t^{us}	-0.63** (0.29)	0.25 (0.49)	3.61* (2.02)	-0.55* (0.31)
	Constant	8.63** (1.96)	0.35 (3.59)	-15.71 (15.14)	10.47** (2.38)
		U.S. Imports			
Dependent variable		ln IM_{tt}	ln IM_{rt}	ln IM_{pt}	ln IM_{at}
Independent variable	ln GDP_t^{us}	3.31** (0.63)	3.11** (1.20)	0.56 (1.36)	1.21 (0.93)
	ln ER_t	0.32 (0.32)	0.55 (0.53)	0.48 (0.49)	0.56* (0.29)
	ln P_t^{ca}	-2.08** (0.27)	-1.67** (0.44)	0.82* (0.42)	-0.20 (0.26)
	Constant	4.71* (2.70)	2.92 (5.02)	8.22 (5.52)	2.73 (3.73)

Note: ** and * denote rejection of the null hypothesis at the 5% and 10% significance levels, respectively. Standard errors are given in parentheses.

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A Comprehensive Assessment of Highway Inventory Data Collection Methods

by Mohammad Jalayer, Huaguo Zhou, Jie Gong, ShunFu Hu, and Mark Grinter

The implementation of the Highway Safety Manual (HSM) at the state level has the potential to allow transportation agencies to proactively address safety concerns. However, the widespread utilization of HSM faces significant barriers as many state departments of transportations (DOTs) do not have sufficient HSM-required highway inventory data. Many techniques have been utilized by state DOTs and local agencies to collect highway inventory data for other purposes. Nevertheless, it is unknown which of these methods or any combination of them is capable of efficiently collecting the required dataset while minimizing cost and safety concerns. The focus of this study is to characterize the capability of existing methods for collecting highway inventory data vital to the implementation of the recently published HSM. More specifically, this study evaluated existing highway inventory methods through a nationwide survey and a field trial of identified promising highway inventory data collection (HIDC) methods on various types of highway segments. A comparative analysis was conducted to present an example on how to incorporate weights provided by state DOT stakeholders to select the most suitable HIDC method for the specific purpose.

INTRODUCTION

The Highway Safety Manual (HSM) provides decision makers and engineers with the information and tools to improve roadway safety performance. In the first edition of the HSM, predictive methods, which can be employed to quantitatively estimate the safety of a transportation facility in terms of number of crashes, were provided for three types of facilities: rural two-lane roadways, rural multi-lane highways, and urban/suburban arterials. A National Cooperative Highway Research Program (NCHRP) 17-45 project recently developed safety prediction models for freeways and interchanges as well (Bonneson et al. 2012). Since the release of the HSM in 2010, many states have sought to tailor the various safety measures and functions within the report to better reflect road safety in their specific locations. This manual provides valuable insight that can help practitioners to prioritize projects, compare alternatives, and select the most appropriate countermeasures in the planning/ design/ construction/ maintenance process.

To implement methods presented in the HSM, a major challenge for state and local agencies is the collection of necessary roadway information along thousands of miles of highways. Collecting roadway asset inventory data often incurs significant but unknown cost. To date, state departments of transportations (DOTs) and local agencies have employed a variety of methods to collect the roadway inventory data, including field inventory, photo/video log, integrated GPS/GIS mapping systems, aerial photography, satellite imagery, airborne Light Detection and Ranging (LiDAR), static terrestrial laser scanning, and mobile LiDAR. These methods vary based on equipment needed, time required for both collecting data and reducing data, and costs. Each method has its specific advantages and limitations. Particularly, vehicle-mounted LiDAR, a relatively new type of mobile mapping system, is capable of collecting a large amount of detailed 3D highway inventory data, but it requires expensive equipment and significant data reduction efforts to extract the desired highway inventory data. On the other hand, a traditional field survey requires less equipment investment, training, and data reduction efforts. However, this method is not only time-consuming and labor-intensive, but also exposes data collection crews to dangerous roadway environments.

The efforts and costs associated with collecting various data with different techniques vary greatly. Therefore, there is a need to understand the application of existing highway inventory data collection (HIDC) methods for gathering HSM-related roadway inventory data. This study sought to present an in-depth review of various roadway asset inventory data collection methods and to compare the quality and desirability of these methods. A national survey was conducted to all the state DOTs to collect the related information toward these various data collection techniques. Additionally, field trials were conducted to identify the most promising methods for collecting and recording highway inventory data to support HSM implementation. By virtue of the fact that many state DOTs are currently redesigning their asset management plans to meet MAP-21 requirements, the outcomes of this research effort may provide a resource for saving money and time.

RESEARCH BACKGROUND

Highway Inventory Data for Highway Safety Manual

The HSM can be utilized to predict the safety performance of a roadway segment or an intersection. The safety performance is evaluated by using a system of equations, known as Safety Performance Functions (SPFs), to estimate the average crash frequency based upon roadway characteristics and traffic conditions. The input data for different types of roadway segments and intersections are quite different. Tables 1 and 2 summarize the required input data for the safety predictive models in the HSM. The check mark indicates the required variables for roadway segments and intersections.

Currently, few states have existing highway inventory databases that contain all the required variables for the input of the HSM models. Particularly, a significant amount of roadside information, such as roadside slope, grade, roadside fixed objects and their density, and offset to the edge of travel way are missing in the current Illinois Department of Transportation (IDOT) databases. Therefore, the main objective of this study is to evaluate which data collection method is able to collect those roadside features in the most economical and effective way. Because these features are also absent in many state DOT databases, the findings of this study will be helpful to provide guidance for other states.

Review of Highway Inventory Data Collection Methods

HIDC methods can be broadly divided into two different categories: land-based and air- or space-based methods as shown in Table 3 (Gong et al. 2012). These methods vary in equipment used, data collection time, data reduction time, accuracy, and cost. A brief description of the available data collection methods and related studies is provided in Table 4.

In general, it can be noted that although there are a considerable number of studies on various HIDC methods, none of them have solely focused on supporting HSM implementation. Therefore, the challenge is to match the best methods to HSM-oriented highway inventory applications. Additionally, it is not clear to what extent these methods have been implemented by various state DOTs. Such information might aid other state DOTs and teach valuable lessons regarding which methods are preferred. This study was aimed at characterizing the utility of these existing HIDC methods for collecting HSM-required road inventory data through a national survey and field evaluation of selected HIDC methods.

SURVEY DATA COLLECTION AND ANALYSIS

In many states, there is a lack of worthy highway databases that include all the required variables as inputs for the HSM predictive models. On the other hand, many state DOTs do have road inventory databases that provide some data elements that can be used in the HSM predictive models. A

Table 1: Highway Inventory Data Required for Road Segments in the Highway Safety Manual

Variables	Rural Two-lane Highways	Rural Multilane Highways	Urban/ Suburban Arterials	Descriptions
Number of through lanes	√	√	√	
Lane width	√	√		
Shoulder width	√	√		
Shoulder type	√	√		
Presence of median		√	√	
Median width		√		
Presence of passing lane	√			
Presence of rumble strips	√			A road safety feature that alert inattentive drivers by causing a tactile vibration
Presence of two-way left-turn lane	√		√	
Driveway density	√			
Number of major/minor commercial driveways			√	
Number of major/minor residential driveways			√	
Number of major/minor industrial/institutional driveways			√	
Number of other driveways			√	
Horizontal curve length	√			A feature that increases road safety and comfort in the design of horizontal curves
Horizontal curve radius	√			A feature that increases road safety and comfort in the design of horizontal curves
Horizontal curve superelevation	√			A feature that allows a driver to negotiate a curve at a higher speed and more convenient
Presence of spiral transition	√			A feature used to gradually change the curvature and superelevation of a roadway
Grade	√			A feature determined by the percent grade for the roadway between each point of change in grade
Roadside hazard rating	√			A feature is used to characterize the potential hazard related to roadside environment

Table 1: continued

Variables	Rural Two-lane Highways	Rural Multilane Highways	Urban/ Suburban Arterials	Descriptions
Roadside slope		√		Features determined by the slope ratio (the vertical rise divided by horizontal run) for the foreslope (the slope extends from the outside of the shoulder to the bottom of the ditch)immediately outside the roadway shoulder
Roadside fixed object density/offset			√	A feature determined by the number of roadside fixed objects on both sides of the roadway segments divided by the length of the segment
Percent of length with on-street parking			√	
Type of on-street parking			√	
Presence of lighting	√	√	√	
Presence of auto speed enforcement	√	√	√	

Source: AASHTO (2010)

Table 2: Highway Inventory Data Required for Intersections in the Highway Safety Manual

Variables	Rural Two-lane Highways	Rural Multilane Highways	Urban/ Suburban Arterials	Descriptions
Number of intersection legs	√	√	√	A feature determined by the number of approaches in each intersection
Number of approaches with left-turn lane(s)	√	√	√	
Number of approaches with right-turn lane(s)	√	√	√	
Intersection skew angle	√	√		A feature determined by angle at which the legs of an intersection meet
Presence of lighting		√	√	
Pedestrian volume/lane			√	
Number of bus stop within 1000 ft			√	
Number of alcohol sales within 1000 ft			√	
Presence of schools within 1000 ft			√	

Source: AASHTO (2010)

Table 3: Categorization of Highway Inventory Data Collection Methods

	Land Based	Air or Space Based
GPS	Field Inventory Integrated GPS/GIS Mapping	
GPS + Imaging	Photo/Video Log	Satellite Imagery Aerial Imagery
GPS + Imaging + LiDAR (Using a laser to illuminate a target and measure the reflected light)	Static Terrestrial Laser Scanning (Using direct 3D precision point information acquired from stationary 3D laser scanners to extract highway inventory data) Mobile LiDAR (Driving an instrumented vehicle while collecting direct 3D precision point information using either land-based LiDAR systems or photogrammetry systems while traveling at highway speeds)	Airborne LiDAR (Using direct 3D precision point information acquired from aircraft-based LiDAR systems to derive highway inventory data)

question is how different state DOTs have collected these inventory data and is there any lesson that can be learned from them. In order to gain an understanding of the implementation status of various HIDC methods and their perceived strengths and shortcomings, a web-based survey was developed and sent to 50 state DOTs and seven Canadian provinces. More specifically, the respondents were asked to indicate their primary data collection methods and their opinions on the adopted methods regarding cost, time, accuracy, safety, and data storage requirements. The survey focused on a few roadside features that are known to be difficult to collect but play an important role in the HSM models.

The survey analysis results, based upon 30 respondent states, demonstrated that over 50% of responding states use field inventory, integrated GPS/GIS mapping, video log, and aerial imagery for collecting roadside feature data. In truth, the field inventory method is still required for many roadway features due to equipment limitations since new technologies may not be suitable for all assets. According to the survey results, it is evident that satellite imagery and airborne LiDAR are less popular choices among state DOTs because it is difficult to identify small objects using these methods. Additionally, mobile LiDAR is uncommon but appears to be growing and most popular. Figure 1 depicts the percentage of states using each type of HIDC method.

Figure 1: Technology Adoption Percentage in Respondent States

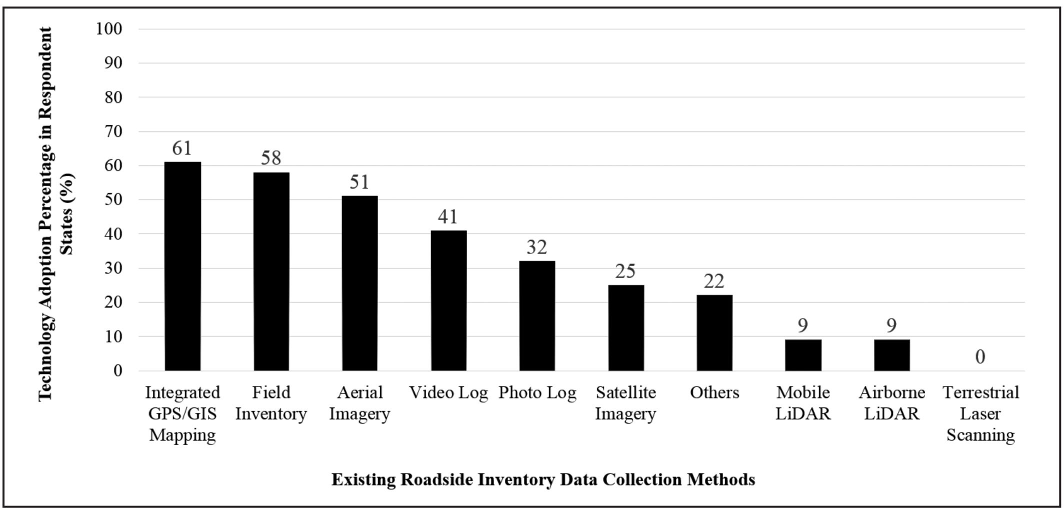


Table 4: Existing Highway Inventory Data Collection Methods and Related Studies

	Methods						
	Field Inventory	**Photo/Video Log**	**Integrated GPS/GIS Mapping Systems**	**Aerial/Satellite Photography**	**Terrestrial Laser Scanning**	**Mobile LiDAR**	**Airborne LiDAR**
Description	Uses GPS survey equipment and conventional optical to collect desired information in the field.	Driving a vehicle along the roadway while automatically recording photos/videos which can be examined later to extract information	Using an integrated GPS/GIS field data logger to record and store inventory information	Analyzing high resolution images taken from aircraft or satellite to identify and extract highway inventory information	Using direct 3D precision point information (3D point clouds) acquired from stationary 3D laser scanners to extract highway inventory data.	Driving an instrumented vehicle while collecting direct 3D precision point information using either land-based LiDAR systems or photogrammetry systems while traveling at highway speeds	Using direct 3D precision point information acquired from aircraft-based LiDAR systems to derive highway inventory data
Advantages	Low initial cost, low data reduction effort, and capability of collecting rich and highly accurate roadway inventory data	Less exposure to traffic and short field data collection time	Low initial cost, low data reduction effort, and the ability to transfer inventory data back to the home office through a wireless connection	Elimination of field work and data collection time, no traffic exposure, no disruption to traffic, and compatibility of images with GPS	Operating in daylight or darkness, high data accuracy and extremely rich and accurate data collection that is valuable to multiple DOT programs	Collecting huge amounts of data in a very short time, survey crew safety is superior compared with traditional survey methods	No exposure to traffic, short field data collection time, and collection of rich data in a short amount of time
Disadvantages	Crew exposure to traffic and long field data collection time	Inability to measure feature dimensions and need for large data reduction efforts	Crew exposure to traffic, long field collection time, and GPS outage problems due to trees	Difficulty to identify features such as signs or traffic signals from overhead imagery	Long field data collection time, exposure to traffic, high initial cost, long data reduction time, and large data set size	The need for expensive equipment, long data extraction time, and large data set size	High initial cost, large data set size, and long data reduction time
Related Studies	Khattak et al. (2000)	Maerz and McKenna (1999), Hu et al. (2002), Degray and Hancock (2002), Jeyapalan and Jaselskis (2002), Jeyapalan (2004), Robyak and Orvets (2004), Wu and Tsai (2006), Tsai (2009), Wang et al. (2010), Balali et al. (2013)	Caddell et al. (2009)	Hallmark et al. (2001) Veneziao (2001)	Pagounis et al. (2009), Slattery and Slattery (2010), Caltran (2011)	Tao (2000), Vosselman et al. (2004), Laflamme et al. (2006), Pfeifer and Briese (2007), Kampchen (2007), Barber et al. (2008), Huber et al. (2008), Lato et al. (2009), Garza et al. (2009), Lehtomaki et al. (2010), Graham (2010), Tang and Zakhor (2011), Yen et al. (2011a), and Yen et al. (2011b)	Jensen and Cowen (1999), Hu et al. (2002), Hatger and Brenner (2003), Souleyrette et al. (2003), Shamayleh and Khattak (2003), Zhang and Frey (2006), Pfeifer and Briese (2007), McCarthy et al. (2007), Uddin (2008), Chow and Hodgson (2009)

It should be noted that most of the respondent states indicated that they use a combination of several data collection methods to meet their roadside inventory data needs. The results revealed that guardrails, shoulders, and mileposts are the most predominant objects being collected but using different methods. Moreover, only 9% of states collected roadside slope and curvature alignments.

Additionally, the survey respondents were requested to indicate their level of satisfaction with their primary collection method using a scale of 1 to 5 (representing unacceptable, fair, good, very good, and excellent, respectively) where one is worst and five is the best. Table 5 illustrates the results for the nine satisfaction indicators considered in the survey, including equipment cost, data accuracy, data completeness, crew hazard exposure, data collection cost, data collection time, data reduction cost, data reduction time, and data storage requirement. Based on these parameters, most states express their level of satisfaction as good for the primary data collection methods, which they have used more frequently to collect the required datasets.

Table 5: Levels of Satisfaction for Primary Data Collection Method of State DOTs

Satisfaction Factors	Unacceptable (%)	Fair (%)	Good (%)	Very Good (%)	Excellent (%)	Sum (%)
Equipment Cost Rating	0	21	58	21	0	100
Data Accuracy Rating	0	7	41	45	7	100
Data Completeness Rating	7	17	34	34	7	100
Crew Hazard Exposure Rating	4	29	39	21	7	100
Data Collection Cost Rating	3	24	55	17	0	100
Data Collection Time Rating	3	34	48	14	0	100
Data Reduction Time Rating	11	26	30	26	7	100
Data Reduction Cost Rating	4	39	29	21	7	100
Data Storage Requirement Rating	0	14	52	31	3	100

The data shown in Table 5 indicate that most agencies rated their current systems from fair to good for most performance categories. Table 6 presents the rating of each satisfaction indicator in Table 5 for each data collection method based on the level of satisfaction with the primary data collection method. It showed that satellite imagery, photo logs, and aerial imagery scored highest on all the evaluation elements. Examination of the scores of different evaluation elements reveals that most methods had lower rankings for data reduction time, data collection time, and data collection cost. This clarifies that the focus of concern of state DOTs is on the time required for data collection and reduction and the associated cost. Moreover, state DOTs that used either airborne LiDAR or mobile LiDAR expressed less satisfaction toward these two methods in equipment cost, data reduction cost, and data reduction time performance categories. Their concerns are clearly related to the data reduction time associated with these two methods. Both methods collect a tremendous volume of data that is difficult to process. Some of the other interesting findings were that the New York State DOT rates its GPS/GIS system as unacceptable to fair in several categories, and the California State DOT appears generally dissatisfied with its photo log system. Overall, no single technology stands out as the obvious choice of methods for roadside feature data collection, and most agencies perceive that their inventory methods could be substantially improved.

Table 6: Level of Satisfaction on Adopted Inventory Data Collection Methods by State DOTs

	Highway Inventory Data Collection Methods							
Satisfaction Factors	**Satellite Imagery**	**Photo Log**	**Aerial Imagery**	**Field Inventory**	**Video Log**	**Integrated GPS/GIS Mapping**	**Mobile LiDAR**	**Airborne LiDAR**
Equipment Cost Rating	3.1	3.0	3.1	3.1	3.1	2.9	2.0	2.5
Data Accuracy Rating	3.3	3.5	3.6	3.5	3.4	3.8	3.0	3.0
Data Completeness Rating	3.2	3.3	3.3	3.4	3.3	3.3	3.4	2.8
Crew Hazard Exposure Rating	3.2	3.4	2.9	2.9	2.9	3.0	2.5	3.0
Data Collection Cost Rating	3.2	2.9	3.0	2.8	3.0	2.8	2.5	2.5
Data Collection Time Rating	3.2	2.8	2.9	2.8	2.8	2.7	2.6	2.0
Data Reduction Time Rating	2.8	3.1	2.9	3.1	2.8	2.9	2.0	2.0
Data Reduction Cost Rating	3.2	3.1	2.9	2.7	2.8	2.8	2.5	2.0
Data Storage Requirement Rating	3.2	3.5	3.4	3.3	3.1	3.3	3.0	3.4

FIELD TRIAL AND RESULTS

Based on the literature review and survey, the research team identified five potential methods to be further evaluated: GPS data logger, robotic total station, GPS enabled photo/video log, satellite/aerial imagery, and mobile LiDAR. Four different types of roadway segments, including rural two-lane highway, rural multi-lane highway, urban and suburban arterial, and freeway segment, were chosen as the test sites for these methods. These segments varied in length but were not shorter than one mile.

The data reduction effort required for each data collection technique has a significant impact on the utility of the technique. Specifically, one previous study revealed that the manual data collection was more cost-effective than automated methods such as mobile mapping systems, as the latter incur high equipment costs and a significantly greater data reduction effort (Khattak et al. 2000). However, recent developments in automated data reduction methods and declining equipment costs (e.g., laser, camera) may have changed this conclusion. Given this fact, the research team recorded the time spent conducting data reduction tasks such as extracting objects, and determining clear zone distance, side slope and other parameters from datasets. A list of promising data collection methods and the proposed data reduction methods are provided in Table 7. Moreover, researchers also evaluated the feasibility and training needs for DOT personnel to use these programs. In general, the effort of data reduction was directly proportional to the quantity and richness of data collected in the field (Zhou et al. 2013).

Table 7: Proposed Data Reduction Methods

Data Collection Method	**Data Reduction Method (if required)**	**Descriptions**
Field Inventory	N/A	
Photo/Video Log	Manual review, photogrammetry	
Integrated GPS/GIS Mapping Systems	N/A	
Aerial Photography	GIS package (ArcGIS)	
Satellite Imagery	GIS package (Google Earth Pro)	
Mobile LiDAR	Point cloud post-processing software	A software which has a capability to decimate files intelligently without losing the important featured-related information such as locations.

GPS Data Logger

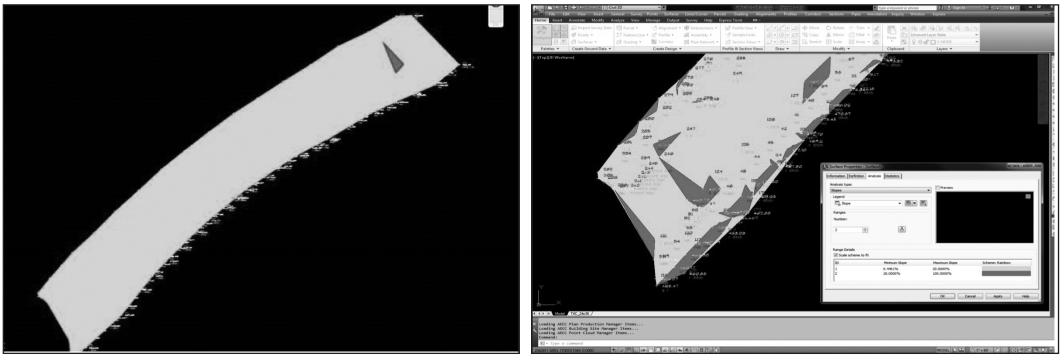
A GPS data logger is a GPS unit that records time of observation, location, elevation, and crew-entered notes. The data logger is equipped with an internal camera, allowing images of recorded locations to be stored and associated with the location data. Output from the data logger may be viewed on a mapping application such as Google Earth. Figure 2 illustrates a sample of this device in use to locate a traffic sign.

Figure 2: A GPS Data Logger Device for Data Collection

In general, the GPS data logger device is very user-friendly, reduces the need for extensive training, and can be operated by one surveyor. As for data collection, the GPS data logging technique is accomplished by placing the device next to the object to be recorded. In doing so, at the beginning of data collection work, the device must be initialized. Initialization refers to the automated startup routine that GPS receivers employ to scan the visible sky, identify observable satellites, and make a location determination. Depending on the number of satellites in view and their geometrical distribution above the target, this process may require from a few minutes to as many as 15 minutes. Once initialization is complete, location data are provided in real time even if the receiver is in motion. Notably, in this method, data collection time is very sensitive to the type of objects, the objects' density, the distance between objects, and the terrain. Therefore, using a four-wheel, all-terrain vehicle can reduce data collection time significantly (Figure 2). In this study, by the help of the aforementioned vehicle, the average times for setting up the device and collecting data per object were five minutes and one minute, respectively.

As to the data reduction effort, one of the primary tasks is the organization of all data collected for the purpose. The data reduction steps required by this method, for this research, included importing the collected data files into a Computer Aided Design (CAD) software program (e.g. AutoCAD Civil 3D), establishing a drawing-file template that includes many of the standard file settings and objects for use in a new file, and importing the resulting data files into the drawing format. The latter consisted of a series of discrete points with associated elevation and description attributes. By virtue of the drawing file, a highway alignment drawing was assembled. Moreover, additional processing using the discrete point elevations to define a surface representing the topography, called "slope banding," was simultaneously employed to identify roadside slope based upon percentage of slope (in dark color) (Figure 3).

Figure 3: A Sample of Slope Banding



In this study, the analysis of results demonstrated that the GPS data logger can not only gather all the objective highway inventory data to be implemented in the HSM but also can meet the accuracy required by the HSM safety predictive models; i.e., four inches accuracy of feature locations can be achieved. One of the shortcomings is the likelihood of GPS outage in areas with tall buildings and significant tree cover. Crew exposure to traffic is another issue that requires mitigation strategies such as setting up warning signs and traffic cones, which consumed a significant percentage of the time required to survey each segment.

Robotic Total Station

During the late 1980s, electronic distance measuring equipment was successfully integrated with electronic theodolites, used for measuring angles in horizontal and vertical planes, to create "total station" surveying instruments. This new generation of surveying instrument directly displays horizontal and vertical angles, slope distance, and derived horizontal distance, vertical distance, and x,y,z coordinates. With the addition of electronic data collection in the early 1990s, survey field work productivity has dramatically improved. A typical survey crew using a total station instrument consists of three people: an instrument person to point the instrument and initiate measurement, a party chief to direct the work and sketch additional data, and a rodman to walk to the object to be recorded and plumb the reflector prism equipped survey rod over the object. Surveying total stations and robotic total stations employ electronic distance measuring systems that measure the time required for light to travel from the instrument to the target and back. A retro-prism mounted on a pole is placed at the target and the instrument's light beam is directed toward it and then sent directly back by the reflective prism. By adding auto tracking of the prism via radio links and robotic servos, total station systems have been developed that automatically continuously track the prism target and transmit data to a data collector and operating controller located on the prism pole. This type of system is referred to as a robotic total station. A robotic total station may be operated by a single person who controls the robotic total station remotely while walking with the prism pole and data collector. During this study, a single surveyor using a robotic total station required an average of one minute to collect information for each object. Figure 4 depicts the robotic total station in use during the data collection activities. Notably, in comparison with the GPS data logging, the initial system setup and data collection time per object were higher.

Figure 4: A Robotic Total Station Device for Data Collection

The robotic total station method requires the same data reduction effort as GPS data logging. A skilled operator, using up-to-date software, has the capability to process survey crew-derived data at rates in excess of 2,000 ft. per hour. The results indicated that this method is able to collect all the required asset roadway inventory data with a precision of 0.01 ft., more than adequate for the accuracy requirements for implementing the HSM. A major deficiency of the robotic total station method is that it has an operating radius of approximately 1,000 ft. from each setup point. Therefore, the robotic total station must be relocated as the survey progresses, a process that requires approximately 15 minutes for each required move. Loss of prism tracking, which is to automatically point the instrument at the prism at all times by a radio link, video imaging system, and light beam recognition system controlled by the instrument's programmable logic system, is an additional issue associated with robotic total stations. Loss of tracking may be caused by line of sight interference due to terrain or highway traffic. Several minutes may be required to re-establish contact with the robotic total station with every loss of tracking event. To operate the system, the surveyor must walk to the object being measured. This exposes the surveyor to traffic, especially when collecting edge of pavement, shoulder, and centerline data. Crew safety must be addressed through warning signs, traffic cones, and high-visibility clothing.

GPS Enabled Photo/Video Logging

The collection of geo-tagged digital videos and photos is carried out using a Red Hen video mapping system (www.redhensystems.com). Equipped with a video camcorder and a GPS antenna, the video mapping system is able to collect geo-tagged digital video with essential locational information, which may be imported into ArcGIS 9.3 software (with a ArcView 9.3 or Arc Editor 9.3 license) using a video for ArcGIS extension (or GeoVideo) (Figure 5). In the instance of data collection time, the GPS enabled photo/video logging requires a relatively short time but an extensive feature extraction effort in the office. In this study, the average time for data collection employing this method was nine minutes per mile.

In respect to the data reduction effort, with the help of high-resolution imagery (e.g., 1-ft digital orthophotos, an undistorted aerial imagery that can be used to measure the true distances, or satellite imagery) as a background and video files collected in the field in MPG format that produces better quality videos than other formats, features in the form of points, lines, and polygons can be traced through on-screen digitizing and saved as feature classes in ArcGIS. In the present research, extraction of required features took an average of 50 minutes per mile or one minute per object. Figure 6 illustrates an example of object extractions using both video logging and high-resolution imagery.

Figure 5: A Video Logging System Configurations in Use for Data Collection

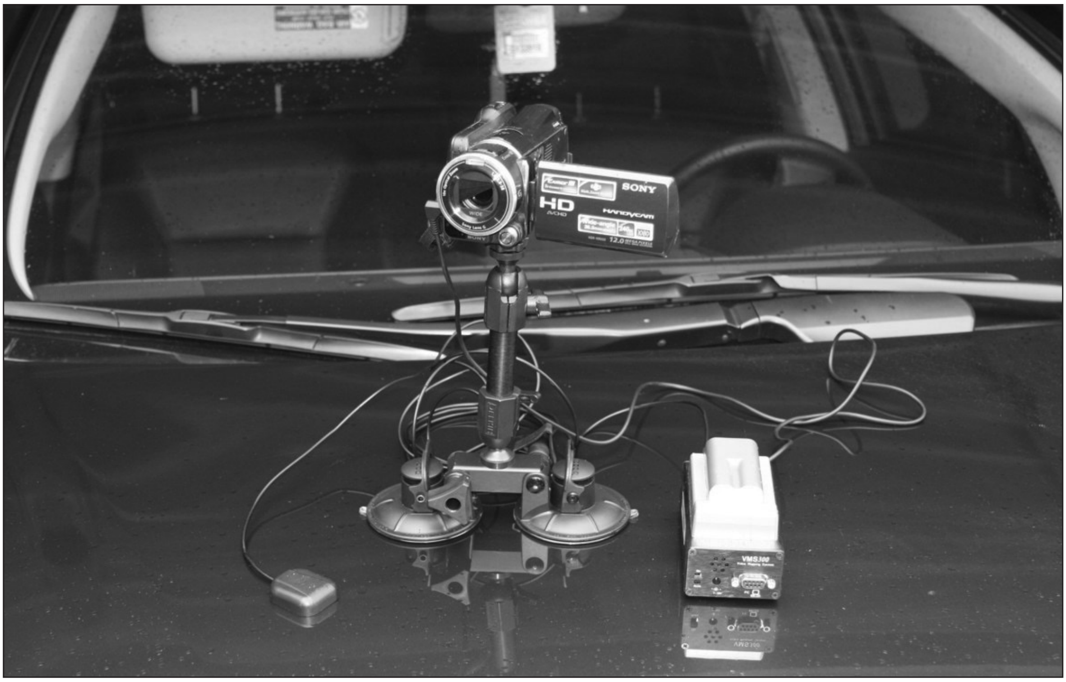
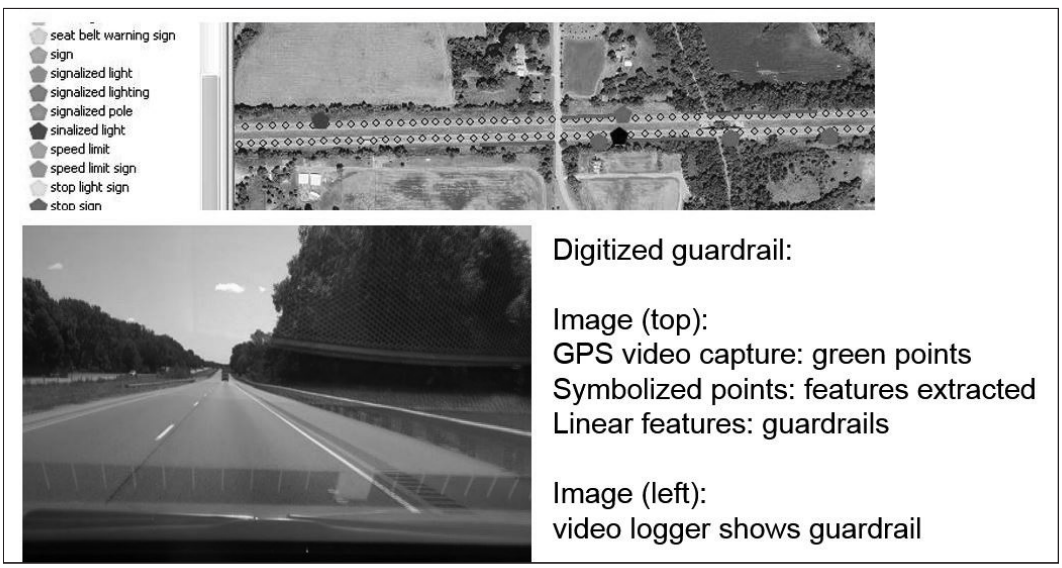


Figure 6: A Sample of Object Extraction Utilizing Both Video Logging and High-Resolution Imagery

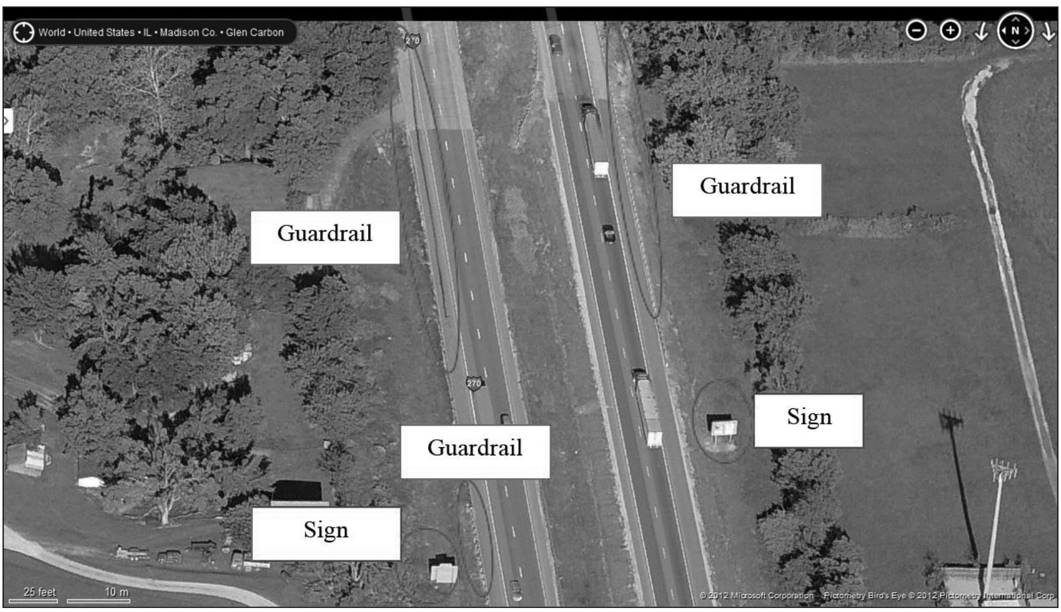


Due to recording videos on a vehicular platform, this method eliminates the risk of exposing the data collection crew to road traffic. Additionally, working with high-resolution aerial photographs or satellite imagery, the photo/video log method can provide all roadside inventory data to be implemented in the HSM, except roadside slope with reasonable accuracy. A locational accuracy of six inches for all roadside objects is achievable with 1-ft spatial resolution images.

Satellite/Aerial Imagery

Satellite/aerial imagery has been employed over the past several decades to obtain a wide variety of information about the earth's surface. High-resolution images taken from satellite/aircraft can be utilized to identify and extract highway inventory data input (Gong et al. 2012, Golparvar-Fard et al. 2012, Zhou et al. 2013, Jalayer et al. 2013). Therefore, Google maps and Bing maps are two beneficial tools for this purpose. The increasing availability of high-resolution images offers the possibility of leveraging these images to extract some HSM-related roadside features as shown in Figure 7. Notably, one of the considerable benefits of the satellite/aerial imagery method is the elimination of data collection efforts since all imagery is already freely accessible. Compared to other methods, therefore, this method is the most economical one due to the absence of the field data collection cost. However, similar to the photo/video log method, the satellite/aerial imagery is not capable of collecting some HSM-related highway inventory data. For instance, extraction of roadside slope information is very difficult from images and small vertical objects are not quite visible. Based on the analysis of results, in this method, the average extraction time was 1.5 minutes per object.

Figure 7: Data Extracted Using Satellite/Aerial Imagery Method (Image: Bing Map)



Mobile LiDAR

Mobile LiDAR is an emerging technology that employs laser scanner technology in combination with Global Navigation Satellite Systems (GNSS) and other sensors to capture accurate and precise geospatial data from a moving vehicle. This system can collect data on approximately 30 miles of highway per day with a high data measurement rate of 50,000 to 500,000 points per second per scanner (Tang and Zakhor 2011, Gong et al. 2012). Figure 8 shows a photo of an outside view of a mobile LiDAR van and a picture of a computer screen inside the van to show the different mounted cameras and data collection progress.

Regarding data collection, this method is capable of collecting a huge amount of data in a very short time, using an equipped vehicle, in comparison with conventional survey methods (Gong et al. 2012, Zhou et al. 2013). Taking advantage of this technology, in this study, an average of 30

Figure 8: A Photo of a Mobile LiDAR Van (left figure) and a Snapshot of the Computer Screen inside the Van (right figure) (Image: Woolpert Co.)

minutes was required to collect information for each mile of segment. However, the data reduction is a major undertaking with mobile LiDAR and the time associated with the data reduction part in this method is significant. Additionally, the processing of and feature extraction from mobile LiDAR data involves a fairly intensive computational effort and requires software and technical expertise. In terms of commercial packages for LiDAR data processing, Terrasolid Suite, Virtual Geomatics, TopoDOT, and QTModeler are found to be applicable for a variety of data extraction purposes. In particular, the Terrasolid Suite is the most commonly used software for airborne and mobile LiDAR data processing. Because of this, it was chosen as the program to benchmark the data reduction time. The data processed during the data reduction steps include point clouds which is a set of data points in some coordinate systems, geo-referenced imagery, data collection path, and an AutoCAD file. One of concerns with the mobile LiDAR method is the need for large data storage space, here 9.3 Gigabyte (GB) of space per mile of roadway. Given this fact, the mobile LiDAR data are typically divided into manageable blocks to reduce any difficulty during the process. For the purpose of this research, a typical block did not exceed 2 GB. As each type of highway segment was broken into equal sized blocks, data extraction was performed on representative blocks and then the results were utilized to infer the data reduction time for the whole highway segment. In this study, determining roadside slope, roadside fixed objects density, super-elevation rate, and grade took 5, 15, 15 and 15 minutes per block, respectively.

The mobile LiDAR has the capability of collecting all categories of HSM highway inventory data. Although the data collection time in this method is short, the cost of field data collection is higher than other methods (Zhou et al. 2013). However, these shortcomings cannot overshadow the potential of this method; it collects survey-grade data, which can only be matched by the robotic total station method, but with no traffic exposure or need for road closures. The main strength of this method also lies in its ability to collect data that are valuable for multiple DOT programs. The rapid development of computing hardware and LiDAR data processing methods indicate that the mobile LiDAR method will soon be comparable to other methods in terms of data reduction time.

Overall, GPS data logger and robotic total station can gather all required feature data, but they impose longer field data collection times and expose data collection crews to dangerous road traffic. Photo/video logging and aerial imagery, when used together, can collect nearly all required feature data, except roadside slope. The mobile LiDAR has the capability to collect all required feature data in a short amount of field time, but the data require extensive reduction efforts.

The results of field trials are summarized in Table 8. In the table, the capability of each HIDC method is evaluated using the metrics, including the capability of collecting HSM-related roadside features, total data collection time, total data reduction time, unit data collection and reduction time, and total cost. For cost analysis, two unit labor costs were assumed: $75 per hour for a person trained at an introductory level and $130 per hour for an expert level person. Based on the quotes from five LiDAR companies, the average data collection cost per mile for mobile LiDAR was considered to be $200. In the present research, the photo/video log method required the least total time (man-hr./mi) and the robotic total station method required the most. Specifically, the mobile LiDAR technology ranked at the median level, with 5.5 man-hr./mile.

Furthermore, based on Table 8, the total cost per mile to prepare the required highway inventory dataset for photo/video log, satellite/aerial imagery, GPS data logger, mobile LiDAR, and robotic total station methods were $72, $107, $700, $915, and $1,075, respectively. In particular, the photo/video log had the lowest cost and the robotic total station had the highest cost.

Table 8: Comparison Between Different Highway Inventory Data Collection Methods

Methods	Type of Segment Selected	Capability of Collecting HSM-related Roadside Features	Total Length (mi)	Total Data Collection Time (man-hr)	Total Data Reduction Time (man-hr)	Total Time (man-hr/mi)	Total Cost ($/mi)
Photo/Video Log	1, 2, 3, 4	Some	28.0	4.0	23.0	0.96	$72
Satellite/Aerial Imagery	1, 2, 3, 4	Some	7.0	---	10.0	1.43	$107
Mobile LiDAR	1, 2, 3, 4	All	14.2	8.0	70.0	5.50	$915
GPS Data Logger	2, 3, 4	All	1.3	6.0	3.5	7.31	$700
Robotic Total Station	1, 3, 4	All	1.3	13.0	3.5	12.70	$1,075

(Note: 1= rural multi-lane highways; 2= freeway segment; 3= rural two-lane highway; 4= urban/suburban arterials)

COMPARATIVE ANALYSIS OF SELECTED DATA COLLECTION METHODS

In addition to unit cost, some other factors are important in selecting data collection methods, such as data quality and completeness, safety, and disruption of traffic. To consider those factors, based on the field trial results, an evaluation matrix was developed to compare different data collection methods, as shown in Table 9. Eleven criteria were utilized to assess the performance of the different technologies. Each criterion was assigned a score of 1 to 5 (5 being the best and 1 the worst) to indicate the relative performance of one method compared to the others. Specifically, the equipment cost for the satellite/aerial imagery method had a score of "5" because it did not incur any field data collection cost. The total weighted score is the summation of scores of each criterion multipled by its corresponding weighing factor. For GPS data logger method, as an example, the total weighted score is 24, which is sum of (3×0.25) + (2×0.25) + (2×0.25) + (2×1.00) + (3×2.00) + (3×2.00) + (2×1.00) + (5×0.25) + (5×0.25) + (5×0.50) + (5×0.25).

For each evaluation criteria, a weighing factor (WF) was designated. These WFs, that imply the relative importance of each data collection method, were identified through discussions with stakeholders at IDOT. A weight of 2.0 was assigned for data completeness and data quality because the highest data quality and completeness were required to have collected data to serve different offices (planning, design, pavement management, and safety) in the agency. Transportation agencies can assign their own WF for each evaluation criteria for their specific purposes. This method, as used in multi-criteria analysis (MCA) approaches, is widely utilized to assess and recognize the importance of one criterion over another in an intuitive manner when quantitative ratings are not available (Dodgson al. 2009). All these criteria were employed to rank various HIDC methods based on the summation of weighted components. The results demonstrated that the mobile LiDAR has the highest overall score when data completeness and data quality are the top priority for the agency.

Table 9: Evaluation Matrix for Highway Inventory Data Collection Methods

	Criteria	GPS Data Logger	Robotic Total Station	GPS Enable Photo/Video Log	Satellite/ Aerial Imagery	Mobile LiDAR	Weighting Factor
Field Data Collection	Equipment Cost	3	2	4	5	1	0.25
	Labor Cost	2	1	4	5	3	0.25
	Data Collection Time	2	1	4	5	3	0.25
	Safety	2	1	4	5	3	1.00
	Data Completeness	3	4	2	1	5	2.00
	Data Quality	3	4	2	1	5	2.00
	Disruption to Traffic	2	1	4	5	3	1.00
Field Data Reduction	Software Cost	5	4	3	2	1	0.25
	Labor Cost	5	3	4	2	1	0.25
	Data Reduction Time	5	3	4	2	1	0.50
	Data Storage Size	5	4	2	3	1	0.25
Total Weighted Score		24	23	23	21	29	

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to identify cost-effective methods for collecting highway inventory data for implementing in the HSM. Several promising methods, including the GPS data logger, robotic total station, GPS-enabled photo/video log, satellite/aerial imagery, and mobile LiDAR, were identified through a comprehensive literature review to compare and determine their capabilities and limitations. Moreover, field trials for collecting HSM-related highway inventory data on four types of roadway segments (rural two-lane two-way roadways, rural multi-lane highways, urban and suburban arterials, and freeway) were performed to evaluate and compare the utility of these methods. The findings of this research indicate that the GPS data logger, robotic total station, mobile LiDAR, and the combination of video/photo log method with aerial imagery are all capable of collecting HSM-related information. Based on the perceived advantages and disadvantages of each data collection method, the following recommendations are made for consideration by state and local transportation agencies:

- The GPS data logger method can be employed for short distances, low speeds, and low to medium traffic volume roadways that are not obstructed by buildings or trees.
- The robotic total station technology can be employed for points of specific interest, such as intersections.
- The photo/video log method, together with high-resolution aerial imagery, can be used to collect roadside inventory data for large-scale statewide data collection.
- The mobile LiDAR technology can be utilized to gather highway inventory data with the highest data quality and completeness for serving multiple offices in state DOTs and local agencies. In order to share the costs of the mobile LiDAR data collection and processing, identifying multiple clients within the DOT is important.

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The Effect of Governance Forms on North American Airport Efficiency: A Comparative Analysis of Airport Authority vs. Government Branch

by Qi (Mia) Zhao, Yap Yin Choo, and Tae Hoon Oum

This paper applies a stochastic cost frontier model to a panel of 54 major airports over 2002-2008 to examine how the two dominant governance forms of publicly owned airports in the United States and Canada, namely, operation and governance by a government (city, county, or state) branch, or by an airport authority, affect airport efficiency performance. Our key findings are (a) airports operated by an airport authority achieve higher cost efficiency (on average, 14% higher technical efficiency) than those operated by a government branch; (b) airports operated by a government branch have lower labor share than those operated by an airport authority; and (c) there is no statistically significant difference in the efficiency performance between airports operated by U.S. airport authorities and Canadian airport authorities.

INTRODUCTION

Since the UK government began to privatize its airports in 1987, a great diversity has emerged in the ways in which countries tackle airport ownership and governance issues. In Europe and Australia, many airports have been fully or partially privatized and put under different regulatory regimes. However, in Canada and the United States (henceforth referred to as "North America" for convenience), despite a long tradition of privately owned utilities and transport industries, the majority of commercial airports are still publicly owned and mostly operated either by a government branch (city, county, or state governments) or an airport authority, which is a quasi-governmental organization.

Despite the uniqueness of the North American airport governance structures, few studies have investigated their effects on airport efficiency performance. Many studies, including Barros and Dieke (2007), Oum et al. (2004), Oum et al. (2006), Oum et al. (2008) and Vasigh and Gorjidooz (2006), have focused on the effects of ownership forms and/or regulatory policies on airport efficiency. Indeed, there has been little research about the way in which different governance structures affect airport efficiency or productivity performance. Furthermore, very few studies have focused solely on measuring and comparing the effects of airport governance forms on the efficiency performance of North American airports.

In addition, the literature on airport governance structures provides few concrete, quantitative analyses of how different governance structures affect airport efficiency or productivity. Especially in North America, there has been no consensus so far as to which airport governance structure is better to foster efficiency. Therefore, this paper seeks to find empirical evidence on comparative efficiency performance by the two most widely used airport governance structures in North America: an airport authority vs. a government branch.

To achieve these objectives, we estimate a stochastic cost frontier model using an unbalanced panel data of 54 airports over the 2002-2008 period. Our model will allow us not only to measure the unobserved airport inefficiency, but also allow us to study how much of the inefficiencies are attributable to the different airport governance forms. We employ a parametric method to measure efficiency in order to identify the direction of a potentially non-neutral input-augmenting production structure being employed by the airports operated by the two distinct governance structures.

The structure of this paper is as follows: In the second section, we summarize literature on the effects of ownership and governance forms on airport efficiency. This section also summarizes the fundamental characteristics of airport governance forms adopted in North America. The third section presents the framework of our econometric model for measuring the efficiency and identifying the effects of governance forms. The fourth section describes the data and details on variable construction. The empirical results and a discussion of the findings are given in the fifth section. The last section summarizes the study and considers further research needs.

LITERATURE SURVEY AND GOVERNANCE FORMS OF NORTH AMERICAN AIRPORTS

Literature on Airport Ownership, Governance Structure, and Firm Performance

Since the 1990s, the momentum to privatize airports has been gaining strength around the world. The privatization of airport ownership is usually accompanied by some form of economic regulations, including price regulations. The issue of full and partial privatization and associated economic regulation of airports has attracted a wide range of researchers to measure and analyze airport efficiency performance. There are many studies already on this efficiency measurement: for the UK, Beesley (1999) and Starkie (2001); for Australia, Forsyth (2002) and Hooper et al. (2000), and Air Transport Research Society (2002-2011). Oum et al. (2004), investigate 60 airports worldwide under different ownership forms and provide both theoretical and empirical evidence on the impact of different economic regulations on airport efficiency performance. Their empirical results indicate that privately owned airports do not necessarily achieve higher capital input productivity or total factor productivity than publicly owned airports do.

However, it is not only ownership and its associated regulations that determine performance, but also airport governance structures themselves can have significant effects on performance. Gillen (2011) adopts a descriptive approach to examine the evolution of airport governance, and proposes that researchers consider the issue of airport governance in a two-sided framework (airports and airlines).[1] Despite the importance of governance structure on the performance of airports, few studies purposely measured and analyzed the effects of governance forms on efficiency performance of North American airports, in particular comparing airports governed/operated by an airport authority vs. those governed/operated by a government branch. Although most empirical evidence, including Oum et al. (2008), suggests that airports operated by a port authority are less efficient than those run by either a government branch or an airport authority, it has not yet been clearly determined how the airports operated by the latter two governance forms differ in their efficiency performances.

Some studies argue that the difference in efficiency between airports operated by the two governance forms (an airport authority vs. a government branch) is negligible in North America. For example, Oum et al. (2006) examined the impact of six different ownership/governance forms on the variable input productivity performance of 116 airports worldwide and found, among other findings, there is no significant difference in efficiency performance of airports operated by an airport authority from those operated by a government branch. On the other hand, other studies such as Craig et al. (2005) and Oum et al. (2008) detect a better efficiency performance of airports operated by an airport authority. Oum et al. (2008) compare the efficiency of airports owned/operated by seven different governance forms based on a panel data of 109 airports worldwide.[2] Based solely on U.S. airport data, Craig et al. (2005) find results consistent with Oum et al. (2008) that, in term of technical efficiency, the airports operated by airport authorities outperform those operated by government branches. However, given that Craig et al. (2005) did not include non-aeronautical services, it is not clear whether or not their results would have changed if they included the non-aeronautical revenue activities as a part of outputs in view of the fact that the majority of U.S. airports generate 40%-70% of their total revenues from non-aeronautical service activities. Although Zhuo et al. (2013) investigated the effects of U.S. airport governance forms, their analysis focused on the relative performances of the three alternative measurement methods: productivity index approach, DEA (Data Envelopment Method) approach, and stochastic frontier method approach.

Governance Forms in North American Airports

In Canada, in order to promote commercialization and efficiency into the airport sector, the (Canadian) Airport Authority form of governance was introduced beginning in 1992, transferring the responsibility for capacity planning, operation, and management of airports from the federal government (in fact, Transport Canada) to locally based not-for-profit corporations on long-term leases. These airport authorities are self-financing, not-for-profit, non-share-capital corporations incorporated under Canada Business Corporations Act, but do not pay income tax. Their leases are for 60 years with an option to renew for an additional 20 years. Although some business practices are controlled through the lease document, they are not subject to any special economic regulation through legislation. Furthermore, the airport authorities enjoy the freedom to set the prices for various airport activities (e.g., parking, rent, landing aircraft, and terminal use) and determine service levels within the safety regulatory framework. In addition, unlike the airport authorities in the United States, Canada's airport authorities operate airports with virtually no federal assistance or subsidy. In fact, since they are required to make annual ground lease payments, Canadian airport authorities have become a source of significant general treasury revenues for the federal government.

On the other hand, governance and ownership of airports in the United States is actually quite complicated as it can differ for each state. Therefore, we can only describe the general pattern that has emerged in the types of airport governance in the United States. It has long been the tradition that airports in the United States are operated by local or regional government branches (i.e., a division or department of aviation). Such an aviation department is usually separated from other departments, but often uses some functions of local government such as accounting services, purchasing decisions, and fire fighting services. Within an aviation department, the board of directors is appointed by the chief executive officer of the local government and is ultimately responsible to the (city) council. Generally speaking, the board of directors in an aviation department cannot enter into contracts without the approval of the council, which literally owns the airport. Moreover, the annual budget, bond sales, and other similar measures of an aviation department also need to be approved by the council.

As an alternative to direct control by local/regional government, airport authorities were first established to assume control over public airports during the 1950s and 1960s. Unlike those in Canada, U.S. airport authorities are considered public agencies since they are created by the local/regional governments that own airports. Although few airport authorities, such as the Great Orlando Aviation Authority and the Metropolitan Washington Airports Authority, lease the airport from the government, the majority of local/regional governments directly transferred and delegated all airport managerial responsibilities to an airport authority at virtually no cost or lease payment. At large, an airport authority resembles an autonomous corporation with its own functional departments, such as finance and procurement department. While airport authorities are structured as independent and self-supporting institutions, the board members of an airport authority are always elected by the local/regional government. The board members are authorized to appoint the chief executive officer of an airport authority, and the board has the right to veto the authority's decision. Therefore, the local government, to a greater or lesser degree, can exercise varying levels of oversight and control the authority via the makeup and structure of the board. In some states, such as Florida, the elected public officials are allowed to serve as board members, while in other states, such as Michigan, state legislatures have ruled out the elected public officials from the boards of airport authorities. For instance, the mayor of Orlando and other public officials are serving as the board members of the Great Orlando Aviation Authority, whereas the board of the Cincinnati/Northern Kentucky International Airport only consists of civic and business leaders.

In most of the past studies it is conventional to lump together both Canadian and U.S. airport authorities into the same category. However, it is important to note that differences could occur between U.S. airport authorities and their Canadian counterparts. Regardless of the governance form, U.S. airports have developed particular contractual and financial relationships with airlines (their major customers) that distinguish them from airports in Canada. For instance, U.S. airports enter into legally binding contracts known as airport-use agreements which detail the conditions for the use of both airfield and terminal facilities. These contracts are negotiated between the airport and its airline customers. The contracts will specify the fees and rental rates an airline has to pay and the method by which these fees are to be calculated. Regarding sources of capital investment, many U.S. airports are financed partly or largely from the private sector through the bond market. Moreover, U.S. airports are eligible to be funded by the federal government via the Airport Improvement Program (AIP), which is administered by the Federal Aviation Administration (FAA). In addition, while Canadian airports are not directly regulated, U.S. airports are subject to some general pricing rules. For instance, U.S. airports are required to set aeronautical fees so as to collect revenues that reflect the costs of providing services.

U.S. airport authorities are also different from their Canadian counterparts with respect to selection of board members. For U.S. airport authorities, board members have to be appointed by the state or local government that owns the airport, while the board members of an airport authority in Canada are generally appointed by local community organizations. However, it remains a question how such different selection processes affect airport efficiency performance. There is no doubt that politically motivated appointment of board members leaves U.S. airport authorities vulnerable to changes in administration and to the exertion of political influence. It is noticeable, nonetheless, that board members of U.S. airport authorities either serve on a voluntary basis or are paid only a small stipend for attending each official meeting or activity. It is therefore possible that the board members of a U.S. airport authority are more likely to represent the communities that the airport serves and thus have a strong interest in the performance of the airport. On the other hand, the board members of Canadian airport authorities receive compensation for their service on the board and thus may be actually distant from the communities that airports serve.

While the definition of an airport authority varies, it is often noted that airport authorities are likely to be less liable to political interference. To a large extent, airport authorities may be relieved from the pressure to use various services provided by the city or county, and avoid the contract approval process and other constraints imposed on a government branch such as the city's aviation department. Moreover, managers of airport authorities may have greater knowledge and expertise about the aviation industry in general and airport management in particular. In addition, it has been long argued that there is some potential inefficiency in procurement practices of aviation departments. Airports run by a government branch rely on the local government staff to make purchasing decisions, which often make the process longer and less efficient. The political influence from local government, may prevent aviation departments from procuring services from the most cost effective sources.

ECONOMETRIC MODEL

Different methodologies have been proposed to measure and compare airport efficiency performance. These methods can be broadly classified into non-parametric and parametric. Non-parametric methods include the partial and total factors productivity (TFP) indices, data envelopment analysis (DEA), and numerous forms of DEA-derivative methods. Hooper and Hensher (1997), Nyshadham and Rao (2000), Yoshida (2004), and Air Transport Research Society (2002-2011) used regression analysis to decompose a TFP or VFP (Variable Factor Productivity) index and further investigate the productive efficiency of airports from different regions, while Sarkis (2000), Gillen and Lall (2001), and Barros and Dieke (2007), applied a DEA method to evaluate the efficiency performance of airports.

The non-parametric approaches, such as TFP and DEA, readily handle a large number of input and output categories, more easily than they can be accommodated in econometric estimation methods. But econometric estimation methods, if data are available, build on established economic theory relationships and separate out the influences on cost and/or productivity. Barros (2008) and Martin et al. (2009) used the parametric approach to investigate the cost efficiency performance of Spanish airports.[3] In this study, we argue that it is not sufficient to simply describe airport performance but also to be able to assess and understand how different governance structures can affect it. Hence we chose the econometric method as a preferred method to use for accomplishing our key objectives, to isolate the effects of different governance structures from other variable also affecting airport's efficiency.

The Stochastic Frontier Analysis (SFA) was first developed by Aigner, Lovell and Schmidt in 1977. The basic empirical framework for SFA is a regression specification involving a logarithmic transformation that adds a positive (truncated) random error term, along with the traditional symmetric noise term, to capture unexplained inefficiency. We use the framework proposed by Battese and Coelli (1995) to estimate the frontier production (or cost) function and the inefficiency model simultaneously, avoiding the econometric problem of the two-steps procedure.

In the short run, if an airport tries to minimize its production cost (C) given the outputs (Q), variable input prices (W), and capital inputs (K), then the cost minimization frontier in a logarithmic form can be expressed as $lnC^*(Q_{it}, K_{it}, W_{it}, t; \boldsymbol{\beta})$, where i represents airport and t represents time. In reality, airports may deviate from their cost minimization objective for various reasons and such deviations indicate the existence of inefficiency. To reflect this reality, for airport i, a positive random term ξ_{Tit} is denoted as technical inefficiency, which indicates the deviation of airport's actual cost from its efficient cost frontier. Further, since our interest centers on determining whether and/or how governance structures can affect efficiency performance, it is assumed that the technical inefficiency term ξ_{Tit} depends on the variables indicating airport governance form Z_{it}, with the dependence expressed as $\xi_{Tit}(Z_{it}; \varsigma)$. Moreover, it is possible that governance structures can assert influence not only on airport technical inefficiency but also on allocative inefficiency primarily by affecting input (labor vs. non-labor) mix. In order to reduce the complexity in estimation, the impact of governance structures on allocative inefficiency is analyzed by simplifying the functional form of $\xi_{Ait}(Z_{it}, W_{it}; \rho)$ to include only the interaction terms between governance form variable Z_{it} and input price variables (W_{it}). By applying Shephard's lemma, this specification can identify how different governance forms change variable input mix. Taken together, the observed actual production cost of airport i at time t can be expressed as

$$(1)\quad lnC_{it} = lnC^*_{it}(Q_{it}, K_{it}, W_{it}, t; \boldsymbol{\beta}) + \xi_{Ait}(Z_{it}, W_{it}; \rho) + \xi_{Tit}(Z_{it}; \varsigma) + \varepsilon^c_{it}$$

where, $lnC^*_{it}(Q_{it}, K_{it}, W_{it}, t; \boldsymbol{\beta})$ is the deterministic kernel[4] of the stochastic cost frontier, ξ_{Ait} captures the effect of governance structures on airport variable input usage, $\xi_{Tit} \geq 0$ captures the effect of technical inefficiency, $\varepsilon^c_{it} \sim iid\, N(0, \sigma^2_v)$ is the effect of the symmetric random noise term, and the vector $\boldsymbol{\beta}$ and ρ are the parameters to be estimated. In particular, our model includes three outputs in vector Q_{it} (number of passengers q_{1it}; number of aircraft movements q_{2it}; and non-aeronautical output q_{3it}), two variable input prices in vector W_{it} (labour price w_{1it}; and price of the soft cost input[5] w_{2it}), and three quasi-capital inputs in vector K_{it} (number of runways k_{1it}; number of gates k_{2it}; and terminal size).[6]

The translog cost functional form is adopted to estimate the kernel of the stochastic cost frontier model. In addition to governance structures, many other factors, such as location, are important with airports but beyond managerial control. Therefore, we augment the cost frontier to account for observed airport heterogeneity by adding two variables: percentage of international passengers in total passenger traffic (π_{it}) and, Canada dummy variable (D_i). In addition, since economic conditions of the day is the most powerful driver of changes in the air transport industry at large, a set of year dummies (T_t) is included in the cost frontier to reflect the impact of general economic conditions on airport operating cost.

As mentioned earlier, the physical measure is treated as a fixed input, i.e., the physical measure enters the cost frontier rather than the price of capital. However, in practice, airports may not be able to adjust their capacity as output changes. In order to account for the short-run disequilibrium adjustment in capacity, we estimate the restricted translog cost frontier, which is log-linear in the physical measure of capital inputs. Adjusted to these specifications, the stochastic cost frontier adopted in the study can be written as follows:

$$\begin{aligned} LnC_{it} = {} & lnC^{*}_{it}(Q_{it}, K_{it}, W_{it}, t;\ \beta) + \xi_{Tit}(Z_{it}; \varsigma) + \xi_{Ait}(Z_{it}, W_{it}; \rho) + \varepsilon^{c}{}_{it} \\ = {} & \alpha + \gamma\pi_{it} + \varphi D_i + \sum_{t=1}^{6}\omega_t T_t + \sum_{j=1}^{3}\beta_j\, lnq_{jit} + \sum_{j=1}^{3}\lambda_j\, lnk_{jit} + \sum_{j=1}^{2}\delta_j\, lnw_{jit} \\ & + \frac{1}{2}\sum_{j=1}^{3}\sum_{n=1}^{3}\phi_{jn}\, lnq_{jit} lnq_{nit} + \frac{1}{2}\sum_{j=1}^{2}\sum_{n=1}^{3}\tau_{jn}\, lnw_{jit} lnw_{nit} \\ & + \sum_{j=1}^{3}\sum_{n=1}^{2}\vartheta_{jn}\, lnq_{jit} lnw_{nit} + \sum_{j=1}^{2}\rho_j Z_{jit}\, lnw_{jit} + \xi_{Tit} + \varepsilon^{c}{}_{it} \end{aligned} \tag{2}$$

where ξ_{Tit} is the technical inefficiency model, which is assumed to have a non-negative half normal distribution as follow:

$$\xi_{Tit} = \varsigma_0 + \varsigma_1 Z_{1it} + \varsigma_2 Z_{2it} + \mu_{Tit}$$
$$\mu_{Tit} \sim N(0, \sigma_z^2)$$

and $\varepsilon^{c}{}_{it}$ is white noise error

$$\varepsilon^{c}{}_{it} \sim N(0, \sigma^2)$$

As the cost function must be linearly homogeneous in input prices, the following restrictions are imposed in the estimation of the above model:

$$\delta_1 + \delta_2 = 1,\ \vartheta_{11} + \vartheta_{12} = 0,\ \vartheta_{21} + \vartheta_{22} = 0,\ \vartheta_{31} + \vartheta_{32} = 0,\ \tau_{11} + \tau_{12} = 0,$$
$$\tau_{12} + \tau_{22} = 0,\ \frac{1}{2} * \tau_{11} + \tau_{12} + \frac{1}{2} * \tau_{22} = 0,\ \rho_1 + \rho_2 = 0$$

In addition, we also impose the following symmetric conditions in the estimation:

$$\phi_{12} = \phi_{21},\ \ \phi_{13} = \phi_{31},\ \ \phi_{23} = \phi_{32},\ \ \tau_{12} = \tau_{21}$$

AIRPORT SAMPLE AND VARIABLE CONSTRUCTION

Our sample consists of an unbalanced panel of 54 airports in the United States and Canada for the 2002-2008 period. These airports are governed/operated by either an airport authority or a government branch (see the list in Appendix A). The data re compiled from various sources, including the U.S. FAA (Federal Aviation Authority) and airports' annual reports. Some data were obtained directly from airports. For more details on the data, the reader is referred to any annual issue of the ATRS Global Airport Performance Benchmarking Reports (2002-2011).

The airport outputs commonly used in economic analysis are the number of passengers enplaned and deplaned, the tonnages of air cargo handled, and the number of aircraft movements (ATM or Air Transport Movements). The number of passengers handled is obviously the most important output measure for most airports. The air cargo services are generally handled by airlines, third-party cargo handling companies or other firms who lease spaces and/or facilities from the airports. As a result, the airports' rental incomes from such space/facility leases are included in the airport's non-aeronautical revenue. Since most of cargo services are not operated directly by airports, we do not include air cargo services as a separate output for airports. Some may also argue ATM should not be included as an airport's output because aircraft movements (landings and takeoffs) are the means by which passengers and air cargo are carried. ATM may be considered as an intermediate activity required to handle passengers and cargos, given that almost all airport activities are related to the movement of aircraft, like most other studies, we decided to include the number of ATM as an output.

In addition to the outputs discussed above, airports also derive revenues from concessions, car parking, land and office rentals, and other numerous non-aeronautical services they provide. These services are not directly related to aeronautical activities in a traditional sense, but they are important and becoming increasingly more important source of revenues for airports. In fact, as shown in Figure 1, the non-aeronautical revenues account for anywhere between 30% and 85% of the total revenue of North American airports. Since many of the airport inputs are not separable between the aeronautical and the non-aeronautical activities of an airport, any productivity or efficiency measure that excludes the non-aeronautical services as an output would bias empirical results seriously against the airports generating a larger portion of their revenues from commercial and other non-aeronautical activities than their peers. For this reason, we decided to include the non-aeronautical services output as the third output. Since non-aeronautical services include numerous items and activities, it is difficult to construct an "exact" price index consistent across all airports in different regions and over time. Therefore, we construct the non-aeronautical output quantity index by deflating the total non-aeronautical revenues of an airport by the cost of living index (COLI) of the census metropolitan region in which the airport is located.

On the input side, we initially considered four general categories: (1) labor, which is measured by the number of full-time equivalent employees who work for and are paid for by an airport operator; (2) purchased goods and materials; (3) purchased services, including those contracted out to external parties; and (4) capital, which consists of various facilities and infrastructure. In practice, however, few airports provide separate expense accounts for input categories (2) and (3). We therefore combine them to form a single input category (henceforth referred to as "the soft cost input"). Since airports' operating expenses are measured in different currencies and are subject to very different price levels depending on location of the airport, again we adopt the COLI as the proxy for the soft cost input price index, and create the soft cost input quantity index by deflating the soft cost input expenses by the COLI. Moreover, as the proxies for capital input, we consider three physical measures of capacity: the number of runways, the number of gates, and the terminal size (measured in square meters).

Table 1 reports the summary statistics of our data on the airports operated by a government branch and by an airport authority for selected years. The table shows: (a) all of the outputs and proxy capital measures show that, overall, the airports operated by airport authorities are smaller than the airports operated by the government branches; (b) on average, the labor cost shares of the airports operated by airport authorities are higher than the airports operated by government branches; and (c) the airports operated by airport authorities have higher shares of international passengers in their total passengers and also generate a higher share of total revenues from non-aeronautical revenue as compared with airports operated by government branches.

Table 1: Summary Data for Comparing Between Two Groups of Airports
(The numbers in parentheses are standard errors)

	Airports Operated by Government Branch			Airports Operated by Airport Authority		
	2002	2005	2008	2002	2005	2008
Output Measures						
Number of Passengers (million)	23 (19)	27 (22)	28 (23)	14(12)	15(14)	15(12)
Number of Aircraft Movements(000's)	328 (221)	347 (251)	349(245)	245(162)	242(160)	222(134)
Non-Aeronautical Revenue						
(million COLI deflated $)	74(51)	79 (56)	91 (69)	52(39)	61(46)	75(75)
Proxy Capital Measures						
Number of Runways	3.4(1.2)	3.5 (1.3)	3.6 (1.2)	3.2(1.1)	3.3(1.2)	3.3(1.2)
Number of Gates	73 (46)	79(47)	79(48)	59(42)	58(39)	64(41)
Terminal Size (000's Squared Meter)	200 (183)	224 (195)	212(159)	121(102)	126(100)	133(10)
Variable Inputs' Prices						
Wage (000's US$)	58 (16)	69(21)	86(27)	55(12)	67(13)	84(19)
Soft Cost Input Price Index) (COLI: cost of living index)	1.04(0.2)	1.14(0.2)	1.26(0.3)	0.99(0.1)	1.08(0.2)	1.18(0.2)
Variable Inputs' Share						
Labour Cost Share (%)	39%(10)	40%(11)	38%(11)	46%(10)	42%(10)	43%(9)
Other Characteristics						
Percentage of International Passengers (%)	8%(11)	8%(11)	7%(12)	10%(14)	10%(15)	11%(15)
Share of Non-Aeronautical Revenue (%)	49%(11)	49%(12)	50%(11)	52%(13)	54%(12)	56%(13)
Percentage						
Canadian Airports (%)				26%	26%	25%
US Airports (%)				74	74	75
Number of Airports in the sample	26	25	24	27	27	28

EMPIRICAL RESULTS AND DISCUSSIONS

Table 2 presents two alternative stochastic cost frontier models estimated by the Gauss maximum-likelihood computer program. In Model I, we postulate there is no difference between Canadian and U.S. airport authorities; i.e., the two countries' airport authorities perform identically. Therefore, in Model I, all sample airports are classified into two categories: (1) airports operated by a government branch and (2) airports operated by an airport authority. In Model II, we separate Canadian and U.S. airport authorities: i.e., the airports governed/operated by Canadian airport authorities perform differently from those governed/operated by U.S. airport authorities. In other words, in Model II we distinguish our efficiency models among three types of airport governance forms: (1) a government branch; (2) a U.S. airport authority; and (3) a Canadian airport authority.

Part A of Table 2 reports the estimation results for the kernel of the translog variable cost functions, including the effects of airport characteristics on variable costs. Part B reports the estimation results of the Technical Inefficiency Model; i.e., impacts of governance forms on technical efficiency of the airports which are of our particular interest in this paper.

Table 2: Stochastic Cost Frontier Estimation Results

A. Estimation Results for *Translog* Variable Cost Function				
	Model 1		Model II	
Parameters	Coefficient	t-statistics	Coefficient	t-statistics
α (constant)	-0.934	-3.79**	-0.936	-3.47**
ω_1 (Year 2003)	0.043	3.29**	0.040	3.21**
ω_2 (Year 2004)	0.022	0.94	0.021	0.87
ω_3 (Year 2005)	0.048	1.89*	0.044	1.72*
ω_4 (Year 2006)	0.066	2.82**	0.059	2.46**
ω_5 (Year 2007)	0.085	3.01**	0.082	2.78**
ω_6 (Year 2008)	0.117	2.61**	0.115	2.50**
γ (%International)	0.684	2.34**	0.652	2.32**
φ (Canadian dummy)	-0.241	-1.13	-0.236	-1.12
Coefficients of Outputs				
β_1 (non-aeronautical output)	0.325	3.36**	0.338	3.60**
β_2 (passengers)	0.290	3.21**	0.269	3.18**
β_3 (aircraft movements)	0.081	1.17	0.077	1.21
Coefficients of Proxy Capital Measures				
λ_1 (runway)	0.088	0.50	0.095	0.61
λ_2 (number of gates)	0.108	1.05	0.111	1.06
λ_3 (terminal size)	0.017	0.26	0.013	0.21
Coefficients of input prices				
δ_1 (wage)	0.394	2.99**	0.416	2.91**
Coefficient for Interactions between Governance Structure and Input Price				
ρ_1 (Government − branch $*$ wage)	-0. 069	-1.57	-0.058	-1.29
ρ_2 (Canadian Airport Authority $*$ wage)			0.014	0.31
Coefficients of Interactions among Outputs				
ϕ_{11} (non-aeronautical * non-aeronautical)	0.361	2.33**	0.356	2.43**
ϕ_{22} (passenger * passenger)	0.276	0.61	0.243	0.54
ϕ_{33} (aircraft movements * aircraft movements)	-0.241	-0.88	-0.270	-1.02
ϕ_{12} (non-aeronautical * passenger)	-0.247	-0.97	-0.232	-0.93
ϕ_{13} (non-aeronautical * aircraft movements)	-0.075	-0.29	-0.026	-0.17
ϕ_{23} (passenger *aircraft movements)	0.044	0.24	0.083	0.31
Coefficients of Interaction between Input Prices				
τ_{12} (wage *wage)	0.172	0.76	0.185	0.97
Coefficients of Interaction between Outputs and Input Prices				
ϑ_{11} (non − aeronautical $*$ wage)	-0.056	-0.28	-0.055	-0.29
ϑ_{21} (passenger * wage)	-0.393	-1.48	-0.305	-1.11
ϑ_{31} (aircraft movement * wage)	0.511	2.30**	0.505	2.18**
B. Estimation Results for the Technical Inefficiency Model (Impacts of Governance Form)				
Parameters			Coefficient	t-statistics
ς_0(Constant)	-0.798	-3.1**	-0.766	-3.04*
ς_1(Government -branch dummy)	0.141	1.75*	0.145	1.77**
ς_2(Canadian Airport Authority dummy)			0.028	0.22
$\sigma_z^2 + \sigma^2$ (Variance Parameter)	0.058	-	0.061	-
$\frac{\sigma_z^2}{\sigma_z^2+\sigma^2}$ (Ratio of the Variances)	0.744	-	0.755	-
Log-likelihood value	***264.39***		***266.12***	

** Significant at $\alpha = 0.05$; * Significant at $\alpha = 0.10$

Hypotheses Tests for Model Choice

Does Canada's airport authorities' efficiency performance differ from that of U.S. airport authorities? To answer this question, we need to compare Model I and Model II in Table 2. Model II includes two more parameters than Model I, namely, ρ_2 (Canadian Airport Authority $*$ wage) in the allocative efficiency part A, and ς_2 (Canadian Airport Authority dummy) in the technical efficiency part B.

The t-statistics for both of these parameter estimates indicate that neither of the following two hypotheses can be rejected when we test each of the following two hypotheses one at a time sequentially:

Ho. ρ_2 (Canadian Airport Authority $*$ wage) = 0 *H1* $\rho_2 \neq 0$

Ho. ς_2 (Canadian Airport Authority dummy) = 0 *H1* $\varsigma_2 \neq 0$

The following joint hypotheses on both homogeneous allocative inefficiency parameters and technical inefficiency parameters for U.S. and Canadian airport authorities can be tested using the asymptotic likelihood ratio test criterion: [7]

Ho $\rho_2 = \varsigma_2 = 0$

Since the computed Chi-square statistic, $\lambda = -2\{log[\widehat{L(\hat{\theta}_R})] - log[\widehat{L(\hat{\theta}_U})]\}$ = -2 (264.39-266.12) = 3.46, is much smaller than the critical value (5.99) of the Chi-square distribution with 2 df at 5% level, we cannot reject the hypothesis that both allocative inefficiency and technical inefficiency parameters are identical between U.S. and Canadian airport authorities. In other words, this Likelihood Ratio (LR) test result shows that Model I (Canadian airport authorities are identical to U.S. airport authorities in terms of both the allocative inefficiency and technical inefficiency parameters in the model) could not be rejected in favor of Model II (Canadian airport authorities have distinctly different inefficiency parameters from the U.S. airport authority model). Although some experts argue that Canadian airport authorities differ from their U.S. counterparts in terms of their relationship with airlines, financial sources available, and selection of board members, and thus should be considered as different types of airport governance, our test results show that as far as their allocative inefficiency in terms of using labor-soft cost input mix and technical inefficiency are concerned, Canadian and U.S. airport authorities appear to be identical. Therefore, in the rest of this paper we will focus on discussing our empirical results mostly based on Model I. Model II will be referred to occasionally when we need to discuss potential differences on the efficiency performance between Canadian and the U.S. airport authorities, albeit they are not statistically significantly different at 5% level.

Does the non-neutrally input augmenting allocative inefficiency specification in our translog cost function improve our cost measurement? In Model I of Table 2, the parameter estimate ρ_1 (for government branch dummy * wage) is only marginally significantly from zero only at 12% level, but not significant at 5% level. The negative coefficient, -0.069, implies that there is evidence, albeit weak, that the labor cost (soft cost input) share at the airports operated by a government branch (an airport authority) is, on average, 6.9% less (more) than a similar airport operated by an airport authority (a government branch). The airports operated by a government branch may be forced to outsource more of their services, such as police and fire fighting services, and ground access services. (a part of soft cost input) to government departments.

Does our stochastic frontier technical inefficiency model significantly improve accuracy of technical inefficeincy measurement? In both Models I and II, the ς_0 (constant) coefficient in the technical inefficiency model is statistically very significant. This implies that the stochastic frontier specification with the half normal truncated distribution of technical inefficiency significantly improves the measurement of inefficiency over the model without the half normal inefficiency specification. Similarly, the coefficient ς_1 (government branch dummy) is statistically significantly different from zero at 5% level in both Models I and II. This implies that specifying our stochastic frontier technical inefficiency model differently between the airports operated by airport authorities and those operated by government branches has significantly improved the accuracy of technical inefficiency measurement. The coefficient estimate, 0.141, implies that, on average, the technical inefficiency for airports operated by government branches is about 14% larger than those operated by airport authorities.

Results of Joint Hypotheses Tests

Table 3 presents the test statistics for and the results of further likelihood ratio tests on the following three important joint hypotheses:

(a) H_0: $\varsigma_0 = \varsigma_1 = 0$: The conventional econometric model without stochastic frontier technical inefficiency component and without differential technical inefficiency effects between the airport authority and the government branch

(b) H_0: $\rho_1 = \varsigma_0 = \varsigma_1 = 0$: The model without specification of stochastic frontier, differential allocative inefficiency or differential technical inefficiency between the two forms of governance

(c) H_0: $\rho_1 = \varsigma_1 = 0$: The effects of the differential allocative inefficiency and differential technical inefficiency between the airport authority and the government branch are jointly zero; i.e., $\varsigma_0 \neq 0$, *but* $\rho_1 = \varsigma_1 = 0$.

Table 3: Hypothesis Tests on Stochastic Cost Frontier Model I

Null Hypothesis	Log[Likelihood($\hat{\theta}_R$)]	log[Likehood($\hat{\theta}_U$)]	$\chi^2_{0.95}$ critical value	Computed Test Statistics
	–	–	–	–
(a) H_0: $\varsigma_0 = \varsigma_1 = 0$	261.19	264.39	5.99	6.38**
(b) H_0: $\rho_1 = \varsigma_0 = \varsigma_1 = 0$	258.88	264.39	7.82	11.01**
(c) H_0: $\rho_1 = \varsigma_1 = 0$	259.71	264.39	5.99	9.35**

** Significant at $a = 0.05$; * Significant at $a = 0.10$

Based on the likelihood ratio test statistics reported in Table 3, all three hypotheses are rejected at least at 5% level of significance in favor of the respective alternative hypotheses. It is worth pointing out that although the allocative inefficiency parameter ρ_1 was only marginally significant in our stand-alone test, the null hypotheses of zero coefficients were strongly rejected at 5% level in the joint tests (b) and (c) above with the technical inefficiency differential between government branch and airport authority management cases. This implies that when measuring efficiencies for North American airports, it is worth incorporating both the allocative inefficiency and the technical inefficiency modules in stochastic frontier models as we have done in this paper.[8]

Empirical Results from the Chosen Model

Effects of airport governance structure on airport input mix. The impact of the airport governance structures on variable input usage is identified via the coefficient of the labor price (wage) interacted with the government branch dummy variable in Model I. While the coefficient was only marginally significant at 12% level when we tested the single coefficient by itself, it was strongly significant when it was jointly tested with the technical inefficiency parameters. The value of the coefficient,

-0.069, implies that on average the airports operated by a government branch tend to have about 6.9% lower labor cost share (equivalently, 6.9% higher soft cost input share) than those operated by an airport authority (base case in our allocative inefficiency specification).[9]

This result is partly because many airports operated by a government branch do not have some functional departments (e.g., accounting and security) and use these services supplied by the local government departments. Partly as a result of the procurement provisions of the local government, airports run by a government branch may not purchase services from the most cost-effective source, and thus tend to have a higher soft cost share because of higher outsourcing activities.

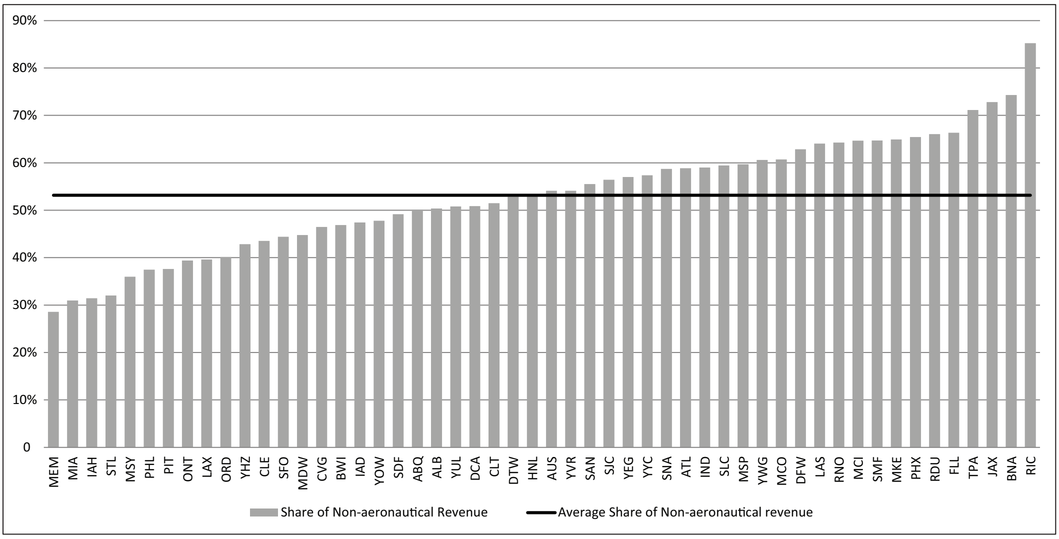
Effects of airport governance structure on technical inefficiency. Part B of Table 2 shows the effect of governance structures on airport technical inefficiency. The coefficient for airports operated by a government branch is positive and significant at the 10% and 5% levels in Model I and II, respectively. Our results show that the airports run by a government branch are on average 14% technically less efficient than those run by a Canadian or U.S. airport authority. Consistent with the results obtained by Craig et al. (2005) and Oum et al. (2008), our finding confirms that independent institutions, such as the airport authorities, achieve a higher efficiency performance since they enjoy sufficient freedom to operate airports in a commercially oriented manner. While separated from other government departments, the aviation branch operates under the general requirements of the local government bureaucracy and thus is influenced by other political activities. Such factors may hinder efficient airport operations.

Canadian vs. U.S. airport authorities. As discussed already, our result shows there is not any statistically significant efficiency difference between airports operated by U.S. airport authorities and those run by Canadian airport authorities. Casual commentators normally favor Canadian airport authorities over U.S. airport authorities since politically motivated appointment of board members leaves U.S. airport authorities vulnerable to political influence on airports' business decisions. Our empirical results do not support such argument.

The effects of airport characteristics on costs and/or efficiency. The stochastic frontier cost Models I and II reported in Table 2 give remarkably similar results on the effects of various airport characteristics on the variable cost frontier. All the parameter estimates of the two models have identical signs. All the coefficients statistically significant in Model I are also statistically significant in Model II. Since Model I (Canadian airport authorities are identical to U.S. airport authorities in terms of both the allocative inefficiency and technical inefficiency parameters in the model) could not be rejected in favor of Model II (Canadian airport authorities have distinctly different inefficiency parameters from the U.S. airport authority model), only the parameter estimates of Model I are used to describe below the effect of each airport characteristics on the cost frontier.

Non-aeronautical output is one of the most statistically significant variables, and has a positive coefficient of about 0.325. This indicates that a 1% increase in non-aeronautical service output, holding other variables constant, causes total variable cost to increase by only about 0.325%. The strong statistical significance of this coefficient implies that omission of non-aeronautical services output in measuring airport cost and/or efficiency would cause a serious bias on the empirical results by committing model specification error. Figure 1 shows that although the share of non-aeronautical revenue in the airport's total revenue varies across our sample airports, the average value is well over 50%. This implies that, for an average airport, a 10% increase in non-aeronautical revenue would increase an airport's total revenue by 5% while increasing costs only by 3.25%. Therefore, omission of non-aeronautical revenue would lead to over-estimation of costs (or equivalently, under-estimation of efficiency or productivity) for the airports whose management focuses on generating a higher percentage of total revenues from non-aeronautical services, including commercial services.

Figure 1: Share of Non-Aeronautical Revenue for Sample Airports in 2008



The three proxy capital stock measures (the number of runways, number of gates and terminal size) are neither individually nor jointly statistically significant in our cost function. The inclusion of these proxy variables does not seem to help improve our cost function. This means that although it is extremely difficult, if not impossible, to construct a capital stock index consistently comparable across all airports in different jurisdictions with different accounting systems and taxes/subsidies, there is a need to continue with the effort for constructing such capital stock series.

Most of the year, dummy variables (base year 2002) are individually statistically significant and positive, and all year dummy variables together are jointly statistically significant in our cost function. These positive coefficients indicate upward shifts of the cost frontier in the post-2001 period even after controlling for the effects of all of the variables included in our model. This may be because airports in North America had to bear the ever-increasing security costs in the post 9/11 period.

The percentage of international traffic has a statistically significant positive coefficient, meaning that the airport in which international passengers account for a larger share of total traffic faces more upward pressure on airport operating costs than a similar airport with a lower share of international traffic. The parameter estimate, 0.68, indicates that airports with one percentage point higher international passenger share are expected to have 0.68% higher operating costs, ceteris paribus.

Canada country dummy has a negative coefficient but is not statistically significant. This implies that airports in Canada and the United States have similar cost structures.

CONCLUDING REMARKS

This study has found that the choice between the two dominant forms of airport governance in Canada and the United States, i.e., airport authorities vs. government branches, has a significant effect on cost efficiency performance of the airport. In particular, our findings indicate that airports operated by an airport authority outperform those operated by a government branch by, on average, 14% in terms of technical efficiency. This result provides new supporting evidence for the argument that the governance form in which management can exercise a greater degree of autonomy and face less political pressure are more likely to improve efficiency performance. Furthermore, by modeling the interrelationship between governance form and airport variable input usage, we found that the airports run by a government branch tend to have a higher share of the soft cost input cost (including outsourcing cost) than those run by an airport authority. Since little attention has been paid to the influence of governance forms on an airport's input mix, this paper provides a greater account of the impact of governance forms on efficiency performance, and offers a new platform for improving cost frontier specifications for future studies.

Estimation of the hypotheses tests led us to conclude: (a) The efficiency performance and cost structure of the airports operated by Canadian airport authorities are not statistically different from those operated by U.S. airport authorities; (b) our stochastic frontier specification of our cost model significantly improved the accuracy of efficiency measurement, suggesting to future research that it is worth incorporating both the allocative inefficiency and the technical inefficiency modules in the stochastic cost frontier models for measuring airport efficiency.

In addition, our results also show that it is important to include non-aeronautical services as a part of airport outputs because, otherwise, empirical results on cost efficiency would get biased against the airports whose management focuses on increasing commercial and other non-aeronautical revenues.

The empirical constructs of the current study offer a useful starting point for a more in-depth analysis of the effects of airport governance forms. To further extend our study, it is possible to formulate more flexible models that account for the presence of observed and unobserved heterogeneity across individual airports. Due to estimation problems, we had to simplify our model structure dealing with the interrelationship between governance forms and airport input mix, which clearly is one of the potential future improvements in model specification and estimation. In addition, the incorporation of the nature of contractual relationships between airports and airlines (major customers) is another area that warrants further research. The complex specification required for such work, however, may increase the computational complexity and difficulty.

Endnotes

1. A growing number of economists argue that the two-sided platforms (airports and airlines) internalize the "demand externalities" that each agent in isolation cannot internalize efficiently. Rochet and Tirole (2006) define the two-sided markets as a situation in which the volume of transactions between end-users depends not only on the overall level of the fees charged by the platform but also on the way in which the transactions are structured and governed.

2. By estimating a stochastic cost frontier via a Bayesian approach, they found that the airports run by an airport authority perform far more efficiently than those operated by a government branch in North America.

3. Airport studies of efficiency utilizing parametric and non-parametric approaches are reviewed and summarized in Liebert and Niemeier (2010).

4. Deterministic kernel is the costs of a fully efficient institution in absence of random factors.

5. The soft cost input consists of all costs and expenses other than personnel costs and capital expenditure.

6. Since we believe there is no way of creating consistent measures of airport capital inputs or capital stocks comparable across airports in different jurisdictions, we decide to use these three physical measures of capital stocks as quasi-capital input measures.

7. Let θ be a vector of parameters to be estimated, and H_0 specify hypothesized restrictions on these parameters. Let $\hat{\theta}_U$ be the ML estimator of θ obtained without imposing the parameter restrictions and be $\hat{\theta}_R$ the constrained ML estimator. If we let $\widehat{L(\hat{\theta}_U)}$ and $\widehat{L(\hat{\theta}_R)}$ be the likelihood functions evaluated at these two estimates, then it is well known that the following likelihood ratio test statistics (λ) is asymptotically Chi-square distributed with degrees of freedom equal to the number of restrictions imposed in the null hypothesis H_0, provided H_0 is true.
$$\lambda = -2\{log[\widehat{L(\hat{\theta}_R)}] - log[\widehat{L(\hat{\theta}_U)}]\}$$

8. Furthermore, the ratio of variances reported at the bottom of Table 2 indicates that about 74% of the total variation is accounted for by our technical inefficiency model (Part B in Table 2). This is another indicator that the incorporation of our technical inefficiency frontier in our translog cost function was a worthwhile practice.

9. By applying Shephard's lemma to Model I we can give this interpretation of the coefficient ρ_1.

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APPENDIX A: List of Sample Airports, 2002-2008

North America - United States			
	Code	Airport Name	Governance Structures
1	ABQ	Albuquerque International Airport	Government Branch
2	ALB	Albany International Airport	Airport Authority
3	ATL	Hartsfield-Jackson Atlanta International Airport	Government Branch
4	AUS	Austin Bergstrom Airport	Government Branch
5	BNA	Nashville International Airport	Airport Authority
6	BWI	Baltimore Washington International Airport	Government Branch
7	CLE	Cleveland-Hopkins International Airport	Government Branch
8	CLT	Charlotte Douglas International Airport	Government Branch
9	CVG	Cincinnati/Northern Kentucky International Airport	Airport Authority
10	DCA	Ronald Reagan Washington National Airport	Airport Authority
11	DEN	Denver International Airport	Government Branch
12	DFW	Dallas/ Fort Worth International Airport	Airport Authority
13	DTW	Detroit Metropolitan Wayne County Airport	Airport Authority
14	FLL	Fort Lauderdale Hollywood International Airport	Airport Authority
15	HNL	Honolulu International Airport	Government Branch
16	IAD	Washington Dulles International Airport	Airport Authority
17	IAH	Houston-Bush International Airport	Government Branch
18	IND	Indianapolis International Airport	Airport Authority
19	JAX	Jacksonville International Airport	Airport Authority
20	LAS	Las Vegas McCarran International Airport	Government Branch
21	LAX	Los Angeles International Airport	Government Branch
22	MCI	Kansas City International Airport	Government Branch
23	MCO	Orlando International Airport	Airport Authority
24	MDW	Chicago Midway Airport	Government Branch
25	MEM	Memphis International Airport	Airport Authority
26	MIA	Miami International Airport	Government Branch
27	MKE	General Mitchell International Airport	Government Branch
28	MSP	Minneapolis /St. Paul International Airport	Airport Authority
29	MSY	Louis Armstrong New Orleans International Airport	Government Branch
30	ONT	Ontario International Airport	Government Branch
31	ORD	Chicago O'Hare International Airport	Government Branch
32	PHL	Philadelphia International Airport	Government Branch
33	PHX	Phoenix Sky Harbour International Airport	Government Branch

APPENDIX A: List of Sample Airports, 2002-2008 (continued)

34	PIT	Pittsburgh International Airport	Airport Authority
35	RDU	Raleigh-Durham International Airport	Airport Authority
36	RIC	Richmond International Airport	Airport Authority
37	RNO	Reno/Tahoe International Airport	Airport Authority
38	SAN	San Diego International Airport	Airport Authority
39	SAT	San Antonio International Airport	Government Branch
40	SDF	Louisville International Airport	Airport Authority
41	SFO	San Francisco International Airport	Government Branch
42	SJC	Norman Y. Mineta San Jose International Airport	Government Branch
43	SLC	Salt Lake City International Airport	Government Branch
44	SMF	Sacramento International Airport	Government Branch
45	SNA	John Wayne Orange County Airport	Government Branch
46	STL	St. Louis-Lambert International Airport	Airport Authority
47	TPA	Tampa International Airport	Airport Authority
North America - Canada			
	Code	Airport Name	Governance Structures
48	YEG	Edmonton International Airport	Airport Authority
49	YHZ	Halifax International Airport	Airport Authority
50	YOW	Ottawa International Airport	Airport Authority
51	YUL	Montreal-Pierre Elliot Trudeau international Airport	Airport Authority
52	YVR	Vancouver International Airport	Airport Authority
53	YWG	Winnipeg International Airport	Airport Authority
54	YYC	Calgary International Airport	Airport Authority

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Do State Fiscal Constraints Affect Implementation of Highway Public-Private Partnerships? A Panel Fixed Logit Assessment

by Zhenhua Chen, Nobuhiko Daito, and Jonathan L. Gifford

Infrastructure public-private partnerships ("P3s") have gained considerable recognition as useful policy tools for state and local governments to deliver critically needed infrastructure projects. The objective of this study is to empirically test one of the claims often made regarding states' motivations for employing this procurement mechanism: P3s can help overcome fiscal constraints on state infrastructure investment. In addition, this study empirically analyzes how state P3 enabling legislation affects the behavior of both the public and private sectors. A regular logit model and a fixed effects logit panel model are employed to test the hypothesis that states with more severe fiscal constraints are more likely to seek P3s for highway infrastructure construction and finance. After controlling for such factors as state economic condition, legislative political affiliation, and highway travel demand, the empirical results indicate that states' fiscal constraints are not associated with the propensity to use highway P3 projects.

INTRODUCTION

Infrastructure public-private partnerships ("P3s") have gained considerable recognition as policy tools for state and local governments to improve efficiency in delivering infrastructure that is critical for economic development. The U.S. Federal Highway Administration (FHWA) defines P3s as "contractual agreements formed between a public agency and private sector entity that allow for greater private sector participation in the delivery and financing of transportation projects" (FHWA Office of Innovative Program Delivery 2013). Scholars have argued that P3s could be justified on the basis of the potential for easing fiscal constraints on the public sector through access to the private sector's innovative cost-saving practices and financial resources.

The focus of policy debate regarding transportation P3s has been on developing the capacity among state transportation agencies to implement P3 programs and projects. DeCorla-Souza et al. (2013a) suggest key factors of capacity include: statutory and policy frameworks, a pipeline of potential P3 projects, procurement system adequacy, and oversight mechanism adequacy.

Questions such as whether and how P3s can enable cost savings through infrastructure delivery and overcome fiscal constraints of public agencies have been widely discussed and debated (Välilä 2005). Due to the limited number of P3 projects, however, *ex post* analyses on whether the presumed benefits have been achieved are limited, particularly in the U.S. context (U.S. Congressional Budget Office 2012).

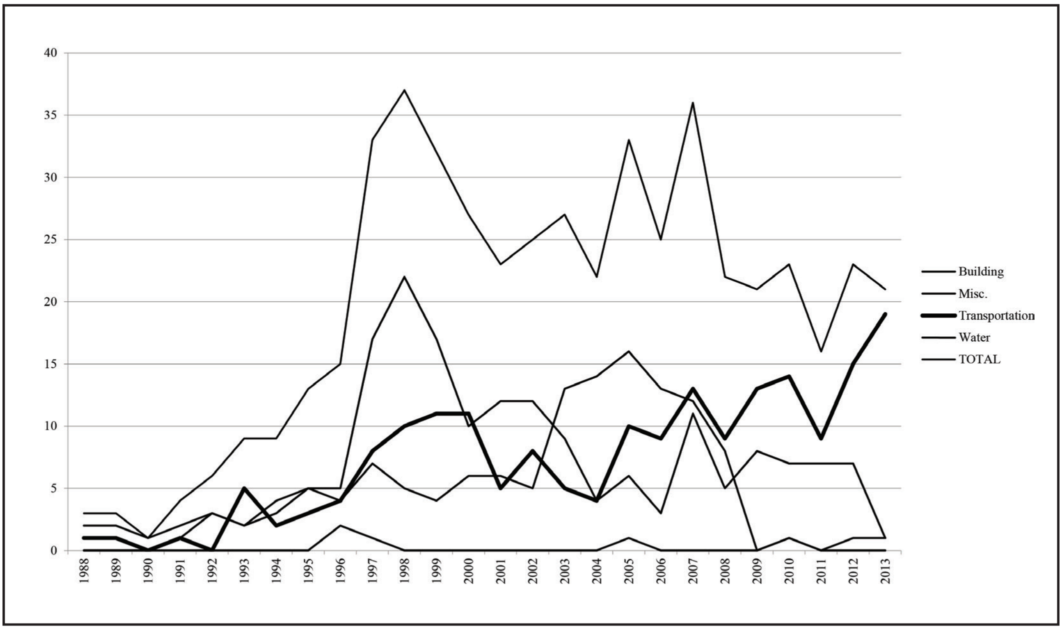
Since few studies have empirically tested whether P3s are employed more extensively by state authorities with particular fiscal circumstances or not, the objective of this study is to empirically test one of the claims often made regarding states' motivations for employing this procurement mechanism: through opening access to private capital, P3s could help public authorities overcome their fiscal constraints for investing in infrastructure. The paper also investigates how the enactment of P3 enabling legislation may affect the behavior of both public and private sectors. By addressing these empirical questions, this study intends to shed light on the state of the practice of P3s in highway finance.

The rest of this paper is structured as follows. The second section reviews the background and relevant literature. The third section presents the data used in the analysis. The methodology of the analysis is discussed in the fourth section, which is followed by a discussion of research findings in the fifth section. The last section summarizes and concludes.

BACKGROUND

P3s have become a popular procurement mechanism in the United States not only in the transportation sector but also in other sectors, such as water/wastewater, prison, and government buildings (Figure 1). The aggregate number of P3s in all sectors that reached financial closes emerged and soon dramatically increased in the 1990s. In the 2000s, the number of P3s fluctuated due in part to the financial crisis in 2008. While water and general building P3s decreased during the 2000s, the number of P3s in the transportation sector has shown steady growth to date.

Figure 1: Number of U.S. P3 Financial Closes by Sector, 1988-2013



Note: Transportation sector numbers encompass all P3 contract types, including leases and management contracts.
Source: *Public Works Financing* Newsletter Database.

In the context of highway capacity expansion projects in the United States, the traditional procurement model is referred to as design-bid-build model (DBB). A highway construction project has multiple components, such as design, construction, operation, and maintenance. A public agency is the owner of the asset to be built, and the agency is responsible for funding the project. Certain stages of the project will be contracted out to a private firm to do the job: design can be done either by in-house engineers or contracted to an engineering firm; construction is usually done by a private contractor; and the completed highway asset can be maintained by in-house staff or contracted to a private firm specialized in the service.

While this model can ensure accountability of each project stage and achieve transparency, it may not be the best approach to achieve cost efficiency, which is a growing concern under the tight budget conditions of government agencies. In this traditional DBB model, the contractor for each stage has the incentive to minimize its cost, possibly at the cost of another stage of the project. If there is a discrepancy between design specifications and the actual site condition, the process to reflect the site condition on the blueprints, obtain necessary approvals, redevelop a construction strategy, and do the job could easily lead to cost and schedule overruns. Under such scenarios, the public agency may bear the responsibility of the potentially significant costs of these changes.

Design-build contract (DB) evolved to address design risks as follows: by contracting both design and construction phases, change-orders may decrease considerably. In this contract, the design risk has been transferred to the private contractor. Thus, some may argue that the DB contract can be considered a form of P3s (Congressional Budget Office 2012). By incorporating the project's maintenance stage to the contract, the cost savings of project bundling could be extended further. When the operation and management stages of the project are bundled to the DB contract (hence, a design-build-operate-maintain, or DBOM, contract), the private partner would be incentivized to optimize the life-cycle cost of the project. For example, the partner may choose a design specification of the asphalt such that the initial construction may be more costly but the life-cycle cost will be more cost efficient.

If the financing arrangement is also bundled to the contract, involving private equity investment to the project, then a design-build-finance-operate-maintain contract (DBFOM) is used. In this case, project finance arrangement is made for the private partner to finance the initial capital investment of the project. Project finance is a financial technique used to finance projects that involve large upfront capital investment (e.g., power plant, water plant, highway).

In this model, the initial investment is realized by combining equity investment from companies participating in the project (e.g., contractor, operator, designer, and investor) and debt financing (e.g., bank loan and bond). Revenues from the project will be used to repay the debt obligation and for operational and maintenance expenses, and the remainder will be the profit, which is equivalent to the return on the equity investment. Multiple private companies form a legally independent project specific entity (Special Purpose Vehicle, or SPV) solely for providing the service defined in the project, such as design-build, operation, and maintenance. Importantly, since the SPVs are legally distinct from participating firms, lenders will make their lending decisions based not on the general credit and firm-wide cash flow but on the conditions specific to the project.

The economic advantage of P3s has been found on the basis of the incomplete contract theory framework (Välilä 2005). In this line of thought, the emphasis is on bundling of project components and transfer of project risks from the public authority to a private partner, as well as the costs of implementing such complex contractual transactions. Hart (2003) first formalized the P3s' cost efficiency through bundling of project components and suitable project risk allocation based on incomplete contract theory framework. In this model, procurement approaches have distinct implications for contractors in terms of incentives for cost savings. Hart predicted that a traditional DBB model would be desirable when construction of the building can be well specified while the quality of the service cannot be well specified. P3 procurement might be more efficient when the service quality can be well specified in the contract while the quality of the initial construction could not be well specified.

Martimort and Pouyet (2008) extended the analysis by focusing on the externality of one project stage to the others and the asset ownership. In this context, a positive externality of production is present when, for example, building specification is such that the operational/maintenance costs become more efficient (e.g., more costly high specification of asphalt lowers the maintenance costs during the operational phase). Their model showed that when it is costly to specify service requirements in the contract, transferring the ownership to the private contractor would incentivize the private partner to exert its best effort to increase the asset value through lowering its costs of production (Martimort and Pouyet 2008). Bennet and Iossa (2006) showed that, when a positive externality is present, ex ante incentive for cost saving and quality service is stronger if, after the contract life the asset is to be under the ownership of the private partner. The authors argued that based on this finding that the P3s may not be a preferable model in sectors against which there is strong resistance, political or otherwise, for long-term private ownership (Bennet and Iossa 2006). De Bettignies and Ross (2009) compared public financing and private financing of public infrastructure projects, based on the industrial organization and corporate finance theories. The authors argued that private borrowing might be ex-post superior to public borrowing, because private developers would be willing to commit to smaller debt and repayment obligations with high expected returns. In this view, financially unviable projects would not materialize due to the lack of willingness of private lenders and developers. Public agencies might continue with the investment in projects with smaller expected financial returns for economic development, policy, or political motives, but only with public financing arrangements.

Project finance arrangements are made for infrastructure projects that involve private financing. Brealey et al. (1996) explored theoretical justifications of employing project finance techniques for infrastructure projects, and how both the public sponsor and the private partner might benefit from it. They point out that a commonly held notion that the cost of capital might be cheaper for governments could be misleading, since the lower interest rates merely reflect the risks borne by taxpayers. They argue that the benefit of project finance for infrastructure projects might be found because they allow bringing in the expertise of cost savings and efficient management of certain risks by the private firms, while avoiding full "privatization." This is so because privatization would entail designing complex new regulatory institutions, which may be inappropriate for certain sectors such as education (Brealey et al. 1996).

Variations of P3 contracts include design-build-operate contracts (DBO), design-build-finance (DBF), which involves short-term financing by the private partner, design-build-maintain (DBM), and so forth. These capacity expansion projects can be considered as an extension of the traditional construction projects, involving agreed compensation from the public procuring authority to the private partner.

On this theoretical foundation, a P3 procurement model is ex-ante preferred if the transaction costs of employing the model (e.g., legal, financial, consulting, and other fees) are smaller than the cost savings achieved by employing the P3 model. In other words, deciding the procurement model requires comparing the life cycle costs of the P3 approach and the alternative public procurement model. The topic of ex-ante decision models has received policy attention in the United States in recent years (DeCorla-Souza et al. 2013b). In countries such as the United Kingdom (U.K.), Australia, Canada, and the Netherlands, value for money (VFM) analysis is considered an established evaluation framework, primarily due to their extensive experiences with P3 mechanisms for various projects. This is particularly so in the U.K., where the Private Financing Initiative (PFI) employed VFM analysis, which is defined as "the optimum combination of whole-of-life costs and quality (or fitness for purpose) of the good or service to meet the user's requirement" (HM Treasury 2006). Likewise, a P3 business development guidebook published by the Canadian government defines VFM with specific components to be used for project evaluation (Burr et al. 2011).

In the United States, the use of VFM for P3 project evaluation is still in its infancy. A survey of state officials found that only 30% of the responding states use some sort of methods to evaluate P3 alternatives for a project (16 states responded out of 22 states contacted). These analyses are often in-house, and currently there is no standard VFM used for P3 projects (Morrallos et al. 2009).

In recent years, dissatisfaction about the lack of a VFM standard led to active academic and policy debate on P3 project evaluation methods in the United States. DeCorla-Souza et al. (2013b), for example, discussed concerns associated with the use of VFM in its present form. They argued that VFM focuses only on the financial aspect of infrastructure projects, and fails to account for societal benefits or costs of a project. One of the benefits of P3s in the United States is their faster project delivery through access to private capital. They point out that what should be compared in typical situations are a P3 alternative and delayed public provision due to the fiscal constraints of the public sponsor. VFM fails to account for such benefits (DeCorla-Souza et al. 2013b). Overall, the emphasis of policy debate regarding the infrastructure P3s is on improving the state of the practice with enhanced knowledge and experience regarding the use of P3s by state and local governments in delivering transportation infrastructure.

Another important subject of policy discussions is ex-post evaluation of P3s' performance, which has been limited to date. This is in part due to the shortage of experiences in the United States (U.S. Congressional Budget Office 2012). Hodge (2010) argued that whether these projects had actually achieved the theorized cost saving benefits was still empirically unsettled, noting that rigorous empirical analysis or meta-analysis had been very limited or of questionable quality, and only narratives and anecdotal information was available. Few studies include empirical analysis with statistical rigor. Blanc-Brude et al. (2006) compared the cost differences of P3s and publicly procured highway projects that received funding from the European Investment Bank (EIB), using confidential project documents. They tested the hypothesis that P3s would demonstrate higher costs because of the premium of the risks transferred to the private partner and the engineering specifications designed to optimize life cycle cost saving. The analysis found that the construction costs of P3 projects were 24% higher than publicly procured projects, supporting their hypothesis. Dudkin and Välilä (2006) estimated the difference between P3s and publicly procured infrastructure in terms of their transaction costs for establishing and maintaining a partnership, including legal, financial, and technical advisory costs. Because of the small number of samples, they conducted nonparametric statistical tests to investigate if samples came from the same population in terms of their means. They found that the P3 projects were on average 10% more costly than publicly procured projects with regard to their transaction costs (Dudkin and Välilä 2006).

While the economic rationale of P3s and their performance evaluation is an important policy consideration, in this study we are interested in fiscal, institutional, and political considerations behind the decisions of procurement model alternatives. The next section will review relevant literature on this subject.

LITERATURE REVIEW

From an institutional perspective, there have been several studies that investigated the factors affecting the likelihood of governments employing P3 arrangements for infrastructure investments in the international context. Because the factors considered under the realm of institutional and political conditions are broad, we develop hypotheses of empirical specifications based on the literature, rather than analyzing through a formal mathematical model. Checherita (2007) demonstrated that the decision of a country to invest under a P3 arrangement depends on such factors as macroeconomic, political, and financial risks; exogenous economic shocks; and the size of overall government spending (Checherita 2007). Empirical studies have also found that a number of factors, including the magnitude of economic activities, sovereign debt, macroeconomic stability, and presence of stable legal and institutional framework, are associated with the size of P3 projects in a country (Hammami et al. 2006). International comparisons of P3 markets have presented challenges for scholars because of the variety and complexity of these schemes across nations, and limited project-level data on P3 institutions.

The United States is a unique case to analyze P3 institutions, since the market in each state is distinct from those of other states. Few studies have been conducted to address questions on P3 institutions focusing on the specific context of U.S. states. It has been argued that P3 enabling legislation is an essential first step for states implementing P3s and allowing public agencies to take advantage of the benefits of P3s while protecting the public interest. Effective P3 legislation standardizes the process of negotiation as well as the contractual agreements of P3 projects, thereby reducing the transaction costs of the state's P3 market. Moreover, enabling legislation demonstrates a state's commitment to investing in infrastructure in collaboration with the private sector. Hence, the state can inform the private sector about the predictability of the state's market, mitigating the perceived political and institutional risk in engaging in P3s with the public agencies (Decorla-Souza et al. 2013b).

Geddes and Wagner (2013) statistically analyzed what factors contribute to states' passing P3 enabling legislation, as well as favorability of this legislation, measured by a favorability index based on survey responses by P3 experts in the United States. These elements included a requirement of legislative approval for each project, and a prohibition against mixing public and private funds to finance a project, among others. They found that demand side factors, such as traffic congestion and political conditions, were significantly associated with whether a state has passed a P3 enabling legislation as well as the favorability of the state's institution to private investment on transportation infrastructure. Their analysis also demonstrated that supply factors, such as fiscal conditions, had little to do with a state's P3 legislations.

The literature briefly summarized above points to a few factors that might affect states' decisions on procurement models to be employed. First, states are likely to turn to private financing for infrastructure investments when they face fiscal constraints (Geddes and Wagner 2013). When discussing exclusively private financing of these projects, this hypothesis appears intuitive, but the potential impact of the fiscal conditions on the use of P3s may be more nuanced. For example, when considering P3s as broadly defined to include those that do not involve private financing, the higher initial capital investment costs (as pointed in the review in the Background section) may actually negatively affect whether P3 models are selected for given projects. It is therefore necessary to account for the different contract types of P3s when empirically evaluating the effect of the fiscal condition variables.

Second, demand for infrastructure is likely to be associated with states that employ the P3 models. In the context of highways, increasing travel demand of an economy may encourage state highway agencies to respond by employing P3s to rapidly achieve expansion of highway capacities (Zhang 2008, Geddes and Wagner 2013). Third, political factors may influence the use of P3s. This line of thought is prevalent in the literature on infrastructure privatization. Bel and Fageda (2007) argued that political ideology had been considered important for decisions to privatize. In the context of P3s, this consideration may also be complex. Various interest groups may have distinct positions on the use of P3 models, depending on the rent that could be sought. For example, a number of P3 projects involve tolling schemes due to their financial arrangements (e.g., project finance, which requires a revenue stream for operational and maintenance expenses, repayment of debt obligations, and private investors' return on their equity investment). There are a number of interest groups that may oppose tolling of "freeways." Political condition is an important consideration when empirically investigating the use of P3s by state agencies.

This review of the literature suggests that, while scholars have debated why U.S. states and local governments should utilize P3s, none of the studies has empirically assessed whether public agencies' engagement with P3s are actually driven by their fiscal constraints. In addition, statistical analysis of the association between P3 enabling legislation at the state level and actual implementation has been limited. This is the gap in the literature that this study intends to bridge.

DATA

Because highway capital financing and investment policies are implemented at the state level in the United States, the state is selected as the unit of analysis. The assessment focuses on the period between 1998 and 2010. The beginning year of 1998 is selected because highway P3 projects in the United States experienced substantial expansion since then. In addition, the Transportation Infrastructure Finance and Innovation Act (TIFIA) also passed in 1998. Data on the 50 U.S. states were used in investigating the influence of state fiscal constraints on the implementation of highway P3 projects. The following variables are adopted for the analysis (Table 1).

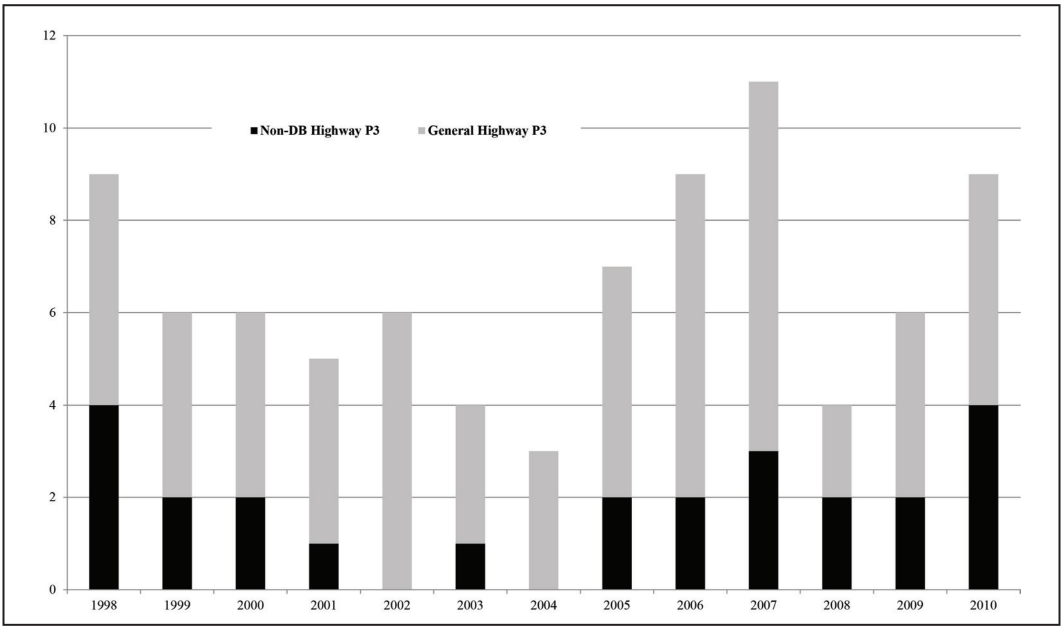
Table 1: Descriptive Statistics

Variables	Mean	Std. Dev.	Min	Max	Unit
Whether state has highway P3 (including DB) (*p3*)	0.09	0.29	0	1	Yes/No
Whether state has highway P3(without DB) (*p3a*)	0.04	0.19	0	1	Yes/No
Lag of state highway net balance (*lagfc*)	60,378	342,891	-1,790,004	3,419,902	Thousands of 2005$
State public debt per capita *(debtpc)*	2,888	1,838	596	10,172	Thousands of 2005$
Highway indebtedness obligation per capita *(laghipc)*	394	337	0.26	2,045	Thousands of 2005$
Lag of state highway capital outlay per capita (*lagcappc*)	232	106	72	757	Thousands of 2005$
Lag of gross state product per capita (*laggsppc*)	39,411	7,526	25,224	65,476	2005$
Growth of vehicle miles traveled per capita (*gvmtpc*)	0	0.08	-0.42	0.92	100%
Dominant party in upper house is Republican (*uh*)	0.49	0.50	0	1	Yes/No
Dominant party in lower house is Republican (*lh*)	0.44	0.50	0	1	Yes/No
Whether governor is Republican (*gov*)	0.52	0.50	0	1	Yes/No
Whether state has P3 enabling law (*p3law*)	0.38	0.49	0	1	Yes/No
Whether state has "cannot carry over deficit law" (*ccod*)	0.74	0.77	0	1	Yes/No

*Total number of observation: 48 (number of states) ×13 (number of years) =624.
Source: Bureau of Economic Analysis, Bureau of U.S. Census and Public Works Financing Newsletter.

- *Public-private partnerships (p3* and *p3a):* Because the financial sources for "design-build" (DB) P3 projects may come from public partners with no private funding source involved, two types of P3 variables are adopted in order to examine whether state fiscal constraints have a different influence on both general P3 projects and non-DB P3 projects. Two dummy variables are created to represent whether a state has P3 projects or not. Both are treated as dependent variables and are analyzed separately. Information on P3 projects such as project location, P3 type, project cost, and date of financial close, is obtained from the P3 project data set produced by Public Works Financing (PWF) Newsletter (2013).[1]
- The dummy variable is coded as "1" if a state in one particular year has one or more P3 projects that are under implementation (including design, planning, or construction), otherwise, a value of zero is coded. Since the scope of assessment only focuses on highway projects, only highway-related P3 projects, including motorway, toll motorway, toll bridge and toll tunnel, are selected for the analysis. Due to the distinct fiscal implications to the states, only the P3s of capacity expansion projects are analyzed, excluding the P3s of other contract types, such as management contracts and brownfield concessions of existing highway capacities. In total, there are 60 highway P3 projects that reached the financial close during the 1998-2010 period,

Figure 2: Highway P3s Including DB and P3 Excluding DB projects in the U.S.



Note: Highway P3s of capacity expansion projects, excluding leases and management contracts.
Source: *Public Works Financing* Newsletter Database.

Figure 3: State Highway Net Balance

State Highway Net Balance (*fc*)	=	**Total Revenue** Federal, state, and local highway user tax revenues Road and crossing tolls Appropriations from general funds Property taxes Other imposts Miscellaneous receipts Bond receipts	−	**Total Disbursement** Capital outlay of state and local roads Maintenance and services of state and local roads Research Law enforcement and safety Interest Bond retirement Grants in aid

Source: Table SF-1, SF-2, Highway Statistics, Federal Highway Administration

which includes 25 non-DB P3 projects.[2] Figure 2 illustrates the variation of both general P3 projects and non-DB P3 projects in the United States.

- *State highway net balance (fc)*: The state highway net balance for the period 1998-2010 is adopted to measure fiscal constraints on state governments in highway financing. It is the difference of total state highway revenue and total disbursements, which is calculated through the equation in Figure 3. According to the FHWA/FTA Final Rule (2007), fiscal constraint is defined as "*a demonstration of sufficient funds (Federal, State, local, and private) to implement proposed transportation system improvements, as well as to operate and maintain the entire system, through the comparison of revenues and costs.*" It is thus reasonable to regard the state highway net balance as the indicator to measure fiscal constraint.[3]

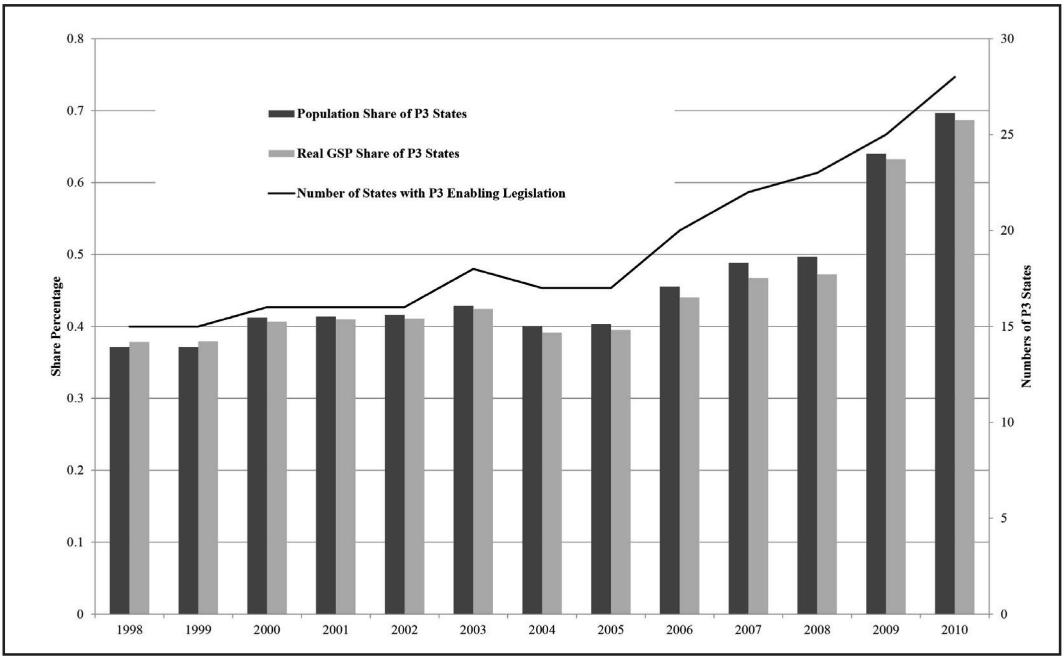
Data on highway capital outlay, revenue, and disbursements are collected from FHWA's annual *Highway Statistics* series (2013). All variables are converted into real monetary terms using World Bank GDP deflator in order to eliminate inflation.

- *State public debt per capita (debtpc):* one of the major arguments for advocating P3 in transportation financing is to reduce the burden of public funds. Since states with higher public debts might be more likely to implement P3 for finance, public debt per capita is introduced to control for the state's financial influence. Data iare collected from the State and Local Government Finance Division at the U.S. Census Bureau.
- *Highway indebtedness obligation per capita (laghipc):* Besides the total public debt of the state discussed above, decision makers could potentially consider P3s for the existing project pipeline driven by the state's debt obligations for highways. Highway indebtedness obligation from the annual *Highway Statistics* for the period 1998-2010 was introduced in the empirical model to control for the financial condition specifically pertaining to its highway capital debt.
- *State highway capital outlay per capita (cappc):* state highway capital outlay per capita is introduced to control for the influence of P3 from the supply side. Theoretically, given the decline of public highway expenditure during the period between 1998 and 2010, as compared with the period of the 1960s to the 1980s, the higher the level of public highway capital outlay per capita, the greater would be the likelihood of its having implemented a P3 project.
- *Gross state product per capita (gsppc):* Data are collected from the regional account of the U.S. Bureau of Economic Analysis (BEA). One year lag of real GSP per capita is adopted to account for the state's economic condition on P3 implementation. The influence of GSP per capita on P3 implementation can run in both directions. On the one hand, the growth in GSP may create more project demand opportunities for collaborations between the public and private sectors and thus may lead to an increase in highway infrastructure using P3s. On the other hand, the opposite linkage may also exist. The decline of an economy may lead to a decrease in public investment, which may consequently provide opportunities for the private sector to be involved in highway projects financing.
- *Growth of vehicle miles traveled per capita (gvmtpc):* This is used to measure variations in highway travel demand through the usage of highway infrastructure. A reasonable assumption is that a higher level of highway user demand requires a higher level of highway capital investment. The data are collected from Table PS-1 of the annual *Highway Statistics* between1998 and 2010, published by FHWA. Per capita level data are used in order to control for the size effect of each state.
- *State legislative composition (uh, lh & gov):* political legislative composition has been found to play a significant role in shaping the decision making about public highway financing policy. For instance, Bruce et al. (2007) found that highway expenditure becomes less if the state has a Republican governor and Republican legislative majorities. To control for these political influences, three political dummy variables are constructed and introduced based on the Composition of State Legislatures, by Political Party Affiliation from the *National Conference of State Legislatures*. *uh* and *lh* are two dummy variables that measure whether the state upper house and the lower house have a Republican majority, respectively. The political affiliation of the governor is also considered. The variable *gov* equals one if the governor is a Republican.
- *Whether state has P3 enabling law (p3law)*: A few studies have found that states with P3 enabling legislation are more likely to implement highway P3 projects (Geddes and Wagner 2013. Rall et al. 2010). The P3 enabling legislation provides guidance for state government to select, develop and execute specific P3 projects. Therefore, the variable is expected to play a role in P3 implementation. One of the features in this assessment is that the P3 enabling legislation variables are coded in a panel data format that includes both regional and temporal information.

We recognize that there are different degrees of favorability of P3 enabling legislation to private investment on transportation infrastructure (Geddes and Wagner 2013). However, investigating the relationships of specific components in the P3 enabling legislations is beyond the scope of this analysis. It is assumed that the inclusion of a dummy variable of P3 enabling legislation would allow us to make a reasonable assessment of the influence of legislative support for the use of P3s.

The number of states with P3 enabling legislation is growing. As illustrated in Figure 4, there were only 15 states with P3 enabling legislation in 1998. During the last decade, the number of states grew to 28 by the end of 2010. This rapid increase of P3 legislation suggests the expansion of potential P3 market across the United States.

Figure 4: Market Share of P3 Enabling Legislation

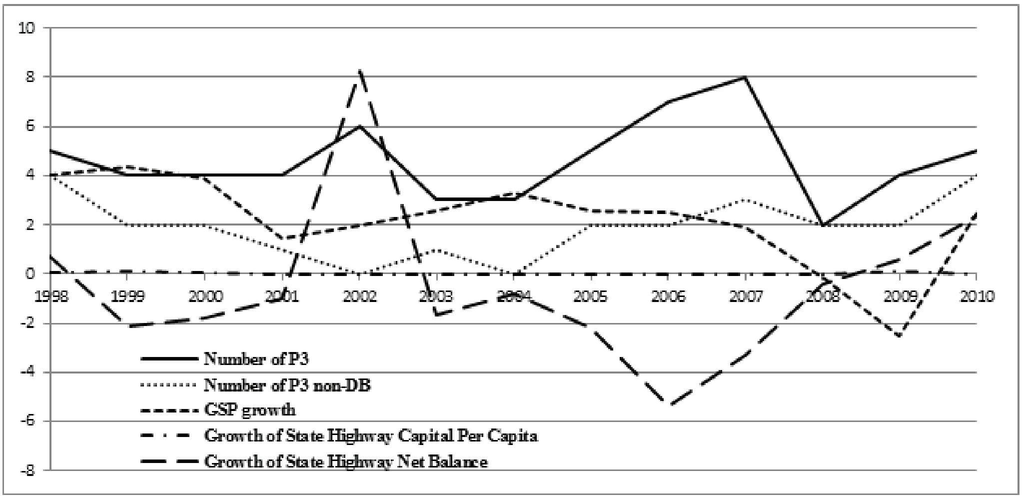


Source: U.S. Bureau of Economic Analysis, and U.S. Department of Transportation

- *Whether state has "cannot carry over deficit" law (ccod):* In the United States, state governments' fiscal constraints are affected by state balanced budget requirements. These legislative requirements can be either constitutional or statutory. Because of the differences in the "cannot carry over deficit" requirement, a government's fiscal constraint varies by state. Whether a state with a "cannot carry over deficit" law is more likely to adopt P3 for highway infrastructure financing is a hypothesis that needs be tested. The information is collected from the State Balanced Budget Provisions, produced by the National Conference of State Legislatures (2010).

The temporal variations of implemented P3 projects, state highway financial status, as well as the state economic output rate are illustrated in Figure 5 The numbers of P3 projects and non-DB P3 projects vary significantly during the period between 1998 and 2010. Gross state product (GSP) growth has a strong lagged influence on the variation of highway P3 projects. After reaching its peak in 2007, the numbers of implemented P3 projects fall significantly following the decline of GSP growth. In addition, the growth of state highway balances also demonstrates a lagged effect on the numbers of P3 projects. While the state highway net balance and the numbers of state highway P3 projects almost move simultaneously in the same direction before 2004, a lagged influence from the state highway net balance becomes more visible during the period after 2004.

Figure 5: Temporal Variation of GSP, State Highway Financial Status and Numbers of Highway P3 Projects



Source: *Public Works Financing* Newsletter Database, Bureau of Economic Analysis and FHWA Highway Administration

METHODOLOGY

The dependent variables *p3* and *p3a* are binary dummy variables. The first denotes whether the state has highway P3 projects, including the DB type. The second denotes whether the state has highway P3 projects, excluding the DB type. The logistic regression model is adopted for this assessment as it measures probabilities of P3 implementation as a function of the explanatory variables. The general model structure can be specified as follows:

(1) $$P(P3\ occurs) = \frac{1}{1 + e^{-(a+b_1X_1+b_2X_2+\cdots+b_kX_k)}}$$

Equation (1) can also be written as:

(2) $$P(P3\ occurs) = \frac{e^{(a+b_1X_1+b_2X_2+\cdots+b_kX_k)}}{1 + e^{(a+b_1X_1+b_2X_2+\cdots+b_kX_k)}}$$

which also equals equation (3) after a log transformation:

(3) $$ln\left(\frac{P(P3\ occurs)}{P(P3\ does\ NOT\ occur)}\right) = a + b_1X_1 + b_2X_2 + \cdots + b_kX_k$$

The left side of Equation 3 indicates the odds that a P3 project is implemented in a state in a particular year, which equals a linear function of a set of explanatory variables *X1, X2, ..., Xk*. *b* denotes the coefficient that needs to be estimated. The value is interpreted as odds ratios under logistic regression.[4]

Another important issue when assessing the determinants of implementing P3 projects is the lagged effect of explanatory variables. This is particularly true when assessing the influence of a state's fiscal constraints on P3 decision making. The hypothesis is that a state adopts P3s for highway investment when facing a higher level of fiscal constraints than in previous years, which can be indicated by the lag of the state highway net balance.

Public highway capital outlay and economic conditions also have lagged effects on P3 project implementation. A higher level of public highway capital outlay in previous years implies a higher level of public fiscal constraint in funding future highway projects, which may thus encourage the adoption of P3. Likewise, the influence of state economic conditions on highway P3 adoption needs to consider lagged effects, as economic conditions normally do not affect a state government's decision making on highway infrastructure projects immediately because of lengthy negotiations that are common to large and complex P3 deals.

The basic model equations are defined as:

$$p3 = \beta_0 + \beta_1 lagfc + \beta_2 lagdebtpc + \beta_3 laghipc + \beta_4 lagcappc + \beta_5 gvmtpc + \beta_6 lgsppc + \beta_7 p3law + \beta_8 ccod + \beta_9 uh + \beta_{10} lh + \beta_{11} gov + \varepsilon \tag{4}$$

$$p3a = \beta_0 + \beta_1 lagfc + \beta_2 lagdebtpc + \beta_3 laghipc + \beta_4 lagcappc + \beta_5 gvmtpc + \beta_6 lgsppc + \beta_7 p3law + \beta_8 ccod + \beta_9 uh + \beta_{10} lh + \beta_{11} gov + \varepsilon \tag{5}$$

The analysis is implemented in two steps. In the first step, a regular logistic regression is estimated on both models. In the second step, a conditional logit with panel fixed effects model is implemented. The panel fixed effect model is necessary for two reasons, which have been extensively discussed by Allison (2009): first, the dependent variables *p3* and *p3a* are measured on two occasions for each individual state; second, a few independent variables, such as the growth of VMT per capita, GSP per capita, highway capital outlay, and state highway net balance, change substantially over time. A panel fixed effect model can adequately control for the individual fixed effects, which cause such variations.

RESULTS

The two models, the general P3 model and non-DB P3 model, are first estimated using regular logit regression. The explanatory variables are regressed respectively on the general P3 variable and the non-DB P3 variable. Regression results are displayed in Table 2.

In the general P3 model, the coefficient of the lagged state highway net balance variable is not significant, but the state debt per capita is statistically significant at 1% level. The odds ratio is 0.999, which suggests that a one unit increase of the state debt per capita in a previous year is likely to cause an equal chance for the state to have or not have highway P3 projects. In other words, the empirical result suggests that a state's debt level does not affect state government's decision on P3 adoption. The coefficient of the lag of state gross product per capita is found to be significant with an odds ratio at 1, suggesting that the variation of the state's economic output in the previous years has an equal likelihood for a state government to adopt a highway P3 project or not in that particular year, with 5% statistical significance.

In terms of the control variables, the P3 enabling law variable and the governor's political affiliation variable are strongly statistically significant. The odds ratio of the P3 enabling law variable is 3.211, suggesting that if a state has P3 enabling legislation, the odds of having a highway P3 project in that year increases by about 321%. Similarly, the odds ratio of the governor's political affiliation can be interpreted as having a Republican governor increases the odds of having a highway P3 project in that year by about 89%.

Table 2: Results of Regular Logit Regression

	General P3 Model (P3)		Non-DB P3 Model (P3a)	
	Odds Ratios	Z Score	Odds Ratios	Z Score
lag of state highway net balance (*lagfc*)	0.999	-0.99	0.999	-0.55
lag of state debt per capita *(lagdebtpc)*	0.999***	-3.00	0.999*	-1.77
lag of highway indebtedness obligation per capita *(laghipc)*	1.000	1.04	1.002**	2.49
lag of highway capital outlay per capita (*lagcappc*)	1.000	0.04	1.000	0.24
lag GSP per capita (*lagsppc)*	1.000**	1.98	1.000	-0.36
growth rate of VMT per capita (*gvmtpc*)	0.773	-0.10	2.497	0.32
Dominant party in upper house is Republican (*uh*)	0.827	-0.55	0.961	-0.07
Dominant party in lower house is Republican (*lh*)	1.286	0.72	1.202	0.33
Whether governor is Republican (*gov*)	1.887**	2.08	3.663**	2.42
Whether state has P3 enabling law (*p3law*)	3.211***	3.38	2.541*	1.77
Whether state has "cannot carry over deficit law"(*ccod*)	0.927	-0.22	0.635	-0.96
Pseudo R2	0.127		0.145	
No. of Obs.	624		624	

Note: *, **, *** denote significant level at 10, 5 and 1 percent respectively.

The values of odds ratios are found to be similar for the estimates in the non-DB P3 model as compared with the general P3 model. The only difference is that the highway indebtedness obligation per capita is significant while the state gross product variable is not statistically significant. The odds ratio is 1, which indicates the state highway indebtedness has an equal likelihood to influence a state agency's decision on adopting P3 for highway projects or not.

Same as the previous model, the odds ratio of the P3 enabling legislation variable is significant at 2.541. Overall, the model suggests that after controlling for various factors, the variation of state fiscal constraints measured by state highway net balance, highway indebtedness, and state debt per capita, do not affect the odds of implementing highway P3 projects.

The estimation results from the panel fixed logit regression are displayed in Table 3. The "cannot carry over deficit law" variable is not included because it has no within-group variance. The results of the general P3 model show that only the lag of state highway net balance variable and the lag of state debt per capita variable have statistically significant estimates. Both of their odds ratios equal one, suggesting that the variations of fiscal constraints of state highway and state debt level do not affect the variation of the odds of highway P3 project implementation on average.

Table 3: Results of Panel Fixed Logit Regression

	General P3 Model (P3)		Non-DB P3 Model (P3a)	
	Odds Ratios	Z Score	Odds Ratios	Z Score
lag of state highway net balance (*lagfc*)	0.999*	-1.91	0.999	-1.33
lag of state debt per capita *(lagdebtpc)*	0.999*	-1.80	1.002*	1.85
lag of highway indebtedness obligation per capita *(laghipc)*	1.000	0.40	1.005*	1.75
lag of public highway capital outlay per capita (*lagcappc*)	1.002	0.51	1.023***	2.59
lag of log GSP per capita (*lgsppc*)	1.000	0.64	1.000	1.57
growth rate of VMT per capita (*gvmtpc*)	0.300	-0.40	4.920	0.66
Dominant party in upper house is Republican (*uh*)	0.508	-1.04	0.146	-1.36
Dominant party in lower house is Republican (*lh*)	2.226	1.36	11.861**	2.10
Whether governor is Republican (*gov*)	1.521	0.91	1.224	0.24
Whether state has P3 enabling law (*p3law*)	1.786	0.71	0.001	0.00
Year dummy				
1999	0.590	-0.70	0.154	-1.56
2000	0.400	-1.09	0.011***	-2.61
2001	0.408	-0.97	0.002***	-2.87
2002	0.935	-0.07	0.000	-0.01
2003	0.306	-1.10	0.001***	-2.84
2004	0.334	-0.95	0.000	-0.01
2005	0.901	-0.09	0.001***	-2.69
2006	1.510	0.33	0.001***	-2.76
2007	2.485	0.68	0.001***	-2.43
2008	0.306	-0.74	0.001***	-2.63
2009	1.003	0.00	0.001***	-2.64
2010	1.106	0.07	0.001***	-2.27
Pseudo R2	0.110		0.379	
No. of Obs.	312		312	

Note: *, **, *** denote significant level at 10, 5 and 1 percent respectively.

After controlling for individual fixed effects, the odds ratios of lags of highway indebtedness per capita and public highway capital outlay per capita become statistically significant in the non-DB P3 model. Both their values are about equal to one, suggesting that the variation of state highway indebtedness per capita and state's highway capital outlay per capita in a previous year have identical probability, with statistical significance, to influence a state government's decision to adopt or not to adopt P3s for highway projects. The dummy variable of dominant party in lower house is significant with a high value, which suggests that that if the dominant party in a state's upper house is Republican, the odds of having highway P3 projects implemented in a particular year increases substantially.

CONCLUSION

Public private partnerships (P3s) as mechanisms for transportation financing have been increasingly adopted by a number of states in the United States over the last decade. While a few studies have suggested that P3s are implemented to release pressure on public financial resource shortages, the associations between P3 involvement and the state's actual fiscal constraint have rarely been empirically investigated.

This study is conducted to investigate whether states with higher (or stricter) fiscal constraints are more likely to seek P3s for highway infrastructure construction and finance. To test this hypothesis, both the regular logit model and fixed effect logit panel model are adopted. A state's fiscal constraints are measured by the state's net balance, state debt per capita, highway indebtedness, and the "cannot carry over deficit" law dummy. After controlling for factors such as state economic condition, legislative political affiliation, and highway travel demand, our analysis reveals that there was not enough empirical evidence to claim that a state's fiscal constraints affect the implementation of highway P3 projects. These results are in line with with Geddes and Wagner (2013), which found that the fiscal conditions had little to do with states' passing of P3 enabling legislations.

We intend to continue the analysis by focusing on the relationship between the institutional factors and their impact on the P3 market in each state. One potential analysis is to focus on detailed components of enabling legislation and examine how they influence the outcomes of P3 deals. Also, it is possible that by employing alternative approaches to account for the fiscal constraints of the states, different outcomes may arise. It may be necessary to conduct in-depth case studies to document and aid in theorizing how specific elements of P3 enabling legislation affect behavioral dynamics of partners. Policy makers will benefit from these insights to improve their decisions on infrastructure investment.

Endnotes

1. The data set includes projects in all stages of development, from those that are in planning, procurement, or construction now, to completed facilities dating back to 1985. It covers all forms of transportation, water/wastewater, and social infrastructure projects.

2. The year of implementation is defined as the year when a P3 reaches financial close.

3. A further discussion of this approach can be found in Camph (2008).

4. In logistic models, odds ratio measures the ratio of the odds that an event or scenario would happen to the odds of the event or scenario not happening and provides an easier way to interpret influences of explanatory variables on the probability of a certain event or scenario to happen. For instance, assuming an explanatory variable is associated with a 60% chance for the adoption of P3 to finance highway projects in a state, the odds of P3 adoption is 1.5 (0.6/0.4),

whereas the odds of not adopting P3 equals to 0.67 (0.4/0.6). Therefore, the odds ratio for P3 being adopted versus P3 not being adopted is 2.25 (1.5/0.67).

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Book Review

Button, Kenneth, and Reggiani, Aura, eds. Transportation and Economic Development Challenges. *Northampton, MA: Edward Elgar Publishing, Inc., 2011. ISBN 978-1-84980-167 6*

Transportation and Economic Development Challenges

by T. Edward Yu

This book is a collection of nine research papers regarding transportation and development from a meeting of Network of European Communications and Transport Activities Research (NECTAR) in 2009. Driven by the rapid change in the institutional environment and technology development related to transportation systems, considerable challenges in transportation planning have emerged. The introduction chapter by the editors starts from the theoretical foundation of two classic economic growth models, the neo-classical model and endogenous growth theory, and their implications for the potential role of transportation in enhancing economic development. Also discussed are the challenges of identifying the causality between economic development and transportation networks and of assessing the economic impact of transportation policy given the availability of adequate data and models. Given the complexity of fully examining the relationship of transportation and economic development, the editors chose research papers for this volume that offer a wide range of academic approaches to address the challenges of planning transportation networks.

Chapter 2 discusses the emerging scale of economic and political systems, megaregion and megapolitans (clustered networks of American cities), resulting from the technological improvement and globalization trends. The authors provide a clear description of those two new geographic units and their historical development. The importance of connecting megaregions and interacting within a megaregion through comprehensive transportation planning is well explained and justified.

Chapter 3 revisits a classical question in public policy – what's the relationship between transportation and economic growth? The author offers a solid discussion on the theoretical and conceptual frameworks of the linkages between those two and extends the literature review in this area up to 2009. The potential economic impact of the American Recovery and Reinvestment Act of 2009 (ARRA) is also briefly discussed. The author concludes that "transport infrastructure alone will not guarantee economic success, but that the positive stories of the effects of transport investment are more common than the negative ones." This is echoed by a recent study that suggests investment in transport infrastructure does not create direct impact on national economic output in the United States but encourages the formation of private capital and other public infrastructure, which in turn supports economic growth (Tong et al. 2014).An interesting perspective of a political issue in transportation policy-making, political pathologies, is offered in Chapter 4. The author elaborates on the issue of conflicts between the interests of society and of the policy makers and the consequences on transportation planning decisions. This issue of political pathologies in transportation policy is critical since it may cause a longer-term impact on economic activities, such as trade, given the long expected life of those transportation infrastructures. The author suggests that institutional structures play an important role in addressing this political issue in decision making.

Chapters 5 and 6 address the question of the location and distribution of transportation services under economic development. The optimal number and location of rail stations and their catchment areas in urban areas is evaluated in Chapter 5. Using the Amsterdam rail system as a case study, the authors shed light on the importance of balancing the access time to stations and the travel time by rail between stations in the decision of the number of stations. Chapter 6 pays attention to the planning of freight logistics under the surging e-commerce in South Korea. Increases in online business transactions stimulate transportation demand between businesses and customers and change traditional logistics flows. The authors propose a conceptual model considering the potential adaptions to address the challenges in hub terminal capacity and to improve efficiency in logistics flows.

Chapter 7 discusses the necessity of creating a standard to evaluate accessibility among geographic units. Using the German "Guidelines for Integrated Network Design" as an example, three components are included in the standard: functional structure and associated transportation networks, quality requirement/criteria for such transportation networks, and assessment of the quality of service within the networks. Although the data requirements for generating such standards would be extensive, this comprehensive system of standards could be a means to examine the basic mobility in a geographic unit for the development of an environmental and economic sustainable transportation system.

Chapters 8 through 10 use real case studies to illustrate the issues and/or concerns of transportation planning. Chapter 8 provides insight into the conflicts between agencies in two state highway projects (US-51 and US 101) of the Sacramento, California, region. The authors point out an important issue of the current situation in the nation: how the local/regional agencies make transportation planning based on the framework adopted by the state/federal agencies in the past. Chapter 9 studies the net impact of rezoning in New York City on the changes in residential development capacity between 2003 and 2007. The findings suggest that rezoning has a modest overall impact on the residential capacity of the city with a concentrated increase in the neighborhoods near rail transit stations. It is crucial to gain a better understanding of the relationship between rezoning and residential capacity in future urban development. The final chapter forecasts demand for waterside industrial lands in Flanders, Belgium. Seven scenarios of the potential impact of changes in economic growth, policy decisions, and inland navigations on the demand for waterside industrial lands are conducted using a freight model. In summary, this volume includes a variety of perspectives regarding the challenges of transportation network planning under changes in economic and political situations. The reader is exposed to alternative views when evaluating transportation planning issues in this book. Most chapters offer a detailed background discussion as well as insights on these challenges or issues, thus benefiting readers with different academic backgrounds.

The book would benefit from a more representative title. As the editors mention in the introduction chapter, this volume briefly covers "one side of the challenge, that relating to transportation networks." (pp. 13). Thus, for example a title such as "Transportation Network Planning Challenges: Alternative Perspectives" may reduce the likelihood of misleading readers as to the topics covered. Also, although the nine chapters include very diverse approaches and perspectives to address the topic of accessibility in the transportation network, the effect of quality of transportation network on economic impact has not been explicitly studied. As Talley (1996) indicated, spatial accessibility and transportation quality-of-service are important in discussing the economic impact of transport systems. This volume would have benefited from inclusion of that aspect. Finally, the quality of the writing in the book is uneven. Some chapters are well written and easy to follow, while some experienced issues of repeating information, poor grammar, or lengthy sentences, which decreases readability and impedes subject comprehension (for instance, the second paragraph in Section 9.5).

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Transportation Research Forum

Statement of Purpose

The Transportation Research Forum is an independent organization of transportation professionals. Its purpose is to provide an impartial meeting ground for carriers, shippers, government officials, consultants, university researchers, suppliers, and others seeking an exchange of information and ideas related to both passenger and freight transportation. The Forum provides pertinent and timely information to those who conduct research and those who use and benefit from research.

The exchange of information and ideas is accomplished through international, national, and local TRF meetings and by publication of professional papers related to numerous transportation topics.

The TRF encompasses all modes of transport and the entire range of disciplines relevant to transportation, including:

Economics	Urban Transportation and Planning
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History and Organization

A small group of transportation researchers in New York started the Transportation Research Forum in March 1958. Monthly luncheon meetings were established at that time and still continue. The first organizing meeting of the American Transportation Research Forum was held in St. Louis, Missouri, in December 1960. The New York Transportation Research Forum sponsored the meeting and became the founding chapter of the ATRF. The Lake Erie, Washington D.C., and Chicago chapters were organized soon after and were later joined by chapters in other cities around the United States. TRF currently has about 300 members.

With the expansion of the organization in Canada, the name was shortened to Transportation Research Forum. The Canadian Transportation Forum now has approximately 300 members.

TRF organizations have also been established in Australia and Israel. In addition, an International Chapter was organized for TRF members interested particularly in international transportation and transportation in countries other than the United States and Canada.

Interest in specific transportation-related areas has recently encouraged some members of TRF to form other special interest chapters, which do not have geographical boundaries – Agricultural and Rural Transportation, High-Speed Ground Transportation, and Aviation. TRF members may belong to as many geographical and special interest chapters as they wish.

A student membership category is provided for undergraduate and graduate students who are interested in the field of transportation. Student members receive the same publications and services as other TRF members.

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In addition to monthly meetings of the local chapters, national meetings have been held every year since TRF's first meeting in 1960. Annual meetings generally last three days with 25 to 35 sessions. They are held in various locations in the United States and Canada, usually in the spring. The Canadian TRF also holds an annual meeting, usually in the spring.

Each year at its annual meeting the TRF presents an award for the best graduate student paper. Recognition is also given by TRF annually to an individual for Distinguished Transportation Research and to the best paper in agriculture and rural transportation.

Annual TRF meetings generally include the following features:

- Members are addressed by prominent speakers from government, industry, and academia.
- Speakers typically summarize (not read) their papers, then discuss the principal points with the members.
- Members are encouraged to participate actively in any session; sufficient time is allotted for discussion of each paper.
- Some sessions are organized as debates or panel discussions.

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