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A Message from the JTRF Co-General Editors

The Fall 2016 issue contains the usual wide variety of contemporary transportation topics that is the distinguishing characteristic of JTRF. Tops in this issue contain the following:

- Safety of shoulder bypass lanes on rural roads
- Transport infrastructure and U.S. economic growth
- Analysis of motorcycle helmet laws
- Changing priorities of port selection decisions
- Critical headways of roundabouts
- Hazardous materials transportation with multiple objectives
- Risk in the international airline industry

In "Safety Evaluation of Shoulder Bypass Lanes at Unsignalized Intersections on Rural Two-Lane Roadways Using Cross Sectional Analysis," Sunanda Disanayake and Alireza Shams use a cross section approach to evaluate crash data for roads with and without bypass lanes. The authors obtained crash data for 1,100 intersections in Kansas. The authors used crash modification factors (CMFs) to conclude that bypass lanes improve safety. The authors also concluded it is beneficial to continue adding shoulder bypass lanes at rural intersections on two-lane roads where traffic volumes are relatively low.

Junwook Chi and Jungho Baek assess the short- and long-run impacts of transport and non-transport public infrastructure on economic growth to provide an implication of the effectiveness of these policy tools in "Modeling the Transport Infrastructure-Growth Nexus in the United States." The authors employ an autoregressive distributed lag (ARDL) approach to explore the dynamic relationships among transport infrastructure, non-transport public infrastructure, private capital, labor hours, GDP, and exports. The authors found that the magnitude of the impact of transport infrastructure on GDP is smaller than that of non-transport public infrastructure, implying that non-transport infrastructure investment is a more effective long-term fiscal stimulus than expanding transport infrastructure.

In "Sturdy Inference: A Bayesian Analysis of U.S. Motorcycle Helmet Laws," Richard Fowles and Peter D. Loeb examine the determinants of motorcycle fatalities using traditional econometric models and a new Bayesian technique developed by Leamer. The technique examines the sturdiness of regression coefficients with what Leamer calls S-values. The authors employed a rich panel data set by state for the 1980-2010 period. The authors found that cell phones, alcohol consumption, and helmet laws affect motorcycle fatalities. Also universal helmet laws appear to have a larger effect on motorcycle fatalities than partial helmet laws.

Neha Mittal and Dale McClung analyze different criteria that shippers employ in their port selection process in "Shippers' Changing Priorities in the Port Selection Decision-A Survey Analysis Using Analytic Hierarchy Process (AHP)." The authors use results from a survey conducted on regional shippers from the chemical and life sciences industries that ship full container and LCL cargo of hazardous and non-hazardous chemicals. Using AHP framework and participants' comparative scores, factors affecting a shipper's port choice are prioritized. The authors found that port congestion and delays at the west coast ports have changed shipper priorities. Price and port characteristics are no longer their primary decision factors.

In "Investigating Mixed Logit Analysis of Critical Headways at a Single-Lane Instrumented Roundabout," Alex Hainen shows how the critical headway may be changing as drivers wait to enter the roundabout. The author examined how drivers are using observations to adjust their critical gap. The author examines 29,403 entering vehicles that rejected two or more headways for a total of 69,123 rejected headways. He used a detailed series of temporal parameters to estimate a mixed binary logit model to understand rejection/acceptance decisions. The author noted that the characteristics identified in the model can be considered by researchers within a simulation environment to enhance microsimulation analysis at roundabouts.

Ta-Yin Hu and Ya-Han Chang analyze a multi-objective formulation for the hazmat transport problem in "Hazardous Materials Transportation with Multiple Objectives; A Case Study in Taiwan." The authors apply a compromise programming method to solve the hazmat transportation problem with two objectives, travel cost, and risk. The path risk is defined based on risk assessment and includes factors such as road characteristics, population, distribution, link length, hazardous material characteristics, and accident rates. The authors develop an aggregate risk indicator for roadway segments. The results show that two conflicting objectives keep making tradeoffs between each other until they reach a compromise solution.

In "An Assessment and Measurement of Risks in the International Airline Industry: A Study of the ICAO Carriers over the Period, 1990-2013," Carl Scheraga and Richard D. Gritta examine a sample of foreign carriers to measure the extent of risks on the international level. The authors define and measure business risk, financial risk, and combined risk for 37 ICAO carriers for the 1990-2013 period. The authors found that the international airline industry has high business risk and extremely high financial leverage, resulting in high variability in operating profits. The authors also concluded that the long-term operating and financial performance of the international airline industry has been poor.

Michael W. Babcock
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Safety Evaluation of Shoulder Bypass Lanes at Unsignalized Intersections on Rural Two-Lane Roadways Using Cross Sectional Analysis

by Sunanda Dissanayake and Alireza Shams

Construction of bypass lanes at rural intersections has typically been considered a low-cost highway safety improvement by the transportation community. However, this needs to be quantitatively evaluated so that the decisions could be made on whether to continue with adding bypass lanes. Highway safety analyses utilize two common approaches to evaluate the effectiveness of a geometric treatment: before-and-after study and cross-sectional study. This paper explains the results using a cross-sectional study approach, where intersections with bypass lanes were compared to intersections with no bypass lanes for which crash data were obtained for more than 1,100 intersections in Kansas. Both 3-legged and 4-legged intersections were taken into consideration separately by looking at intersection-related crashes and crashes within an intersection box.

According to the results, the number of crashes and crash severities were lower at 3-legged intersections with bypass lanes compared with 3-legged intersections without bypass lanes, even though these reductions were not statistically significant at 95% level. When considering a 300-ft. intersection box, statistically significant crash reductions were observed at 4-legged intersections, for all considered crash and crash rate categories. When considering 90% level, crash reduction at 3-legged intersections was also statistically significant when considering a 300-ft. intersection box. Crash modification factors (CMFs) calculated to evaluate safety effectiveness of bypass lanes at unsignalized rural intersections in Kansas showed values less than 1.0 for almost all cases, indicating safety benefits of bypass lanes. Accordingly, it is beneficial to continue with the practice of adding shoulder bypass lanes at rural unsignalized intersections on two-lane roads where the traffic volumes are relatively low.

INTRODUCTION

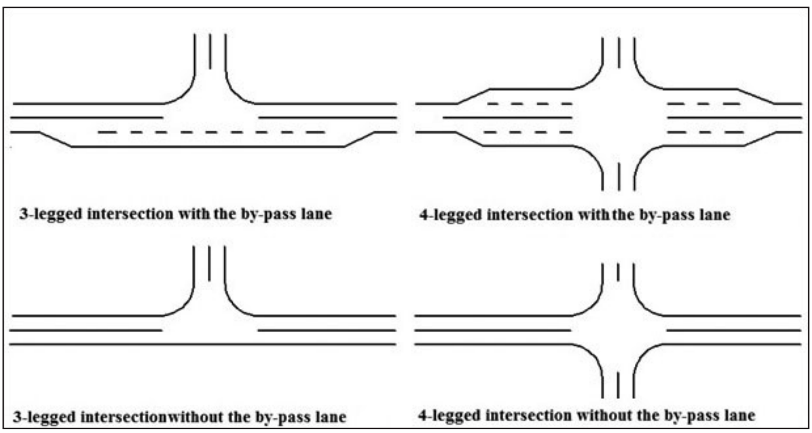
Increased population density in urban areas and higher annual average daily traffic (AADT) of urban roads cause crashes to occur more frequently in urban areas compared with rural areas (NHTSA 2016). However, higher speed limits, lack of traffic control devices, lower enforcement levels, and many other factors increase crash severity on rural roadways. In 2014, 29,989 fatal crashes occurred in the United States, resulting in 32,675 fatalities. Fifty-four percent of fatal crashes and 55% of fatalities occurred in rural areas, although only 19% of the U.S. population lives in rural areas. Urban areas accounted for 45% of fatal crashes and 44% of fatalities. At the same time, the fatality rate per 100 million vehicle miles traveled was 2.5 times higher in rural areas than in urban areas (NHTSA 2016). These statistics clearly show that crashes in rural areas are more severe in nature.

According to statistics from 2010, only 36% of all motor vehicle crashes in Kansas occurred in rural areas; however, in contrast, 69.7% of fatal crashes occurred in rural areas (KDOT 2013a), demonstrating increased crash severity on rural roadways. Nearly 30% of crashes in Kansas occurred at intersections or were intersection-related (KDOT 2013a). Opportunity for crashes increases at intersections, because vehicles approach the intersection from multiple directions making it possible to have more conflicts. Perception that low AADT values on rural roadways decrease the probability of a crash might cause drivers to feel safer on rural roadways, making them less cautionary, which might eventually lead to crashes (Izadpanah, Hadayeghi and Rezaie 2009). Lower law enforcement levels that are typically prevalent in vast rural areas might also be contributing to changes in driver behavior in such areas. These elevated levels of safety concerns at intersections in rural areas make it necessary to look at low-cost approaches to improve highway safety.

Accordingly, this study focused on evaluating safety effectiveness of bypass lanes at rural unsignalized intersections on two-lane roads. Urban high-traffic intersections typically contain a dedicated lane for drivers turning left, but this lane is not commonly present at rural intersections. When a driver approaches an unsignalized intersection behind a left-turning vehicle, the driver must reduce speed and stop. Bypass lanes provide a through-traffic lane in which the following driver can bypass the slow or stopped left-turning vehicle. If a vehicle in a through-travel lane is stopped to turn left, following vehicles are able to utilize the shoulder bypass lane to avoid stopping (Fitzpatrick, Parham, and Brewer 2002). To increase highway safety at 3-legged or 4-legged rural intersections in which a portion of the paved shoulder may be marked as a lane for through traffic, installation of bypass lanes have been identified as a low-cost safety improvement. Figure 1 shows typical bypass lane configurations at 3-legged and 4-legged rural intersections on a two-lane highway and an example site location on how it is actually used.

Figure 1: Typical Bypass Lane Configurations and an Example Site

(a) Typical Configurations



(b) An Example Site

The Kansas Department of Transportation (KDOT) has utilized bypass lanes at rural intersections for a considerable period of time. Because bypass lanes are fairly common on some Kansas roadways, this study was necessary to quantitatively determine the safety benefits (if any) of the continued addition of bypass lanes on two-lane roadways. The study described in this paper served that purpose by quantitatively evaluating the safety effectiveness of bypass lanes by considering the cross-sectional study approach. In this approach, intersections were categorized as intersections with bypass lanes and intersections without bypass lanes, and statistical analyses were utilized to quantitatively determine safety effectiveness of having bypass lanes at those intersections.

In addition, crash modification factor (CMF), which is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site, is becoming increasingly popular with the introduction of the Highway Safety Manual (AASHTO 2010). Accordingly, CMF for bypass lane additions was calculated in this study by using case-control methodology.

No study of this nature has been previously conducted to evaluate the safety effectiveness of bypass lanes in rural areas, and, accordingly, practitioners can make the policy decision on whether to proceed with this practice of adding shoulder bypass lanes, which is very low-cost countermeasure in general.

LITERATURE REVIEW

Studies Related to Bypass Lanes

Even though the studies related to safety and operational effects of bypass lanes are not very common or comprehensive in the literature, a limited number of studies that are available are described here in detail. Sebastian and Pusey (1982) published a report that investigated bypass lanes after passage of legislation in Delaware in 1976 that allowed drivers to pass a stopped, left-turning car on the right, using the shoulder as necessary. This law did not designate a required paved shoulder width, so Delaware drivers utilized roadway shoulders to pass vehicles on the right on two-lane roads (Sebastian and Pusey 1982). At that time, Delaware did not mandate standard widths of travel lanes, bypass lane installation requirements, or pavement markings. This study investigated the savings of user costs, such as operating costs, time/delay, fuel consumption, and vehicle emissions and crash prevention, in order to warrant the use of bypass lanes in designated left-turn lanes (Sebastian and Pusey 1982).

Data were collected at 16 locations for three, two-hour peak periods: morning, noon, and evening. Average daily traffic (ADT) was calculated using Delaware's Department of Transportation (DelDOT) annual summary report, and crashes were reviewed based on three-year crash experiences obtained from DelDOT's traffic crash records. Results indicated that bypass lanes primarily prevented rear-end crashes (Sebastian and Pusey 1982). Conclusions of this report also included statistical proof of beneficial legalization of pass-on-the-right-lanes in order to reduce user operating costs, fuel consumption, travel delays, emissions, and rear-end crashes (Sebastian and Pusey 1982).

Minnesota Department of Transportation (MnDOT) funded a research project with BRW, Inc. to investigate the safety and use of rural intersections without turn lanes, with bypass lanes, and with left-turn lanes in order to determine whether or not bypass lanes should be used as a safety measure at unsignalized intersections (Preston and Schoenecker 1999). Data on 3-legged intersections were collected using a survey sent to 212 government entities within Minnesota. Eighty-two completed surveys were returned. Another survey for 4-legged intersections was sent to 22 government entities, and 14 were completed and returned. Results of these surveys indicated that a majority of counties and cities did not reference MnDOT design guidelines. In addition, survey results revealed that most counties and cities implemented inconsistent pavement markings, that 3-legged bypass lanes had advantages in terms of delay and that 4-legged intersection bypass lanes should not be used (Preston and Schoenecker 1999).

A legal review of bypass lane implementation also occurred because Minnesota revised highway design to include a required 10-ft. paved shoulder. Consequently, users of rural roads began using the shoulder as a bypass lane to avoid turning vehicles, although the intersection was not intended to include bypass lanes. Minnesota finally outlawed passing on the right unless performed on a main-traveled lane of the roadway, thus requiring MnDOT to evaluate design regulations and implementation requirements for signage and marking (Preston and Schoenecker 1999).

Preston and Schoenecker (1999) conducted safety analysis using crash data between 1995 and 1997 under the following categories: 1. Total and average number of intersection crashes, 2. Average crash rate for volume categories of 0-4,000 vehicles per day, 4,000-10,000 vehicles per day, >10,000 vehicles per day, and 3. Distribution by severity and type. Three- and 4-legged intersections were reviewed and categorized into (Preston and Schoenecker 1999) no-turn lanes, bypass lanes and left-turn lanes. An additional before-and-after study was conducted in the same study, which included six years of crash data: three years prior to installation of bypass lanes and three years post-installation of bypass lanes. Sixty-nine intersections were used for the sample size, and crash data used were between 1983 and 1994 (Preston and Schoenecker 1999).

A safety summary of the 2,700 reviewed intersections stated that 3-legged intersections had fewer vehicle crash occurrences compared with 4-legged intersections. The number of crashes did not appear to be a function of entering traffic volume, but crash severity was affected by the volume. No statistical significance was evident between design types, and intersections with left-turn lanes had the lowest percentage of rear-end crashes (Preston and Schoenecker 1999). The before-and-after study summary also showed no statistically significant differences, and intersections with bypass lanes had a lower overall crash rate than the state average crash rate (Preston and Schoenecker 1999). Analysis concluded that safety improvements due to bypass lanes are not statistically significant, suggesting that it is not possible to conclude that bypass lanes should not be used as a safety device (Preston and Schoenecker 1999).

Bruce and Hummer (1991) reviewed delay data to investigate effectiveness of a left-turn bypass lane on a two-lane rural T-intersection. Left-turn bypass lanes are defined as a paved area to the right of the travel lane on a major road and opposite the minor road at a T-intersection on a rural two-lane roadway. (Bruce and Hummer 1991). Bypass design was designated as a 300-ft. taper out to a 12-ft. lane; 700-ft., a 12-ft lane with 600-ft. from end of run out taper to minor road centerline and then 100-ft. past centerline; and a 600-ft. taper to a single-lane travel way (Bruce and Hummer 1991). The experiment relied on traffic simulation using software called TRAF-NETSIM, a detailed, stochastic, microscopic model developed by the Federal Highway Administration (FHWA). Eight factors were identified for use in the simulation: volume of opposing traffic on the major street, volume of right-turning traffic from the minor street, left-turn volume, through volume, speed of vehicles, distance from T-intersection to nearest controlled intersection upstream/downstream, and the presence of a bypass lane. With eight factors, the experiment had a total of 256 combinations, but for efficiency, only 64 combinations were tested (Bruce and Hummer 1991).

Significant variables identified through analysis results included through traffic volume, opposing volume, left-turn volume, speed, upstream signal distance, and presence of a bypass lane. Average travel time saved was found to be 0.50 seconds per vehicle (Bruce and Hummer 1991).

Studies Related to Crash Modification Factors

A crash modification factor evaluates safety effectiveness of any given countermeasure. It is calculated by dividing number of crashes with a treatment with number of crashes without the treatment. A CMF value less than 1.0 shows an expected reduction in vehicle crashes due to a countermeasure, but CMF greater than 1 indicates an increase in crashes after countermeasure implementation (Gross, Persaud, and Lyon 2010). Although a before-and-after study approach is typically used to develop the CMF, alternative methods for CMF calculation were required. In a before-and-after study, CMF is defined by comparing observed crash frequency after countermeasure implementation to crash frequency before countermeasure installation. However, CMFs derived from cross-sectional data are based on a certain time period such as three years, assuming that the ratio of average crash frequencies for sites with and without a feature is an estimate of CMF for implementing that particular feature (Gross and Donnell 2011).

Gross and Donnell (2011) applied case control and cross-sectional method to develop CMF for roadway lighting and shoulder width. Four years (2001-2004) of data were used to estimate CMF for road lighting, including 6,464 intersections in Minnesota. Only 13.7% of the intersections had signal control, and the remainder of the intersections operated with stop signs. Approximately 49% of the intersections were 4-legged, 40% were 3-legged, and 11% were 4-legged skewed intersections, where the two streets were not meeting at right angles. The analysis database included 38,437 crash reports that occurred at the selected intersections. Based on the case–control method, CMF for intersection lighting was 0.886, while calculated CMF was 0.881 for the cross-sectional study. In addition, CMFs developed for lane and shoulder widths were similar when the two methods were directly compared. This study suggested that case–control and cross-sectional studies produce consistent results, especially when the before-and-after study was impractical due to data limitations (Gross and Donnell 2011).

Gross and Jovanis (2007) applied case-control method to evaluate safety effectiveness of lane and shoulder width. Their study estimated CMF as a common acceptable ratio to measure safety effectiveness by comparing the number of crashes with countermeasure implementation and the number of crashes without a countermeasure. The study considered more than 28,000 rural two-lane undivided highways in Pennsylvania from 1997 to 2001. The paper provided a matched case-control design while adjusting for variables such as speed limit, AADT, and segment length. CMF was provided for a wide range of shoulder widths. Results showed that segments without shoulders are safer than segments with shoulder width from 0 to 1.83 meters. However, CMF is less than 1.0 for shoulder width greater than 1.83 meters. According to the authors, case-control estimation could advantageously estimate confidence levels, thereby conveying variability in safety effectiveness. Safety effectiveness range can be considered in economic analysis of alternative action.

METHODOLOGY AND DATA

Background of Observational Studies

Researchers either design an experiment or conduct an observational study to answer a specific question or test whether a certain hypothesis is correct. Typically, experiments are studies implemented in a laboratory context; however, in observational studies, study parameters cannot be completely controlled by researchers (Izadpanah et al. 2009). Road safety studies are classified as observational studies because, in general, a crash involves random circumstances and researchers are unable to control crashes. Observational studies can be categorized as before-and-after studies and cross-sectional studies.

In road safety studies, parameters that potentially influence safety may change during before and after periods. For example, weather conditions and traffic regulations may change just like traffic conditions in any given transportation system. Attributes such as geometric design characteristics of the road are expected to remain the same during each before or after time period. However, in cross-section-based observational studies, safety effects of one group of facilities are compared to another group of facilities. These two groups of facilities should have similar features, except the feature that is being studied, so that the safety effect of the dissimilar feature could be evaluated (Izadpanah et al. 2009).

Cross-sectional Studies

A cross-sectional study, which is a common observational study in transportation safety evaluations, compares the safety performance of a site or group of sites with the treatment of interest to similar sites without the treatment at a single point in time such as present time (Gross et al. 2010). Cross-sectional studies divide intersections into two major groups: Intersections with a treatment such as bypass lanes and intersections without the treatment.

One challenge inherent in observational studies is that crashes are random events and change from year to year (Izadpanah et al. 2009). In addition, other parameters that affect facility safety, such as traffic volume and weather conditions, could also vary for each intersection or study location. In order to evaluate safety effectiveness of a specific treatment, Highway Safety Manual (HSM) recommends a three-year to five-year comparison of crash data at sites with implemented treatment versus sites without the treatment (AASHTO 2010).

Statistical Analysis Using t-test

In order to evaluate the differences in crash experience at two sets of sites, t-test could effectively be utilized. The t-distribution is a symmetrical distribution similar to normal distribution, but has thicker tails making it shorter and flatter (Martz and Paret 2013). The t-distribution is useful for analyzing the mean of an approximately normally distributed population when the population standard deviation is unknown (Martz and Paret 2013). In this study, crash frequency at intersections with bypass lanes and without bypass lanes is the subject quantity to be analyzed. If the average crash frequencies per intersection with and without bypass lanes are μ_1 and μ_2, respectively, the t-test can be used to determine whether a statistically significant difference exists between the two sets of data. In this case, the null hypothesis becomes:

$$H_0 : \mu_1 = \mu_2$$

Depending on the issue being analyzed, the alternative hypothesis can take one of the following forms:

$$H_1 : \mu_1 > \mu_2 \; (one - tail\ test)$$
$$H_1 : \mu_1 < \mu_2 \; (one - tail\ test)$$
$$H_1 : \mu_1 \neq \mu_2 \; (two - tail\ test)$$

When the critical area of the t-distribution is one sided, either greater than or less than a certain value, it is called a one-tail test. A two-tail test would be used to determine if two means are different. The t-value can be computed from Equation 1 (Ruxton 2006).

$$(1) \qquad t = \frac{\bar{X}_1 - \bar{X}_2}{S_p^2 \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

Where,

$\bar{X}_1$ and $\bar{X}_2$ = Sample means
n_1 *and* n_2 = Sample sizes
S_p = Square root of the pooled variance given by,

$$(2) \quad {S_p}^2 = \frac{(n_1 - 1){S_1}^2 + (n_2 - 1){S_2}^2}{n_1 + n_2}$$

Where,

${S_1}^2$ and ${S_2}^2$ = Sample variance of the two populations

The degrees of freedom and level of significance (α) affect the value of t. The degrees of freedom for t-distribution is $(n_1 + n_2 - 2)$, and the level of significance is the probability of rejecting the null hypothesis. When the null hypothesis is true and rejected, it is typically referred to as Type 1 error. If the null hypothesis is not true and is accepted, error Type 2 is said to occur. The probability of occurrence of Type 1 error is the level of significance (α). The most commonly used "α" value in traffic safety studies is 5%, although 10% is also occasionally used. When the t-test is one-tail, the *t*-value is selected for "α"; when the test is two-tail, the *t*-value is selected for "α/2." When conducting the statistical comparison, null hypothesis is rejected if the sample t-value is more than the critical t-value; therefore, the null hypothesis is not true. In other words, a significant difference exists between two sample means (Ruxton 2006). The null hypothesis is not rejected if the sample t-value is less than the critical t-value. In this case, the null hypothesis could be true or no significant difference exists between the population means (Ruxton 2006).

Each t-statistic has an associated probability value (p-value), which is the likelihood of an observed statistic occurring due to chance, given sampling distribution. Instead of comparing t-critical and t-statistical values to determine a significant difference, p-value could be used to compare significance levels (Martz and Paret 2013). A large t-value means a large difference between sample means; therefore, a larger t-value is associated with a smaller p-value. Rejection of the null hypothesis either based on t-value or p-value is shown in Table 1.

Table 1: Rejection of Null Hypothesis Based on t-Value or p-Value

Alternative hypothesis	Rejection region for H_0
H_1: $\mu_1 > \mu_2$ (*one – tail test*)	$t > t_\alpha$
H_1: $\mu_1 < \mu_2$ (*one – tail test*)	$t > t_\alpha$
H_1: $\mu_1 \neq \mu_2$ (*two – tail test*)	$\|t\| > t_{\alpha/2}$
Alternative hypothesis	Rejection region for H_0
H_1: $\mu_1 > \mu_2$ (*one – tail test*)	$\alpha > p - value$
H_1: $\mu_1 < \mu_2$ (*one – tail test*)	$\alpha > p - value$
H_1: $\mu_1 \neq \mu_2$ (*two – tail test*)	$\alpha/2 > p - value$

Significance level sets the standard for how extreme data must be before rejecting the null hypothesis, and p-value indicates how extreme the data are (Martz and Paret 2013). A comparison of p-value and significance level determines whether the observed data are statistically significantly different from the null hypothesis:

- If the p-value is less than or equal to the selected alpha (p-value ≤ α), the null hypothesis is rejected, or a significant difference exists between sample means.
- If the p-value is greater than the selected alpha (p-value > α), the null hypothesis is not rejected, or no significant difference exists between sample means.

Crash Modification Factors (CMF)

Transportation professionals, such as traffic engineers, transportation planners, and designers, can use CMF to evaluate the effectiveness of a given countermeasure. CMF can also be used to compute the number of crashes after implementation of a countermeasure in order to compute the effect of that countermeasure at specific site locations (Gross et al. 2010). A CMF greater than 1.0 indicates an expected increase in the number of crashes, demonstrating that the countermeasure deteriorated safety in that location. In contrast, a CMF less than 1.0 indicates a reduction in crashes after implementation of a given countermeasure, demonstrating that the countermeasure improved highway safety at that location (Gross et al. 2010). Case-control studies have recently been employed on evaluating geometric design elements (Gross and Jovanis 2007) by computing CMFs. In case-control studies, once the treatment is determined, samples of locations with bypass lanes (cases) and number of locations without bypass lanes (controls) are selected based on their status on whether the risk factor (crashes at the location) is present or not.

Application of this method could be explained as follows:

$$(3)\quad Odds\ Ratio(CMF) = \frac{A/B}{C/D} = \frac{A \times D}{B \times C}$$

Where,

A = number of cases with risk factor present
B = number of controls with risk factor present
C = number of cases with risk factor absent
D = number of controls with risk factor absent

However, case-control studies cannot be used to measure exact probability of an event, such as a crash or severe injury, in terms of expected frequency. Instead, these studies are often used to demonstrate the relative effects of treatments (Gross et al. 2010).

Data Collection

In the initial stages of the study, survey forms were sent to area and district engineers of KDOT in order to identify the locations and determine characteristics of rural unsignalized intersections with bypass lanes. Questions on the survey form sought to identify specific information such as road names, average annual daily traffic (AADT), speed limits, pavement markings, and dates when bypass lanes were added. Of those sent, 563 completed survey forms were received. Categorization of received surveys by districts was used primarily to ensure accurate geographical data distribution throughout the state, which was found to be acceptable. Later on, researchers used Google Earth to identify the other set of sites without bypass lanes in the vicinity of those sites with bypass lanes.

The safety effectiveness of any countermeasure is quantified by a reduction in the number of crashes or crash severity caused by treatment implementation. Kansas Crash Analysis and Reporting System (KCARS) database, maintained by KDOT, was utilized in this study to determine crashes at each intersection. KCARS database includes details of all police-reported crashes on the Kansas highway system, and this database is coded in accordance with the Kansas Motor Vehicle Crash Report. In this study, all crashes from 1990-2011 were gathered to evaluate the effectiveness of bypass lanes. For data collection, HSM recommends utilization of a three- to five-year time period because time periods less than three years are subject to high variability due to randomness of crashes, and periods longer than five years are subject to introduction of bias due to changes in reporting standards or physical changes to roadway features (AASHTO 2010). Some characteristics of data variables in the KCARS database are as follows:

Crash ID. KCARS contains a field that identifies the location and specific identification number of each crash. This crash ID is a unique identifier for each crash and can be used to combine crash characteristics from KCARS and other databases, such as the geometric design characteristics database, so that information regarding highway geometric characteristics could be added to crash information.

Crash Location. Several fields in KCARS represent crash location, including county milepost and distance from a named intersection. Because incident responders may not typically have precise positioning equipment to determine the specific milepost of an incident, this value could contain some inaccuracies. Two additional KCARS columns provide longitude and latitude of the crash location, which could also be utilized in obtaining the location of a crash.

Crash Severity. KCARS contains three primary categories of crash severity with five total subdivided injury severity levels as (KDOT 2005): 1. Fatal crashes, 2. Injury crashes (possible injury, non-incapacitating injury, and incapacitating injury), and 3. Property damage only (PDO). When more than one person is involved in a crash, it is assigned to the most severe personal injury severity level experienced by persons involved in the crash.

Equivalent Property Damage Only Crashes

In order to account for severity of crashes at each location, total number of crashes can be expressed in terms of equivalent property damage only (EPDO) crashes. In this approach, a weight is assigned to each fatal or injury crash to represent crash severity of the location (Knapp and Campbell 2005). Accordingly, EPDO crash numbers are calculated as follows:

$$\text{(4)} \quad Number\ of\ EPDO\ crashes = no.PDO\ Crashes + w_1 \times no.Injury\ Crashes + w_2 \times no.Fatal\ Crashes$$

Where,

$$w_1 = weight\ factor\ to\ convert\ injury\ crashes\ to\ PDO\ crashes = \frac{Average\ Injury\ crash\ cost}{Average\ PDO\ crash\ cost}$$

$$w_2 = weight\ factor\ to\ convert\ fatal\ crashes\ to\ PDO\ crashes = \frac{Average\ Fatal\ crash\ cost}{Average\ PDO\ crash\ cost}$$

In Kansas: w1 = w2= 15

Relevant Crashes

In order to determine relevant crashes to be considered in evaluating the effectiveness of bypass lanes, two methods were utilized. This is based on a dilemma in the transportation community on whether location-related crashes should be based on distance or an "intersection-related" variable in the crash databases. This study used both methods to identify any differences/similarities.

1. Consideration of crashes within a fixed distance of 300 feet along each approach leading to the intersections, regardless of whether or not crashes are intersection-related.
2. Consideration of intersection-related crashes using the column in the KCARS database that distinguishes whether or not crashes are intersection-related, no matter how far away from the intersection the crash occurred.

KDOT Traffic Count Maps

For an intersection, a combination of crash frequency and traffic volume results in crash rates, which can be effectively used to compare relative safety at intersections. The traffic volume for each approach is needed to calculate the crash rate at an intersection (Green and Agent 2003). Traffic volumes of major roads considered in this study were mainly obtained from KDOT traffic count maps. However, rural intersections considered in this study included minor local roads not included in traffic flow maps of the Kansas state highway system.

In addition to traffic count maps, AADT values of county major collector rural roads are available on the KDOT website, which provides minor road AADT in some cases. These roads are labeled with road secondary (RS) numbers. Because RS numbers differ from road names, the RS route had to be matched with Google Maps to identify the road name of each RS number. After determining the RS route from the district map, Google Maps was checked simultaneously. A city along the route was chosen on the county map and then side roads were counted to match those on the county map and Google Maps. By matching roads like this, traffic volumes of minor roads were obtained.

Calculation of Crash Rates

Crash rates for selected rural intersections were calculated in terms of crashes and EPDO crashes per million entering vVehicles (MEV) respectively, as follows (Green and Agent 2003).

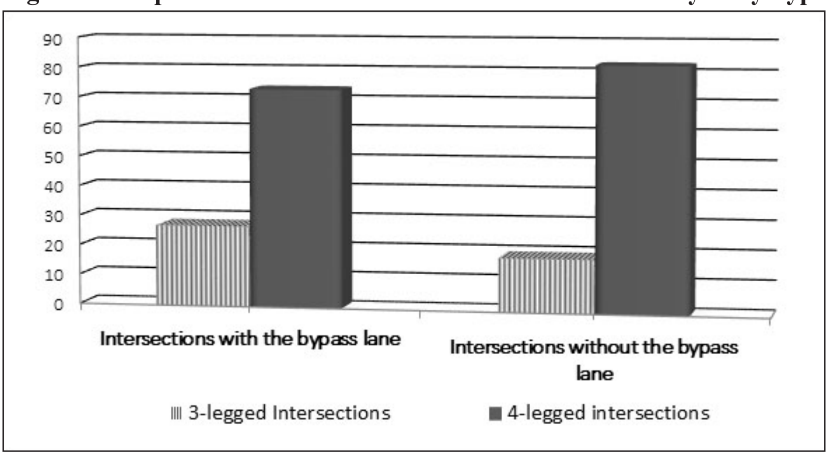
$$(5)\quad Crash\ rate = \frac{Average\ number\ of\ Crashes\ per\ year \times 10^6}{\sum AADT \times 365}$$

$$(6)\quad EPDO\ crash\ rate = \frac{Average\ EPDO\ crashes\ per\ year \times 10^6}{\sum AADT \times 365}$$

RESULTS

Analysis was conducted to determine the safety effectiveness of bypass lanes by comparing crash statistics at intersections with bypass lanes and intersections with no bypass lanes and no left-turn lane. Intersections with bypass lanes were obtained from the returned survey forms. Due to incomplete information in some of the survey forms, out of a total of 574 forms returned, only 558 intersections could be taken into account in the analysis. As the comparison group, 579 intersections without bypass lanes were selected. These intersections were identified by using Google Earth and were located in proximity of intersections with bypass lanes to have similar traffic volume and driver behaviors. Figure 2 shows the proportion of 3-legged and 4-legged intersections in the two samples, intersections with bypass lanes and intersections without bypass lanes. As shown in the figure, among the intersections with bypass lanes, 72% were 4-legged intersections; whereas the corresponding percentage for intersections without bypass lanes was even higher at 83%.

Figure 2: Proportion of Intersections Considered in the Analysis by Type



Crash data were extracted from KCARS from 2009–2011, and then a two-sample t-test was conducted to evaluate the significance of differences in the number of crashes, number of EPDO crashes, crash rates, and EPDO crash rates. A comparison crash analysis was conducted to determine basic crash characteristics for two categories of intersections: 3-legged and 4-legged.

Comparison of Crash Frequency

A two-sample t-test under 95% confidence level was conducted on crash frequency for the two sets of intersections. Table 2 shows the results of statistical comparison of crash frequency within 300 feet along each approach leading to the intersections and intersection-related crashes.

Table 2: Statistical Comparison of Crash Frequency

Statistical parameter	3-legged Intersections		4-legged Intersections	
	Crash selection criteria		Crash selection criteria	
	300ft	Intersection-related	300ft	Intersection-related
Mean crash frequency (With bypass lanes)	0.670	0.521	0.870	0.503
Mean crash frequency (Without bypass lanes)	0.493	0.42	0.463	0.51
Mean crash frequency difference	0.177	0.101	0.407	- 0.007
t-value	1.30	0.82	5.71	-0.13
p-value	0.098	0.207	0.001	0.55

Positive values of the mean difference show a reduction of crash frequency within 300 feet along each approach leading to 3-legged intersections and intersection-related crashes. However, according to the p-values that are greater than 0.05, none of the differences are significant at 5% level. However, the difference is significant at 10% level since $p = 0.098$. Because p-values are less than 0.05 at 4-legged intersections, reduction in the number of crashes at intersections with bypass lanes is significant, when considering intersection boxes. However, for intersection-related crashes, a change in crash frequency is not significant at 5% confidence level.

Comparison of EPDO Crash Frequency

A two-sample t-test under 95% confidence level was conducted on EPDO crash frequency at each intersection. Table 3 shows statistical analysis results of EPDO crash differences 300 feet along each approach leading to intersections and intersection-related crashes.

Table 3: Comparison of EPDO Crash Frequency

Statistical parameter	3-legged Intersections		4-legged Intersections	
	Crash selection criteria		Crash selection criteria	
	300 ft	Intersection-related	300 ft	Intersection-related
Mean EPDO crash frequency (With bypass lanes)	2.16	3.335	3.87	3.71
Mean EPDO crash frequency (Without bypass lanes)	1.89	3.03	2.45	4.0
Mean difference in EPDO crash freq.	0.266	0.318	1.423	-0.305
t-value	0.37	0.33	2.85	-0.43
p-value	0.358	0.372	0.002	0.667

Positive values of the mean difference show a reduction of EPDO crash frequency within 300 feet along each approach and intersection-related crashes for 3-legged intersections. However, since *p*-values are greater than 0.05, none of those differences are statistically significant at 5% level. When considering a 300 ft. intersection box for 4-legged intersections, *p*-values less than 0.05 show a significant reduction in EPDO crash frequency at intersections with bypass lanes. In contrast, for intersection-related crashes, EPDO crash frequency at 4-legged intersections with bypass lanes was slightly higher than intersections without bypass lanes, even though it was not statistically significant.

Comparison of Crash Rates

As mentioned, actual AADT for 35% of intersections of minor roads are unknown. Using only the intersections for which AADTs were available, a two-sample t-test under 95% confidence level was conducted on crash rates at each intersection. Table 4 shows statistical analysis of the crash rate difference within 300 feet along each approach leading to intersections and intersection-related crashes.

Table 4: Comparison of Crash Rates

Statistical parameter	3-legged Intersections		4-legged Intersections	
	Crash selection criteria		Crash selection criteria	
	300 ft	Intersection-related	300 ft	Intersection-related
Mean crash rate (With bypass lanes)	0.276	0.188	0.310	0.123
Mean crash rate (Without bypass lanes)	0.194	0.131	0.157	0.153
Mean difference in crash rates	0.082	0.056	0.153	-0.03
t-value	1.04	0.78	4.78	-1.12
p-value	0.151	0.218	0.001	0.869

Positive values of the mean difference show a reduction of crash rates within 300 feet along each approach leading to 3-legged intersections and intersection-related crashes. However, since *p*-values are greater than 0.05, none of the reductions are significant. With *p*-value less than 0.05, reduction of crash rates for 300 feet along each approach leading to 4-legged intersections with bypass lanes are significant. However, for intersection-related crashes, differences in crash rates at 4-legged intersections with and without bypass lanes are not significant.

Comparison of EPDO Crash Rates

Similar to crash rate analysis, a two-sample t-test under 95% confidence level was conducted on EPDO crash rates at each intersection. Table 5 shows the statistical analysis of EPDO crash rate difference within 300 feet along each approach leading to intersections and intersection-related crashes.

Table 5: Comparison of EPDO Crash Rates

Statistical parameter	3-legged Intersections		4-legged Intersections	
	Crash selection criteria		Crash selection criteria	
	300 ft	Intersection-related	300 ft	Intersection-related
Mean EPDO crash rates (With bypass lanes)	0.84	0.131	1.09	0.75
Mean EPDO crash rates (Without bypass lanes)	0.93	0.147	0.77	0.99
Mean difference in EPDO crash rates	-0.097	-0.016	0.32	-0.242
t-value	-0.25	-0.66	1.69	-1.29
p-value	0.60	0.744	0.046	0.901

Negative values of the mean difference show higher EPDO crash rates at intersections with bypass lanes using both 300 feet along each approach and intersection-related crashes for 3-legged intersections. However, since the p-value is greater than 0.05, both differences are not significant. When considering 300 feet along each approach leading to 4-legged intersections, *p*-value less than 0.05 shows a significant reduction of EPDO crash rates at 4-legged intersections with bypass lanes. In contrast, for intersection-related crashes, differences in EPDO crash rates with and without bypass lanes are not significant at 4-legged intersections.

Crash Modification Factors

As mentioned earlier, CMF is used to compute the expected number of crashes after a countermeasure is implemented at a specific site. A CMF greater than 1.0 indicates an expected increase in crashes, while a value less than 1.0 indicates an expected reduction in crashes after implementation of the countermeasure. Table 6 shows the results of a case-control study conducted in this study to estimate CMF for the implementation of bypass lanes.

Table 6: Case-Control CMFs Based on Data from 2009-2011

Risk Factors	Intersection types	Number of cases under each scenario				CMF
		With bypass lane	Without bypass lane	With bypass lane	Without bypass lane	
		A	C	B	D	
Crashes within 300 ft from intersection	3-legged intersections	46	35	104	59	0.75
	4-legged intersections	123	225	285	260	0.50
Intersection related crashes	3-legged intersections	35	34	115	60	0.54
	4-legged intersections	112	157	296	328	0.79

According to the case-control method utilized in this study, all calculated CMF values are less than one, indicating that future crashes are expected to decrease with the addition of bypass lanes at rural intersections.

SUMMARY AND CONCLUSIONS

The primary objective of this study was to present a statistically reliable conclusion regarding the effect of adding bypass lanes at rural unsignalized intersections. Results of the cross sectional study are presented in Table 7 for 5% level of confidence or p=0.05. A modest decrease in crash frequency, EPDO crash frequency, and crash rates occurred at 3-legged intersections with bypass lanes, but these reductions were not statistically significant under 95% confidence level. EPDO crash rates at 3-legged intersections increased, but they were not statistically significant under 95% confidence interval. When considering a 300-ft. intersection box at 4-legged intersections, significant reductions occurred in total crash frequency, EPDO crash frequency, crash rates, and EPDO crash rate. However, when considering intersection-related crashes, the presence of bypass lanes caused slight increases in crash frequency, EPDO crash frequency, crash rates, and EPDO crash rates, but none of those are significant at 5% level. According to the case-control study, CMFs were calculated to estimate the changes in crashes associated with the addition of bypass lanes at intersections. CMFs lower than 1.0 for all cases indicates an expected reduction in crashes after adding bypass lanes.

A summary of the analysis results based on 10% level are shown in Table 8. Even though 5% level is most commonly used, due to the random nature of crashes, lower traffic volumes at the considered locations making exposure levels relatively low, quality and reliability of crash data obtained from the crash database, and other assumptions that were required to be made, 10% level could be considered as acceptable in this scenario. This change in confidence level makes a few more reductions of crashes and crash rates to be significant due to the presence of bypass lanes.

Table 7: Summary of Cross-Sectional Study Results at 5% Level

Intersections types	Crash types	Crash frequency		EPDO crash frequency		Crash rates		EPDO crash rates	
		Reduction	Significant	Reduction	Significant	Reduction	Significant	Reduction	Significant
3-legged intersections	300 ft.	YES	NO	YES	NO	YES	NO	NO	NO
	Intersection-related	YES	NO	YES	NO	YES	NO	NO	NO
4-legged intersections	300 ft.	YES	YES	YES	YES	YES	YES	YES	YES
	Intersection-related	NO	NO	NO	NO	NO	NO	NO	NO

Calculated CMFs less than 1 also demonstrated the expected reduction in crashes after adding bypass lanes at unsignalized rural intersections. Results obtained using CMF is much clearer in regard to the benefits of bypass lanes, in comparison to t-test results. By considering all analysis results, the overall conclusion of this study is that bypass lanes are beneficial in terms of improving safety and helpful in reducing crashes and crash rates in almost all cases and circumstances considered in this study.

Table 8: Summary of Cross-Sectional Study Results at 10% Level

Intersections types	Crash types	Crash frequency		EPDO crash frequency		Crash rates		EPDO crash rates	
		Reduction	Significant	Reduction	Significant	Reduction	Significant	Reduction	Significant
3-legged intersections	300 ft.	YES	YES	YES	NO	YES	NO	NO	NO
	Intersection-related	YES	NO	YES	NO	YES	NO	NO	NO
4-legged intersections	300 ft.	YES	YES	YES	YES	YES	YES	YES	YES
	Intersection-related	NO	NO	NO	NO	NO	NO	NO	NO

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Modeling the Transport Infrastructure-Growth Nexus in the United States

by Junwook Chi and Jungho Baek

The rising government funding in transport infrastructure has sparked political and academic debates on the economic impacts of transport infrastructure investment in the United States. Although numerous empirical studies have examined the transport infrastructure-growth nexus, existing literature has mixed conclusions of the economic effects of expanding transport infrastructure. The main objective of this paper is to assess the short- and long-run impacts of transport and non-transport public infrastructure on economic growth to provide an implication of the effectiveness of these fiscal policy tools in the short- and long-term. For this purpose, we employ a modern autoregressive distributed lag (ARDL) approach to explore the dynamic relationships among transport infrastructure, non-transport public infrastructure, private capital, labor hours, GDP, and exports. In the long run, we find that a bidirectional relationship exists between transport infrastructure and GDP, suggesting that expanding transport infrastructure improves aggregated economic output, and enhanced economic output increases public investment in transport infrastructure. However, the magnitude of the impact of transport infrastructure on GDP is smaller than that of non-transport public infrastructure, implying that non-transport infrastructure investment is a more effective long-term fiscal stimulus than expanding transport infrastructure.

INTRODUCTION

Public investment in transport infrastructure is often used as a form of fiscal stimulus in the United States. On February 26, 2014, President Obama announced $600 million of transportation funding and outlined his vision of a $302 billion, four-year surface transportation reauthorization proposal. Approximately $63 billion will be used to fill the funding gap in the Highway Trust Fund. His vision includes creating jobs and improving the U.S. economy and private investment, while also increasing access to jobs and U.S. exports (White House 2014). According to the Federal Highway Administration (2014), public investment in highway and street infrastructure has grown to $78.42 billion in 2012, more than a 103% increase over 1960 ($38.49 billion). The rising government spending on transport infrastructure has raised political and academic debates on the economic impacts of expanding transport infrastructure investment in the U.S.

Several empirical studies have examined the effectiveness of transport infrastructure investment as a fiscal stimulus on economic growth, referred to as the *transport infrastructure-growth nexus*. A group of studies support the traditional notion that an increase in transport infrastructure investment improves economic growth through an increase in aggregate productivity (e.g., Munnell 1992; Garcia-Mila and McGuire 1992; Bajo-Rubio and Sosvilla-Rivero 1993; Fernald 1999; Ozbay et al. 2003 and 2007; Jiwattanakulpaisarn et al. 2010; Pereira and Andraz 2012; Pradhan and Bagchi 2013; Agbelie 2014; Blonigen and Cristea 2015). Pradhan and Bagchi (2013), for example, provide empirical evidence of bidirectional causal relationship between road transportation and economic growth. Jiwattanakulpaisarn et al. (2010) use panel data from 48 U.S. states and find that highway infrastructure investment can have a positive effect on state employment growth. Pereira and Andraz (2012) use output, employment, and highway investment data and find a positive impact of highway investment on regional economy at both aggregate and state levels.

Another group of studies, on the other hand, provide evidence that government spending on transportation infrastructure has an insignificant or little impact on growth (e.g., Garcia-Mila et al.

1996; Evans and Karras 1994; Holtz-Eakin 1994; Chandra and Thompson 2000; Berechman et al. 2006; Padeiro 2013) Chandra and Thompson (2000), for example, find that the effect of expanding public infrastructure (i.e., interstate highways) on economic activity remains unclear due mainly to the so-called "leakages" effect of investment across regions and industries. Berechman et al. (2006) also show that a public investment in highway infrastructure indeed produces strong spillover effects relative to space and time, thereby raising questions about the validity of the results obtained by previous studies.

Although the literature on the transport infrastructure-growth nexus is fairly large, several questions still remain unsolved. First, due to mixed conclusions on the transport infrastructure impacts, there is a lack of information on evaluating the effectiveness of government spending on *transport* and *non-transport infrastructure* (e.g., schools, hospital, and other public buildings) as an economic stimulus; hence, it is difficult for policymakers to determine which fiscal policy tool is more effective to boost the economy. Second, given that the economic impacts of infrastructure investment may become substantially weaker over time (Berechman et al. 2006), little attention has been paid to examination of both the short- and long-run effects together. Third, the direction of the causal relationship has not been well documented in existing literature (Jiwattanakulpaisarn et al. 2010). If transport infrastructure and economic growth are cointegrated, there must be Granger causality in at least one direction. The Granger causality test can be used to investigate whether one variable causes the other variable, which will improve understanding of the directional effects (e.g., unidirectional or bidirectional causality). Yet, only a few studies have attempted to examine the causal effect of transport investment on economic growth and the possible reverse impact of economic growth on public capital development. Tong et al. (2014), for example, show that the reverse causality from GDP to transport infrastructure is present, and transport infrastructure Granger causes exports in the U.S. However, their study only focused on the short-run dynamics based on the concept of Granger causality.

The main objective of this paper is to expand the scope of the previous work by re-examining the effects of various macroeconomic aggregates and transport infrastructure variables on economic growth with an enhanced time series econometrics – an autoregressive distributed lag approach to cointegration (referred to as the ARDL model). Empirical focus is on examining the short- and long-run relationships among *transport infrastructure*, *non-transport public infrastructure*, private capital, labor, economic output (GDP), and exports in the U.S. The ARDL model has several advantages in contrast to other conventional cointegration methods. It is efficient to determine cointegration relationship even if the sample size is small and finite. In addition, it can be applicable irrespective of whether the underlying regressors are *I(0)*, *I(1)*, or mutually cointegrated as opposed to other cointegration techniques such as the Johansen and Juselius approach (Johansen and Juselius 1992) assuming that all variables must be integrated at the same order. More importantly, there is no study that simultaneously analyzed the short- and long-run relationships among the selected variables in the existing literature. Through a simple linear transformation, the error-correction model (ECM), which is derived from the ARDL model, simultaneously estimates short- and long-run coefficients. In this paper, the ARDL is the cointegrating (long-run) relationship to determine directional relationships among the selected variables.[1] This dynamic approach will shed new light on dynamic interrelationships among transport and non-transport infrastructure investment and economic growth, and will contribute to the literature of transportation economics. The remaining sections present the model, ARDL modelling, data, empirical findings, and concluding remarks.

THE MODEL

It should be emphasized at the onset that, because the transport infrastructure and economic growth relationships typically estimated in the existing literature are not driven by any particular economic model, little theoretical guidance is available for the correct specification. In tackling this issue, therefore, we rely on an analytical framework addressed by Gillen (1996). This formulates the aggregate production model in which economic output (GDP) in a country typically responds to changes in capital stock of transport (T) and non-transport (G) infrastructure, private capital (K), and labor (L). Since exports increase economic growth, in the empirical model used here we extend the standard model to include exports as is done in Tong, Yu, and Roberts (2014).

In examining the transport infrastructure-growth nexus empirically, we use the ARDL approach developed by Pesaran et al. (2001). To explain the ARDL procedure, we start with a vector of two variables z_t, where $z_t = (y_t, x_t')'$, y_t is the dependent variable and x_t is a vector of regressors. Following Pesaran et al. (2001), we then formulate the conditional error correction model (ECM) of interest as follows:

$$(1)\quad \Delta y_t = \alpha_0 + \pi_y\, y_{t-1} + \pi_{yx.x} x_{t-1} + \sum_{i=1}^{p} \delta_i \Delta y_{t-i} + \sum_{j=0}^{q} \gamma_j \Delta x_{t-j} + \theta w_t + u_t$$

where α_0 is the constant; π_{yy} and π_{yx} are the long-run parameters; δ_i and γ_i are the short-run parameters; and w_t is a vector of exogenous variables (i.e., dummy variables). The ARDL procedure for identifying for the existence of a long-run relationship between y_t and x_t is through the testing of the joint significance of the lagged levels of variables (y_{t-1} and x_{t-1}) in Equation (1). This is equivalent to testing the null hypothesis of $H_0 : \pi_{yy} = 0, \pi_{yx.x} = 0'$ (no cointegration) against the alternative hypothesis of $H_0 : \pi_{yy} \neq 0, \pi_{yx.x} \neq 0'$, using the standard F-test. Narayan (2005)[2] provides two sets of critical values covering all possible classification of the variables into $I(0)$ or $I(1)$ processes; for example, the upper bound values assume that all the variables are $I(1)$, and the lower bound values assume that they are $I(0)$. If the computed F-statistic falls outside the critical value bounds, a conclusive decision can be made; for example, if the computed F-statistic is higher (lower) than the upper (lower) bound of critical values, then the null of no cointegration can (cannot) be rejected. If the F-statistic falls inside these bounds, inference is inconclusive.

DATA AND EMPIRICAL PROCEDURE

Data

Annual data between 1960 and 2012 are collected to estimate Equation (1). The time span is dictated by availability of the data for every series. Following Tong et al. (2014), highway and street infrastructure (T_t) is used as a proxy for transport infrastructure investment. In 2012, for example, the highway and street infrastructure was \$3.26 trillion, accounting for approximately 26% of total government fixed assets (\$12.52 trillion) (BEA). The value of the net stock of government fixed assets (excluding national defense and highways and streets) (G_t) is used as proxy for non-transport capital of the U.S. government. The value of private nonresidential-fixed assets (including equipment, software, and structures) (K_t) is used as proxy for private capital in the U.S. The gross domestic product (GDP_t) is used as a proxy for economic output. The value of exports (EX_t) is used to measure the impact of transport investment on trade. The labor (L_t) represents the combined hours of domestic full-time and part-time employees. All variables are collected from the Bureau of Economic Analysis, U.S. Department of Commerce (BEA 2014). The GDP deflator (2009=100) obtained from the BEA is used to derive real values. Table 1 summarizes our data. Natural logarithms of the variables are used in the analysis. Figure 1 shows logarithms and first differences of the variables. As seen in the figure, transport infrastructure investment has consistently increased since 1960. The recent increase in government funding in transport infrastructure has sparked debates on the economic impacts of transport infrastructure investment and it is the empirical focus of this study.

Table 1: Descriptive Statistics of Variables (1960-2012)

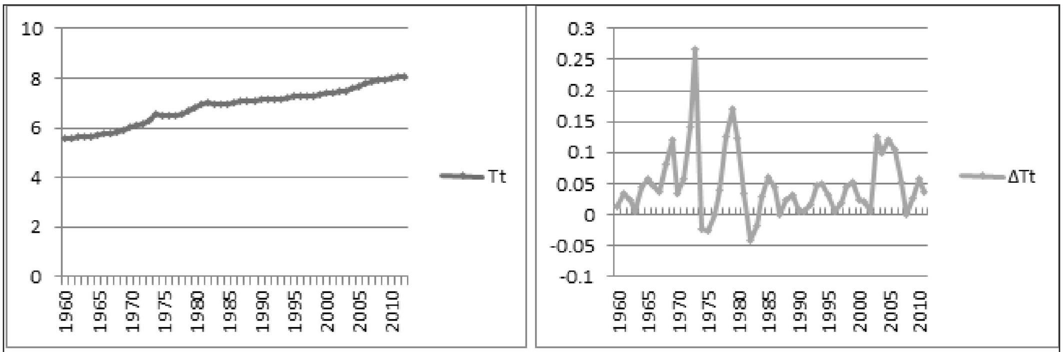
Variable	Description	Mean	Standard Deviation	Minimum	Maximum
T_t	Highway and street infrastructure (billions of 2009 dollars)	1,213	810	264	3,199
G_t	Non-transport public capital (billions of 2009 dollars)	2,978	2,045	508	7,406
K_t	Private capital (billions of 2009 dollars)	8,063	5,186	1,648	17,830
L_t	Labor hours (millions of hours)	180,790	38,927	114,607	237,050
GDP_t	Gross Domestic Product (billions of 2009 dollars)	8,563	3,882	3,109	15,369
EX_t	US exports (billions of 2009 dollars)	709	590	79	2,107

Empirical Procedure

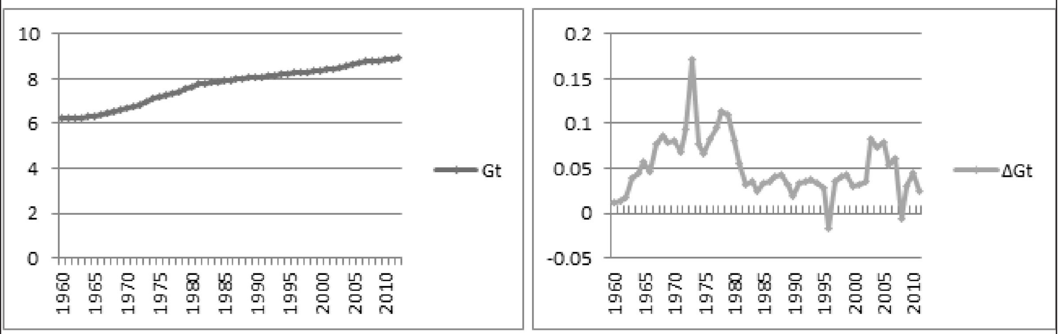
As mentioned earlier, unlike conventional applications of cointegration analysis (i.e., Johansen 1988), the ARDL can be applicable even when it is not known with certainty whether the underlying regressors are *I*(1) or *I*(0); hence, this method does not require a unit root test to determine the order of integration each variable exhibits. Ouattara (2004), however, proves that the bounds test cannot be applicable to *I*(2) processes. Before implementing the ARDL modeling, therefore, it is necessary to conduct a unit root test to make sure that none of the variables are *I*(2) variables.

To determine the order of integration in the selected variables, we employ the Dickey Fuller Generalized Least Squares (DF-GLS) and the Phillips-Perron (PP) unit root tests (Table 2). The results show that for T_t, G_t, $L_{t,}$ $GDP_{t,}$ and EX_t, the null hypothesis of nonstationarity cannot be rejected for the level, while it can be rejected for the first difference of the variables at least at the 10% significance level, indicating they are *I*(1) variables. We find the mixed findings between the two unit root tests for K_t, indicating that these variables can be *I*(0) or *I*(1) processes. From these findings, therefore, we conclude that all the variables must be either *I*(0) or *I*(1) processes and the ARDL can be pursued on them safely.

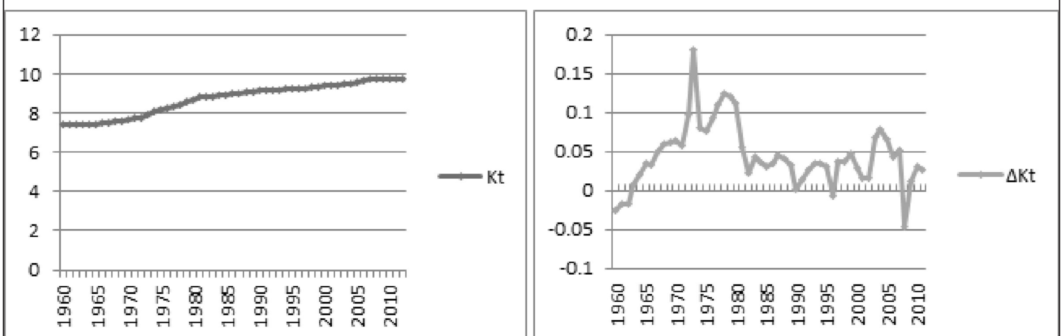
Figure 1: Logarithms and First Differences of the Variables from 1960 to 2012



Logarithms and first differences of T_t

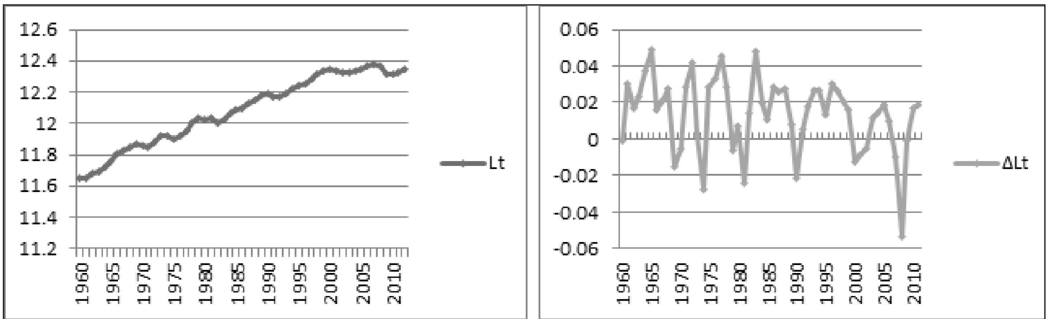


Logarithms and first differences of G_t

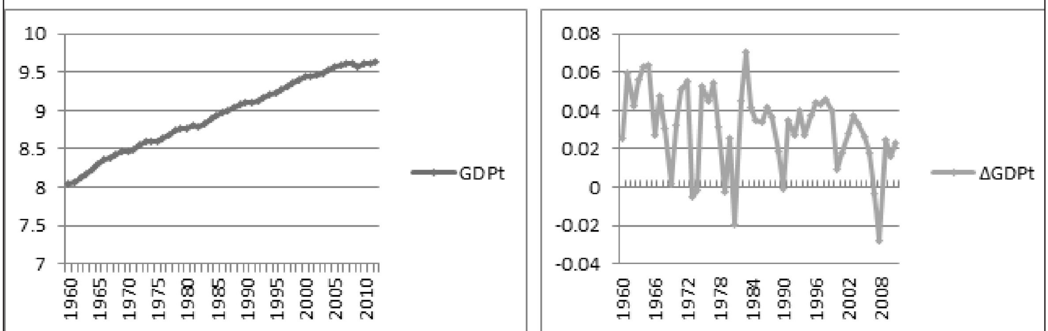


Logarithms and first differences of K_t

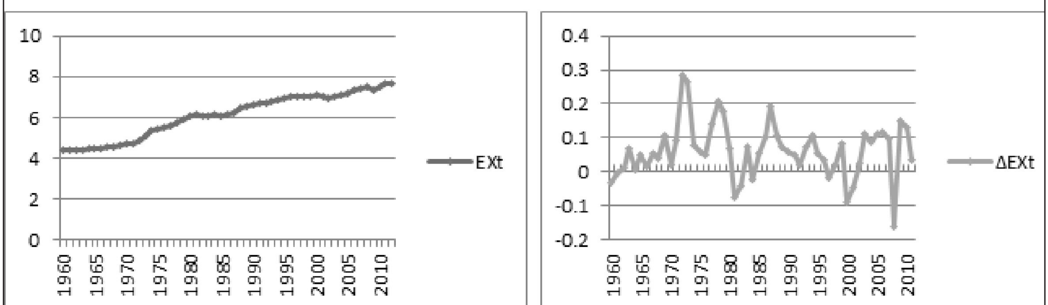
(Figure 1: continued)



Logarithms and first differences of L_t



Logarithms and first differences of GDP_t



Logarithms and first differences of EX_t

Table 2: Results of Unit Root Tests

Variables	Dickey Fuller GLS (DF-GLS) test		Phillips-Perron (PP) test		Decision
	Level	First difference	Level	First difference	
T_t	-2.077	-4.634**	-0.581	-4.443**	I(1)
G_t	-1.111	-3.005*	-1.419	-3.133**	I(1)
K_t	-1.578	-3.175*	-2.674*	-	I(1)/I(0)
L_t	-0.738	-5.411**	-2.165	-4.759**	I(1)
GDP_t	-1.267	-4.890**	-2.560	-4.924**	I(1)
EX_t	-2.164	-3.912**	-0.582	-4.846**	I(1)

Notes: ** and * denote rejection of the null hypothesis of a unit root at the 5% and 10% level, respectively; Schwert criterion is used to determine the lag length for DF-GLS tests; For PP test, the 5% and 10% critical values are -2.928 and -2.599, respectively; The PP test uses Newey-West standard error to account for serial correlation.

As discussed above, Pesaran et al. (2001) recommend implementing an F-test to determine the existence of a long-run (cointegration) relationship among the variables. If the lagged-level variables – that is, $H_0 : \pi_{yy} = 0, \pi_{yx.x} = 0'$ in Equation (1) - are jointly significant, the null hypothesis of non-existence of the long-run relationship can be rejected. For this, a maximum of six lags is imposed on each first differenced variable and the Schwarz Bayesian Criterion (SBC) is used to select the optimal lags.[3] The results show that the calculated F-statistics are statistically significant at the 5% level when using $T_{t,}$ G_t, and GDP_t as the dependent variables (Table 3). On the other hand, the calculated F-statistics using $K_{t,}$ $L_{t,}$ and EX_t as the dependent variables are not statistically significant at the 5% level.[4] This suggests there is a long-run relationship among the variables only when $T_{t,}$ G_t, and GDP_t are used as dependent variables; hence, these three equations are used to estimate the short- and long-run relationships among the variables.

Table 3: Results of Bounds Testing Procedure

Dependent variable	Cointegration hypothesis	F-statistic
$\boldsymbol{T_t}$	$F(T_t \mid EX_t, GDP_t, G_t, K_t, L_t)$	4.855**
$\boldsymbol{G_t}$	$F(G_t \mid T_t, GDP_t, EX_t, K_t, L_t)$	18.291**
$\boldsymbol{K_t}$	$F(K_t \mid T_t, GDP_t, G_t, EX_t, L_t)$	1.919
$\boldsymbol{L_t}$	$F(L_t \mid T_t, GDP_t, G_t, K_t, EX_t)$	2.558
$\boldsymbol{GDP_t}$	$F(GDP_t \mid T_t, EX_t, G_t, K_t, L_t)$	5.928**
$\boldsymbol{EX_t}$	$F(EX_t \mid T_t, GDP_t, G_t, K_t, L_t)$	1.653

Notes: ** and * denote rejection of the null hypothesis of a unit root at the 5% and 10% level, respectively; The order of lag is based on Schwarz Bayesian Criterion; The lower and upper critical values of Narayan (2005) at the 5% level (10% level) are 3.442 and 4.690 (2.927 and 4.068), respectively.

EMPIRICAL RESULTS

Results of the Long-run Analysis

Table 4 reports our key estimation results of the long-run analysis, where the dependent variables are represented in turn by GDP*,* transport infrastructure, and non-transport infrastructure as discussed earlier. For the GDP (GDP_t) equation, the estimated coefficient on the transport infrastructure is statistically significant at the 5% level and has a positive sign, indicating that expanding government investment on transport infrastructure indeed has a beneficial effect on economic growth in the long run. The coefficient of the non-transport capital has a significantly positive effect on GDP, suggesting that an increase in spending on non-transport infrastructure increases growth. The coefficients of the private capital and U.S. exports carry positive signs and are highly significant, implying that these factors are also important in affecting economic growth in the long run. The results reveal the importance of investment in the private sector as a key driving force of economic growth. However, the coefficient of labor is not statistically significant even at the 10% level, indicating that labor hours have little effect on economic growth in the U.S.

For the transport infrastructure (T_t) equation, the coefficient on the non-transport infrastructure is statistically significant at the 5% level and carries a positive sign, indicating that improved non-transport infrastructure, such as health care and education, tends to increase government spending on transport infrastructure in the long run. The estimated effect of the GDP is positive and highly significant, suggesting that economic growth improves public investment on transport infrastructure in the long run. Combined with the results from the GDP equation, this finding shows a significant two-way (bidirectional) relationship between transport infrastructure and economic growth in the U.S. In other words, U.S. economic growth is significantly affected by government investment on transport infrastructure, and transport infrastructure is also affected by U.S. economic growth. This finding contrasts with Tong et al. (2014) who find a unidirectional causation from economic growth to transport infrastructure.[5] The coefficient of labor carries a negative sign and is highly significant, implying that an increase in work hours by employees in domestic industries tends to reduce the need for government spending on transport infrastructure.

Finally, for the non-transport infrastructure (G_t) equation, the coefficient of the GDP is statistically significant at the 5% level and carries a positive sign, indicating that economic growth tends to improve government spending on non-transport infrastructure in the long run. In addition, the coefficient of the labor is highly significant and carries a negative sign, suggesting that an increase in work hours in domestic industries reduces government spending on non-transport infrastructure. Notice that labor is found to be highly significant in the transport and non-transport infrastructure equations, suggesting that labor conditions in the U.S. have a substantive effect on investment in public infrastructure. In other words, the U.S. government appears to increase an investment in both transport and non-transport infrastructures to stimulate economic growth during periods employment rates and works hours. However, the coefficients of the transport infrastructure and exports are statistically insignificant at the 10% level, indicating that they have little effect on U.S. non-transport infrastructure in the long run. Consistent with the findings of Voss (2002) and Narayan (2004), this study finds a lack of evidence of significant crowding in between private and public investment. Private capital has a significant positive effect on non-transport infrastructure, but it has an insignificant impact on transport infrastructure. A possible explanation for the insignificant relationship between private and public capital is that an increase in private capital investment can have both positive and negative effects on public capital investment, which may lead to the insignificant impact (i.e., zero net effect). A rise in private investment can encourage an increased allocation of resources toward public capital formation to stimulate the economy. However, it also can make a public infrastructure investment less attractive if expanding private capital reduces the need for government spending on infrastructure (substitutability between private and public stock).

Table 4: Results of Estimated Long-run Coefficients

Variables	GDP_t Equation	T_t Equation	G_t Equation
T_t	0.551** (0.195)	-	-0.188 (0.240)
G_t	1.023** (0.346)	1.958** (0.384)	-
K_t	0.978** (0.320)	0.368 (0.287)	0.903** (0.161)
L_t	0.578 (0.417)	-1.294** (0.501)	-1.835** (0.824)
GDP_t	-	0.929** (0.319)	1.464** (0.541)
EX_t	0.187* (0.112)	-0.016 (0.076)	-0.098 (0.080)

Notes: ** and * denote rejection of the null hypothesis at the 5% and 10% level, respectively; Parentheses are standard errors.

Results of the Short-run Analysis

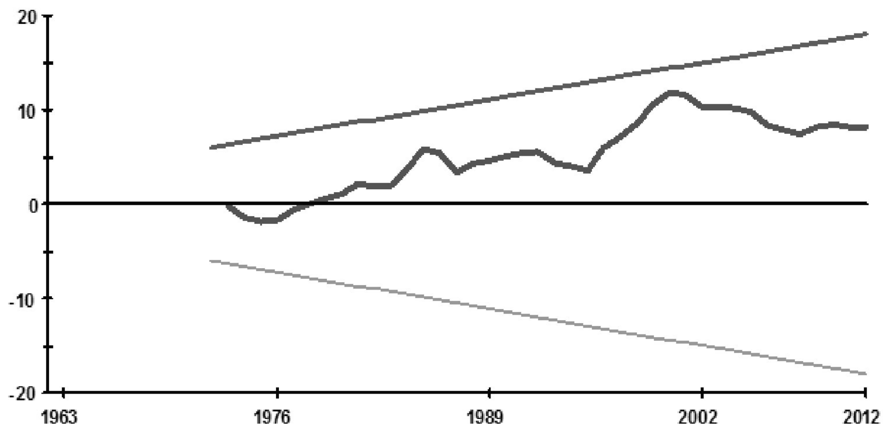
We now turn our attention to the short-run dynamics, which are estimated by coefficient estimates of first-differenced variables in Equation (1) (Table 5). The results of the GDP equation show that the (lagged) coefficients of transport capital, private capital, labor, and exports are statistically significant at least at the 10% level, indicating that these variables are important determinants of U.S. growth in the short run. However, the coefficient of the non-transport infrastructure is not statistically significant even at the 10% level, showing a lack of significant relation between non-transport infrastructure and growth. This further suggests that government spending on non-transport infrastructure may not be an effective fiscal tool to deal with economic downturns in the short run.

The results of the transport infrastructure equation show that the non-transport infrastructure, labor, and GDP have significant effects on transport infrastructure in the short run. These findings are consistent with those of long-run analyses. Finally, the results of the non-transport infrastructure equation show that the private capital and GDP have a significant short-run effect on non-transport capital. Unlike the long-run results, the transport infrastructure is found to have a significant effect on the non-transport infrastructure in the short run.

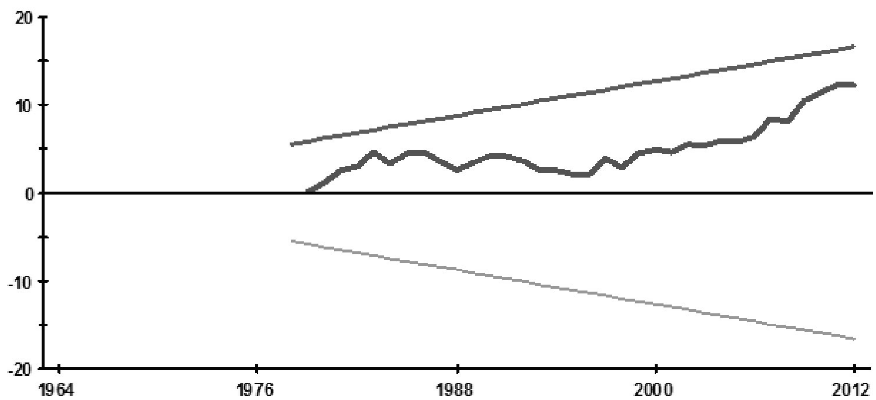
It is important to note that the coefficients of the error-correction terms (EC_{t-1}) carry negative signs and are highly significant for all three equations. This further provides evidence of a stable long-run relationship among the selected variables, thereby justifying our ARDL modeling. We employ CUSUM and CUSUMSQ tests to the residuals to check the stability and robustness of the estimated relationship. These tests show a plot of the recursive residuals and the pair of critical lines at the 5% significance level. Figure 2 illustrates that the CUSUM and CUSUMSQ statistics fall within the two critical lines, suggesting that the parameter estimates are stable. Finally, the estimated ARDL model passes all the diagnostic tests (Table 5).

Figure 2: Test Results of Stability and Robustness of the Estimated Relationship (CUSUM and CUSUMSQ Tests)

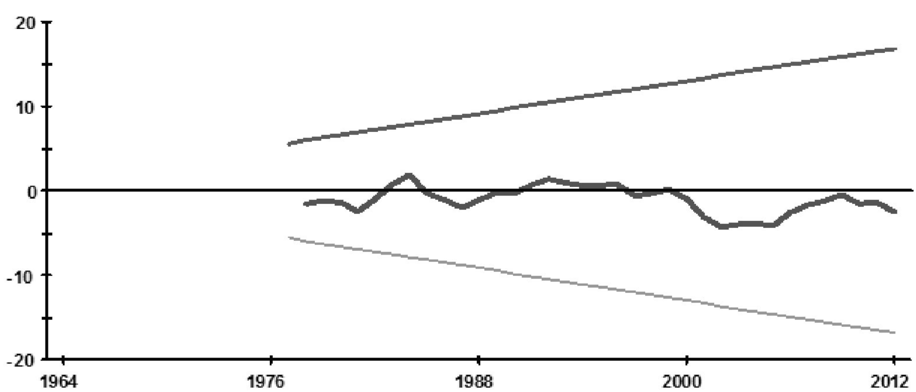
I. Plot of cumulative sum of recursive residuals (CUSUM)



(a) GDP_t Equation



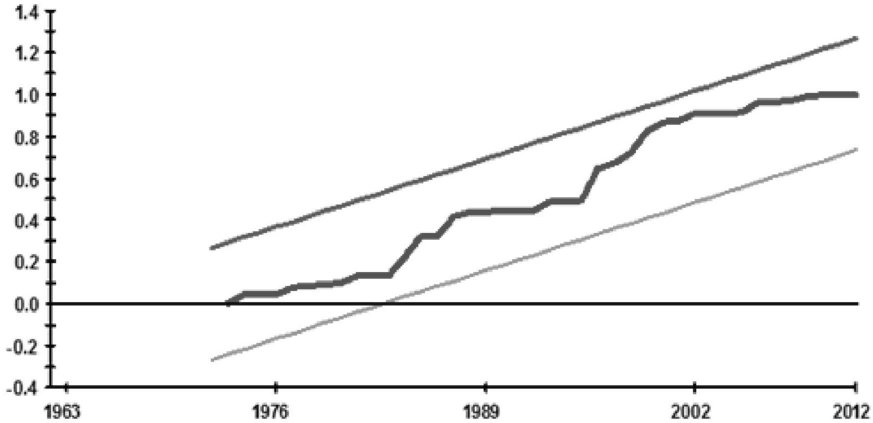
(b) T_t Equation



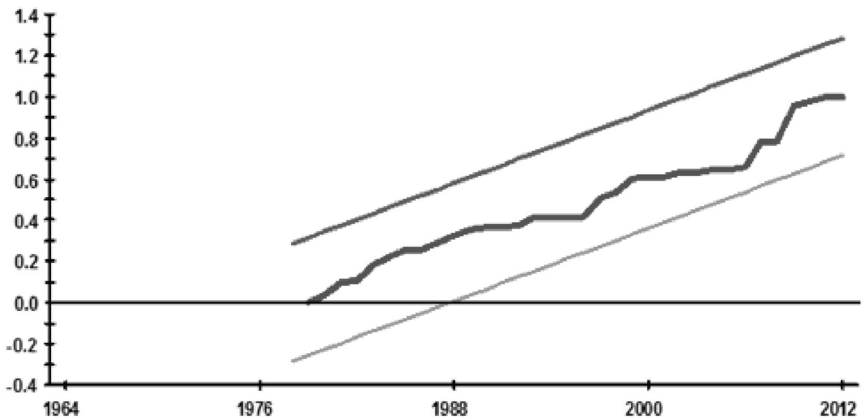
(c) G_t Equation

(Figure 2: continued)

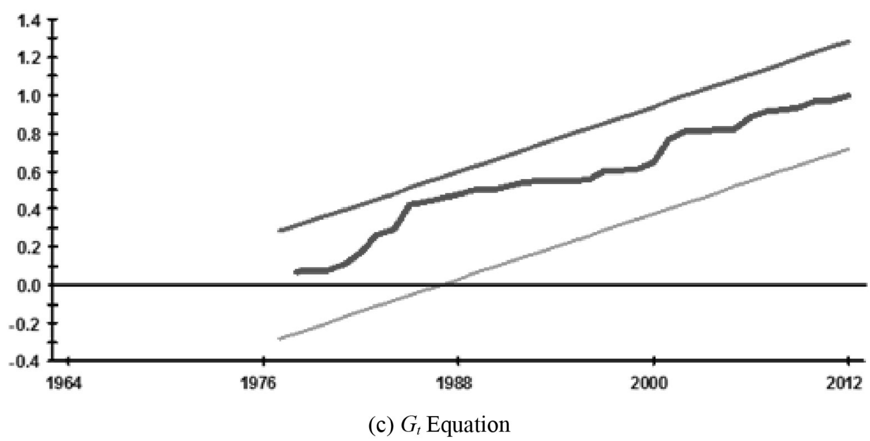
II. Plot of cumulative sum of squares of recursive residuals (CUSUMSQ)



(a) GDP_t Equation



(b) T_t Equation



(c) G_t Equation

Table 5: Results of Estimated Short-run Coefficients

Variables	Equation	Equation	Equation
ΔT_t	0.058* (0.021)	-	0.026 (0.032)
ΔT_{t-1}		0.462** (0.131)	-0.058** (0.025)
ΔT_{t-2}		0.361** (0.119)	
ΔG_t	-0.060 (0.043)	0.988* (0.255)	-
ΔK_t	0.103** (0.031)	0.341 (0.325)	0.843** (0.048)
ΔL_t	0.950** (0.076)	-0.653** (0.294)	0.050 (0.152)
ΔGDP_t	-	-0.369 (0.285)	-0.302** (0.137)
ΔGDP_{t-1}	-0.348** (0.066)	1.299** (0.309)	0.256** (0.074)
ΔGDP_{t-2}		0.666** (0.264)	
ΔEX_t	-0.019* (0.010)	-0.008 (0.038)	-0.013 (0.009)
EC_{t-1}	-0.105** (0.030)	-0.504** (0.109)	-0.136** (0.046)
$F(4)$ for serial correlation	1.667 [0.178]	0.410 [0.609]	1.776 [0.158]
$\chi^2(1)$ for heteroscedasticity	0.168 [0.682]	0.083 [0.772]	0.032 [0.857]
$\chi^2(2)$ for normality	0.056 [0.972]	0.411 [0.814]	3.017 [0.221]

Notes: ** and * denote rejection of the null hypothesis at the 5% and 10% level, respectively; The Lagrange multiplier (LM) test statistic of residual serial correlation is used (the null of no autocorrelation against lag length 4); Heteroskedasticity test is based on the regression of squared residuals on squared fitted values (the null is homoskedasticity); Normality test is based on a test of skewness and kurtosis of residuals (the null is a normal distribution); *P*-values for serial correlation, heteroscedasticity, and normality tests are in brackets.

CONCLUSIONS

This paper examines the short- and long-run relationships among transport infrastructure, non-transport public infrastructure, private capital, labor, economic output (GDP), and exports in the U.S. For this, an ARDL approach is applied to annual data over 1960 to 2012. Our key findings are summarized as follows: 1) a stable long-run cointegration relationship exists when using transport infrastructure, non-transport public infrastructure, and GDP as the dependent variables; 2) both transport and non-transport infrastructure investments have a positive long-run impact on economic growth; 3) economic growth, non-transport public infrastructure, labor are key determinants of transport infrastructure investment in the long run; and 4) economic growth, private capital, and labor are the long-run determinants of non-transport infrastructure.

Several policy implications can be derived from our empirical findings. First, we provide empirical evidence that there is a bidirectional relationship between transport infrastructure and growth in the long run, indicating that expanding transport infrastructure increases aggregated economic output, and enhanced economic output increases public investment in transport infrastructure. This implies that improving transport systems can be a stimulant to achieve economic growth in the U.S. Furthermore, as the U.S. economy grows, there will be a growing need for better transport infrastructure. According to the U.S. Congressional Budget Office (2014), real GDP is forecasted to grow by 3.4% in 2015 and by 2.7% in 2017, which would require a more efficient national transportation network and better accessibility.

Second, our findings show that the magnitude of the impact of non-transport public infrastructure (+1.023) is greater than that of transport infrastructure (+0.551) on economic output in the long run. Consistent with Cullison (1993), we find evidence that expanding non-transport public infrastructure has a relatively large economic impact compared with expanding transport infrastructure capital. Thus, expanding non-transport infrastructure can be a more effective long-term fiscal stimulus, compared with expanding transport infrastructure. As noted by Talley (1996) and Tong et al. (2014), substantial transport infrastructure already exists in the U.S., implying that further investment in transport infrastructure can have little impact on economic growth and development. The U.S. economy has recovered from the economic recession of the 2008 financial crisis, but annual economic growth has been only about 2% on average, which is still well below its historical average (Appelbaum 2014). Based on the findings of this paper, more resources should be allocated to non-transport public capital than transport infrastructure to enhance the effectiveness of fiscal policy and stimulate the stagnant economy.

Finally, the impacts of public infrastructure investment on the GDP are found to vary between long and short run. For non-transport public infrastructure, the results reveal that its long-run impact is positive and significant, while its short-run effect is found to be insignificant. These findings suggest that government spending on public infrastructure could be a more valuable fiscal policy tool to achieve long-term economic growth, rather than a short-term economic stimulant.

This study could be extended in several directions. Future research could investigate the transport infrastructure-growth nexus by taking into account stock and flow approaches. For example, the economic effects of transport infrastructure between the two approaches could be analyzed and compared to provide various implications. Although the scope of this study is limited to transport and non-transport infrastructure, the short- and long-run relationships among public infrastructure, non-infrastructure, and macroeconomic variables could be further investigated. By using this approach, the effectiveness of infrastructure investment at a country level can be evaluated.

Endnotes

1. Although the issue of stock or flow approach is well known in the analysis of the infrastructure-growth nexus, following the relevant studies on the issue, we employ the stock approach in our empirical modeling.

2. Note that the method using the two sets of critical values is first proposed by Pesaran et al. (2001) and they are widely used in literature. However, Pesaran's critical values are based on large sample sizes (e.g., 500-1,000 observations) and cannot be applied for the small sample size. Due to the fairly small samples (53 observations), Narayan's critical values for small sample size are employed in this study.

3. The optimal lags for the equation are $ARDL_{(2,0,0,0,1,0)}$. For and equations, this study uses the optimal lags of $ARDL_{(3,0,3,0,0,2)}$ and $ARDL_{(1,2,0,2,1,1)}$, respectively.

4. The upper critical value at the 5% level is 4.690. If the computed *F*-statistic lies above (below) the upper (lower) critical value, the selected variables are (not) said to be cointegrated.

5. The mixed results on the direction of causation may be derived from the methods. Tong et al. (2014) draw their conclusion based on Granger causality test using VAR models, which mainly focus on the short-run dynamics. In contrast, we use a modern ARDL approach which allows for a simultaneous analysis of the short- and long-run dynamics. Using ARDL approach, we identify cointergration vectors and determine the direction of causation among the variables.

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Sturdy Inference: A Bayesian Analysis of U.S. Motorcycle Helmet Laws

by Richard Fowles and Peter D. Loeb

Motorcycle related fatalities continue to be a major concern for public health officials, economists, and policy makers interested in such matters. In 2006, 3% of all motor vehicles registered in the United States were 2-3 wheelers (motorcycle type vehicles), while riders of these vehicles accounted for 11% of vehicle related deaths. Such a disproportionate number of fatalities associated with motorcycles is certainly grounds for concern.

Most studies of motorcycle fatalities attribute deaths to the avoidance of wearing helmets and the lack of helmet laws, speed, and alcohol usage. This study makes use of a rich panel data set for the period 1980 to 2010 by state and the District of Columbia to examine these factors and others. It is the first study to differentiate between the effects of universal and partial helmet laws on motorcycle fatalities. It also accounts for the effects of cell phone use, alcohol consumption, and suicidal propensities on these crashes after adjusting for a whole host of socioeconomic and driving related factors. The analysis is conducted using a new Bayesian technique, which examines the sturdiness of regression coefficients. This new method uses statistics referred to as S-values that addresses both estimation and model ambiguity. Results indicate that the variables we focus on, i.e., cell phones, alcohol consumption, and helmet laws affect motorcycle fatalities. Further, universal helmet laws appear to have a larger effect on such fatalities than partial helmet laws.

INTRODUCTION

Motorcycle fatalities continue to be of concern to public health officials, economists, and policy makers. It is estimated that motorcyclists have a risk of death in a crash (measured as fatalities per vehicle mile) 34 times higher than experienced in other motor vehicles.[1] In 2006, motorcycles (2-3 wheel vehicles) accounted for 3% of the all motor vehicles registered in the United States. However, motorcycle crashes accounted for 13.7% of motor vehicle crashes that same year.[2] Looking at national trends, one can see that motorcycle fatalities trended downward from 5,144 in 1980 to 2,116 in 1997. The trend then reversed, increasing to 5,312 in 2008. In 2009, fatalities decreased to 4,469 but then started increasing again. By 2011, the number of cyclists killed was 4,612.[3]

The causes of motorcycle fatalities have been attributed to not using helmets and the lack of universal or partial helmet laws, speeding, alcohol, and poor body protection, among others. A great deal of research has gone into estimating the marginal contributions of these factors. However, the results of these studies have not always been convincing or have resulted in significant different estimates of the marginal effects of these factors.[4]

This paper examines the determinants of motorcycle fatalities using traditional econometric models and a new Bayesian technique developed by Leamer (2014, 2016). This new technique extends the analysis presented by Fowles et al. (2015) to examine the sturdiness of regression coefficients with what Leamer refers to as S-values. The analysis employs a rich panel data set by state and the District of Columbia for the period 1980 through 2010.

The models examined not only consider the traditional factors found in many econometric studies, but this paper is one of the first to extend those models to include the effects of cell phone usage and suicidal propensities to motorcycle crashes.[5] Both these latter two factors are recent additions to variables thought to influence motor vehicle crashes and have been found significant in explaining motor vehicle crashes overall as seen, for example, in Blattenberger et al. (2012, 2013).[6] In addition, unlike other studies, this research addresses the relative importance of universal helmet laws versus partial helmet laws in reducing motorcycle fatalities relative to a no helmet law requirement.[7] As such, the paper focuses attention on five factors, i.e., cell phone, two helmet law, and alcohol effects as well as suicidal propensities after adjusting the models for various combinations of normalizing factors.

BACKGROUND

The Focus Variables

The 1966 Highway Safety Act attempted to address safety conditions on U.S. roadways. The act required states to implement a universal helmet law by imposing the risk of reducing up to 10% of their federal highway construction funds for noncompliance. The imposition of a helmet law was expected to increase helmet usage in that head injuries are the most common cause of motorcyclist deaths. The act resulted in 48 states adopting some measure of the law by 1976. However, there was strong opposition to this law by such groups as the American Motorcycle Association. They argued that the act violated a citizen's right of choice. Alternative arguments against requiring the use of helmets were that they were heavy for the riders, impaired vision, and limited hearing. The outcome of these disagreements was the passage of the 1976 Federal Highway Safety Act, which revised the requirement that all riders wear helmets to requiring only those under the age of 18 to wear helmets. Approximately 25% of the states then either abolished or reduced the requirements of the universal helmet law by 1980. Another attempt to increase helmet usage was through the Intermodal Surface Transportation Act of 1991, which provided grants to states that imposed helmet and seatbelt laws. However, this law was repealed in 1995.[8]

Research efforts to establish the efficacy of helmet laws were generally of two types. One method was to compare motorcycle fatalities (and injuries) before and after a state imposed some form of helmet law or, alternatively, the use of regression models to estimate the effect of helmet laws on fatalities.

Hartunian et al. (1983) examined the effect of the repeal of the federal helmet law on motorcycle fatalities. They found an increase in fatalities among the 28 states that repealed or weakened their helmet laws as well as a cost imposed on society of at least \$180 million. Graham and Lee (1986) found a 12% to 22% decrease in motorcycle fatalities when a helmet law was in effect. However, they also found some risk-compensation behavior so that the increase in fatalities after deregulation of the helmet law was dissipated over time. Sass and Zimmerman (2000), on the other hand, found helmet laws were associated with a 29% to 33% decrease in motorcycle fatalities per capita. Weiss, (1992) in examining head injuries, found that helmet laws decrease such injuries by 42%. French et al., (2009) using panel data for 48 states and the period 1990-2005, found a significant effect of universal helmet laws on motorcycle fatalities. Sass and Leigh, (1991) using a selectivity model, found that states with helmet laws would experience on average a lower fatality rate than states without such a law by less than 1%. This is clearly a very different result than what would have been expected, a priori, from other studies.

The above studies did not attempt to distinguish between the potential life-saving effects of universal helmet laws as compared with partial helmet laws. Rather, the emphasis was placed on the general viability of helmet laws on motorcycle fatality measures. The present study is the first, other than that of Fowles et al. (2015), using different Bayesian techniques, that separates these effects.

Alcohol consumption has almost uniformly been found to have a significant deleterious effect on motor vehicle safety in general. Although this is not a new factor for consideration, it is of such import that it deserves to be focused on. Alcohol effects on overall motor vehicle fatalities have been found using both classical and Bayesian methods as seen in Loeb et al. (2009), Fowles et al. (2010), and Blattenberger et al. (2012), among others.[9] French et al. (2009) did find that beer consumption per capita was positively correlated to motorcycle fatalities in a statistically significant manner.

Blood alcohol concentration (BAC) thresholds measured in terms of grams of alcohol per deciliter of blood (g/dL), have also been examined in the literature regarding the influence of alcohol on motor vehicle crashes in general. For example, Loeb et al. (2009) found some evidence that diminishing the acceptable limits on BAC to designate driving while impaired reduced vehicle fatalities. Motorcycle fatalities seem to correlate similarly with alcohol usage and BAC measures found in general transportation studies. French et al. (2009, p. 831) note that, "An estimated 34% of all motorcyclists who were fatally injured in 2006 had BAC levels above 0.01 g/dL (NHTSA 2008). In addition, it has been demonstrated that motorcycle riders have a lower helmet usage rate if they were drinking as compared to non-drinkers."[10] However, French et al. (2009) did not find a significant effect on motorcycle fatalities when evaluating a BAC limit equal to or less than 0.08.

In addition, studies to address the effects of alcohol on safety have examined the effect of the minimum legal drinking age on motor vehicle crashes. The results from these studies have not been consistent. For example, Sommers (1985) found a negative relationship between legal drinking age and fatality rates while recently, Blattenberger et al. (2012) and Fowles et al. (2010) found fragile results regarding the effect of the minimum legal drinking age on motor vehicle fatalities.[11] Lin and Kraus (2009, p.716) indicate, "The effects of other possible interventions such as a minimal legal drinking age, …, for motorcycle riders have not been examined."

Recently, two additional factors have been examined for their influence on motor vehicle related fatalities. They are the effects of cell phones and suicidal propensities.[12]

It is argued that cell phone usage contributes to motor vehicle fatalities due to its distracting effect on the driver, the reduction of attention spans, and its propensity to increase reaction time. Cell phone subscriptions have increased exponentially since 1985 when there were 340,000 subscribers to more than 310 million in 2010.[13] Not only has the number of cell phones available to the public increased, but so has the propensity to use them for both phone use and texting. Glassbrenner (2005) has estimated that approximately 10% of all drivers are on their cell phones while driving during daylight hours. Given the apparent danger of using cell phones while driving, 14 states and the District of Columbia have banned their use by drivers (California, Connecticut, Delaware, Hawaii, Illinois, Maryland, Nevada, New Hampshire, New Jersey, New York, Oregon, Vermont, Washington, and West Virginia.)[14]

The statistical evidence regarding the crash effect of a ban on cell phone use by drivers has generally been in support of such bans but not consistently. Redelmeier and Tibshirani (1997) found cell phones are linked to a four-fold increase in property damage while Violanti (1998) found that cell phones are responsible for a nine-fold increase in fatalities. McEvoy et al. (2005) also found evidence linking cell phone use with motor vehicle crashes as did Neyens and Boyle (2007). Consiglio et al. (2003), using a laboratory environment, found that both hand-held and hands-free devices increase brake reaction time while Beede and Kaas (2006) found hand-held devices adversely affected driver performance. However, other researchers found results inconsistent with those above.

Laberge-Nadeau et al. (2003) found a relation between phone use by drivers and crashes, but this relation diminished as their models were expanded. Chapman and Schoefield (1998) argued that cell phones were life-saving due to the "golden hour rule" allowing victims of crashes or onlookers to call for help and get quick medical responses. The probability of surviving an accident increases with the speed aid can be obtained for the victim, and sufficient cell phones in the hands of the public (and possibly by victims themselves) increases the likelihood of a timely medical response. Sullman and Baas (2004) added to these findings with their investigation, which did not find a significant correlation between cell phone use and crash involvement. Similarly, Poysti et al. (2005) found that, "phone-related accidents have not increased in line with the growth of the mobile phone industry."[15]

These inconsistent results led to a study by Loeb et al. (2009) using classical econometrics and specification error tests where cell phones were found to have a non-linear effect on motor vehicle fatalities. Cell phone usage was first associated with increasing fatalities when there was few cell phones in use, which was followed by a life-saving effect on net with the growth of U.S. cell phone subscribers until slightly fewer than 100 million were in use, after which they were associated with increases in fatalities on net. Since, there are over 300 million cell phone subscriptions in the United States, one anticipates a life-taking effect of cell phones. Blattenberger et al. (2012) and Fowles et al. (2010) have also demonstrated a relationship between cell phones and motor vehicle fatalities using Bayesian methods.

Motorcycle drivers have access to cell phones as do all other motor vehicle drivers. They can accommodate their cell phone activities directly through their helmets (if worn) as well as using devices to attach their cell phones to their bikes. One would anticipate a similar distracting effect and reaction time effect due to cell phone use on motorcyclists as found in the general motor vehicle driving population. In addition, drivers using cell phones in other types of motor vehicles may put motorcyclists at risk as well. However, there are no published studies we are aware of that evaluate the cell phone effect just on motorcycle fatalities. This present study will address that omission.[16]

Suicides and suicide rates have rarely been used as determinants in motor vehicle fatality models. However, there is some statistical evidence that suicides and motor vehicle fatality rates are related. For example, Phillips (1979) examined the importance of imitation and found a 31% increase in automobile fatalities three days following a publicized suicide. Pokorny et al. (1972) and Porterfield (1960) also found a relation between suicides and motor vehicle fatalities. Murray and De Leo (2007), using Australian data, also found a relation between suicidal propensities and motor vehicle collisions. One can make a case for this association based on economic grounds in that suicide via automobile may dismiss the stigma to the victim's family and there may be an insurance component to the decision in that death due to an accident may leave the victim's estate with an asset, i.e., a life insurance policy.

However, the association between suicides and automobile crashes is not consistent among studies. For example, Connolly et al. (1995), Huffine (1971), and Souetre (1988) found strong support for this relationship, while others, e.g., Etzerdorfer (1995), question the ability to determine if the victim of the crash was indeed a suicide.

Most recently, Blattenberger et al. (2012), using a large panel data set and Bayesian and classical econometric methods, found a strong statistically significant and non-fragile positive effect of suicides on motor vehicle fatalities. This leads one to consider whether suicidal propensities may have an effect on motorcycle fatalities. As far as we know, this has never been examined in prior research other than by Fowles et al. (2015) using different methods than those employed in this paper. Fowles et al. (2015) found some indication of suicidal influences on motorcycle fatality rates using classical econometric models. However, their results were fragile when using Extreme Bounds Analysis. Their research also used Bayesian Model Averaging procedures, which selected the suicidal influences on motorcycle fatality rates in only 47.1% of the models. This must be normalized by the fact that millions of models were considered. S-values may add some information to the ambiguity these results provide.

Other Normalizing Variables

Motor vehicle speed and speed variance were considered as potentially important determinants of motor vehicle crashes and fatalities in general. Speed adds utility by diminishing travel time and by providing, at least for some, thrills and excitement. Yet speed is associated with an increase in the probability of crashes and deaths. Peltzman (1975), Forrester et al. (1984), Zlatoper (1984), Sommers (1985), and Loeb (1987, 1988) early on found evidence of the life-taking property of speed. However, Lave (1985) argued that speed variance was the speed related factor that led to motor vehicle fatalities. Additional evidence for this was found by Levy and Asch (1989) and Snyder (1989) while Fowles and Loeb (1989) found evidence relating both speed and speed variance to motor vehicle related fatalities. As with the case of motor vehicles in general, speed has been found to have an impact on motorcycle fatalities.[17]

The effect of speed limits on fatality rates pertaining to the general motor vehicle fleet has been previously examined. These statistical results have provided varying conclusions depending on model specification and data used. Forester et al. (1984) and Loeb (1991) found speed limits contributed to fatalities while Garbacz and Kelly (1987) and Loeb (1990) concluded that they seemed to reduce measures of crash fatalities. To confound matters more, Keeler (1994), Blattenberger et al. (2012), and Fowles et al. (2010) found varying results. French et al. (2009) investigated the effect of speed limits on rural interstates and found no significant effect on various measures of motorcycle fatalities, although they did find a negative and significant effect on measures of non-fatal injuries. As such, it appears as if speed limits affect motorcycle fatalities similar to that in the general motor vehicle population based on this limited comparison.

Measures of income are of particular interest to economists when studying motor vehicle crashes. Assuming that driving intensity and safety are normal goods, then the demand for each should increase with income. Peltzman (1975) argued that income would have an ambiguous effect on crashes given its offsetting effects. The net effect of income would depend on the relative strengths of these offsetting effects. In addition, Peltzman argues that transitory income would have a smaller life-saving effect than permanent income. Furthermore, one might notice a different effect using time series data in an analysis, possibly portraying short-run effects, as opposed to models using cross-sectional data which would possibly portray long-run effects. One would anticipate that income might also affect motorcycle purchases and then crashes. Higher incomes might induce affluent and older members of society to purchase large motorcycles, which might be used infrequently, and thus exacerbate motorcycle fatality rates. Similarly, low levels of income and high measures of unemployment rates might result in substituting lower powered (less expensive) motorcycles for automobiles and thus increase the number of motorcycle crashes.

Additional socio-economic factors used to normalize model specifications have been incorporated in the past. These include measures of poverty, measures of education, and the distribution of the population among different age categories. One might expect young drivers to have less experience than older ones and thus take more risks while driving. Asch and Levy (1987), Garbacz (1990), Loeb (1990), and Saffer and Grossman (1987a, 1987b) find such a relationship. However, McCarthy (1992) and Loeb (1985) find a significant negative association between youthful drivers and fatality and injury measures. One might expect either of these to occur with motorcycle crashes given the number of older individuals purchasing motorcycles in the last two decades.[18]

Education levels, crime rates, and poverty have also been used as normalizing factors in models explaining motor vehicle fatality rates. Higher levels of education might be associated with greater stocks of human capital, which would be then expected to be inversely related with risky behavior. At the overall motor vehicle level, Blattenberger et al. (2012) did indeed find some evidence of this. One might expect the same relationship when one only examines motorcycle fatalities. However, higher levels of education are also associated with higher levels of income and there may be some confounding effects if higher income individuals over the age of, for example, 50, start using motorcycles infrequently and, as such, fail to gain significant experience driving motorcycles.

DATA

We utilize data collected on 50 states and Washington, D.C., over the period from 1980 to 2010. The number of motorcycle fatalities per billion vehicle miles traveled is our dependent variable. Our choice of explanatory variables is based on a rich literature (reviewed in the previous section) highlighting the importance of policy, safety, demographics, and economic determinants of fatality rates. Issues related to the choice of these variables, as well as the general form of the models, are well described in Blattenberger et al. (2012, 2013), Fowles et al. (2010), and Loeb et al. (2009). Our data cover years during which there were significant changes in several important variables that are a priori plausible predictors of fatalities. Notably, the data record the complex and changing pattern of helmet laws across states and over time. The data also capture the explosive growth in cell phone subscriptions from effectively zero to over 300 million. Annual subscription data at the state level were only available beginning in year 2000. For the earlier years we used national level data and imputed state level subscriptions to be proportional to state population proportions for the prior years.[19]

Another major change observed in the data relates to changes in federal law that allowed individual states to modify the 55-mph speed limit on their interstate highways. Our data record the highest posted urban interstate speed limit that was in effect during the year for each state. Within the data, per se blood alcohol concentration (BAC) laws vary widely, even though by 2005 all states and the District of Columbia had mandated a .08 BAC illegal per se law.[20] Alcohol consumption, BAC thresholds for addressing issues of driving under the influence of alcohol, and helmet laws have generally been found to be significant, or of interest, as determinants of motorcycle fatalities. These are of particular interest given the review of the literature in the second section.

We investigate the effect of suicides on motorcycle crashes as well, in that individuals may use motorcycles as the instrument in such actions so as to minimize stigma and for a possible insurance/economic benefit to the estate. In addition, suicide in the model may measure to some extent changes in societal risk taking or life preferences. Also, measures of the percent of young males in the population, the minimum legal drinking age, a measure of poverty, the unemployment rate, education levels, the crime rate, and real income are included in the model as normalizing factors as well as a time trend to adjust for changes over time not specifically picked up by the other regressors in the model. However, we focus in particular on five variables: cell phones, suicidal propensities, alcohol consumption, and two helmet factors.[21] The data are organized by the geographical coding of states into 11 regions.[22] The variables are defined and described in Table 1 along with their expected effects (priors) on fatality rates.[23] Descriptive statistics are provided in Table 2.

Table 1: Explanatory Variables Cross Sectional – Time Series Analysis of Motorcycle Fatality Rates for 50 States and D.C. from 1980 to 2010

	Description	Expected Sign
YEAR	A time trend.	-
PERSELAW	Dummy variable indicating the existence of a law defining intoxication of a driver in terms of Blood Alcohol Concentration (BAC). PERSELAW=1 indicates the existence of such a law and PERSELAW=0 indicates the absence of such a law. (More precisely, PERSELAW = 1 when the BAC indicating driving under the influence is 0.1 or lower.)	-
SPEED	Maximum posted speed limit, urban interstate highways, in miles per hour.	?
REGION	Dummy for Regional Fixed Effects (geographical coding from north to south and east to west).	?
BEER	Per capita beer consumption (in gal) per year.	+
MLDA21	Dummy variable indicating the minimum legal drinking age is 21.	-
YOUNG	Proportion of males (16-24) relative to population of age 16 and over.	?
CELLPOP	Number of cell phone subscriptions per 10,000 population.	+
POVERTY	Poverty rate (percentage).	+
UNPLOY	Unemployment rate (percentage).	+
INCOME	Real per household income in 2000 dollars.	?
ED_HS	Percent of persons with a high school diploma.	-
ED_COL	Percent of persons with a college degree.	-
CRIME	Violent crime rate (crimes per million persons).	+
SUICIDE	Suicide rate (suicides per 100,000 population).	?
GINI	The Gini coefficient. An index measuring income einequality (0 as complete equality and 1 as complete inequality).	+
PARTIAL	Dummy variable indicating the presence of a partial helmet law in a given state for a given year.	-
UNIVERSAL	Dummy variable indicating the presence of a universal helmet law in a given state for a given year.	-

[a] For data sources, see Appendix 1.

Table 2: Selected Statistics for Cross Sectional – Time Series Analysis of Motorcycle Fatality Rates for 50 States and D.C. from 1980 to 2010

	Median	Mean	Range	Standard Deviation
Fatality Rate	1.468	1.654	6.753	8.947
YEAR	1995	1995	30	0.308
PERSELAW	1	0.8937	1	0.311
SPEED	65	64.32	25	6.474
BEER	1.3	1.308	1.52	0.227
MLDA21	1	0.8684	1	0.338
YOUNG	0.19	0.1849	0.19	0.027
CELLPOP	12.856	28.221	207.571	32.238
POVERTY	12.5	13.05	24.3	3.949
UNPLOY	5.6	6.012	15.8	2.137
INCOME	22321	23749	64037	10013.310
ED_HS	81.9	80.54	39.7	7.950
ED_COL	22.3	22.82	39.7	6.003
CRIME	4455	4586	10383	1464.556
SUICIDE	12.4	12.8	24.16	3.376
GINI	0.4053	0.4102	0.261	0.036
NO LAW	0	0.09614	1	0.295
UNIVERSAL	0	0.4314	1	0.495
PARTIAL	0	0.4605	1	0.499

CLASSICAL ECONOMETRIC RESULTS

Various specifications of the standard form:

(1) $Y=X\beta + \mu$ are estimated using Ordinary Least Squares. The Full Ideal Conditions[24] are assumed to be upheld where:

(2) $b = (X^TX)^{-1}X^TY$ and

(3) $\mu \sim N(0,\sigma^2 I)$

with Y as the vector of fatality rates, X a matrix of explanatory variables whose composition conceivably varies across specified models, β a vector of unknown slope parameters, μ a vector of disturbance terms, σ^2 a scalar variance parameter, and b the OLS estimator.

Table 3 presents a sample of regression results starting from a fully inclusive model using all of the variables from Table 1 to a simpler model using our focus variables along with a trend, a minimum legal drinking age dummy, an intercept, and regional dummies.[25] The results are generally in compliance with our a priori expectations. Most notably, with regard to our focus variables, all five (cell phones, suicides, helmet laws, and alcohol) are stable in terms of the sign of their respective coefficients and all are statistically significant at a 1% significance level. Of particular interest is the consistent effects of both the universal and partial helmet laws.

Note that model ambiguity is implicit in Table 3 and thus the standard notion of significance level testing assuming any given model is true (the sampling distribution is known) must be relaxed. This issue is addressed in the following section.

BAYESIAN S-VALUES AND THE DETERMINANTS OF MOTORCYCLE FATALITY RATES

Although it is common to indicate regression results for a variety of model specifications, reported statistics are valid on the presumption of a given model's truth. In practice, alternative tests are made on competing models, each sequentially assumed to be true. Inferences based on sequential search procedures are fraught with problems regarding the statistical validity of models' reported summary statistics. Bayesian theory, however, can directly address both estimation uncertainty and model ambiguity. In this paper we utilize advances in Bayesian research regarding model choice as discussed, for example, in Key et al. (1999), and Clyde (1999). An early investigator in model uncertainty was Leamer (1978, 1982, 1983) who, in a book and series of articles, dealt with specification searches.

One Bayesian approach that addresses model uncertainty is Extreme Bounds Analysis (EBA), developed by Leamer (1978). It is a methodology of global sensitivity analysis that computes the possible maximum and minimum values for Bayesian posterior means in the context of linear regression models.[26] One might think of this as an examination of the stability or lack of fragility of coefficients in the models. This is done by examining a multitude of models, which vary in terms of linear combinations of different regressors. The number of models can easily exceed several million.[27] The global bounds are illustrated in Figure 1 for a two-variable regression model. A typical likelihood ellipse is centered at the OLS estimate. The other ellipse is the same shape and passes through the origin (the prior mean) and the OLS estimate. It contains the set of possible posterior means that could be obtained for all prior variance matrices that are positive definite. This larger ellipse is called the feasible ellipse and highlights a main drawback of EBA: that bounds are very wide. In this example, only the second quadrant (negative Beta1, positive Beta 2) is excluded as a possible joint region that could contain the posterior mean. Marginally, both Beta 1 and Beta 2 are fragile in the sense that there are prior variance matrices that could result in negative or positive posterior estimates for either variable.

That the coefficients for all variables in a regression are necessarily fragile from a global EBA perspective highlights the importance of the prior variance. We incorporate a new perspective on the prior variance developed by Leamer (2014, 2016). S-values (sturdiness statistics) reveal aspects of parameter fragility for minimally specified prior variance matrices that "tame" the global bounds from EBA. Figure 2 illustrates how S-values are obtained for a two-variable regression problem. As in Figure 1, we plot typical likelihood ellipses that are centered at the OLS estimate. There are also two circles centered at the origin that represent two iso-prior probability contours that would result from a prior that is centered at zero with spherically symmetric prior variances. The points of tangencies trace the posterior mean from zero to the OLS point. From a non-Bayesian perspective, this is exactly the ridge regression trace (Hoerl and Kennard (1970)). If the prior variance increases, the posterior mean will fall closer to the OLS point, and if the prior variance decreases, the mean falls closer to the origin. Two middle points are associated with two values of the prior variance. These values translate to prior R-square (variance).[28] The larger prior R-square gives more weight to the explanatory variables in the model, and thus the trace is closer to the OLS point. In Figure 2 there is also a shaded ellipse that contains the possible posterior means associated with all linear combinations of the two explanatory variables. Here, notice that the limits for Beta 2 are fragile, but that the limits for Beta 1 are unambiguously positive. The extreme values for means within such an ellipse form the basis for S-values, which are computed as the midpoint of the extremes divided by half their length.

Table 3: OLS Motorcycle Fatality Rate Models for U.S. States from 1980 to 2010 Estimates and (t values)[a]

	Full Model	Model 2	Model 3	Model 4	Model 5
(Intercept)	212.000	218.300	193.100	195.600	263.100
	(13.622)**	(14.259)**	(13.789)**	(15.560)**	(25.824)**
YEAR	-0.106	-0.109	-0.095	-0.096	-0.132
	(-13.225)**	(-13.873)**	(-13.342)**	(-15.011)**	(-25.638)**
PERSELAW	0.027	0.010	0.060		
	(0.489)	(0.179)	(1.111)		
SPEED	-0.004	-0.004	-0.005		
	(-1.051)	(-1.017)	(-1.245)		
BEER	0.409	0.410	0.421	0.422	0.501
	(5.156)**	(5.166)**	(5.314)**	(5.349)**	(6.480)**
MLDA21	-0.262	-0.258	-0.274	-0.272	-0.253
	(-4.574)**	(-4.510)**	(-4.808)**	(-4.802)**	(-4.363)**
YOUNG	-0.035	0.118	0.209		
	(-0.048)	(0.161)	(0.293)		
CELLPOP	0.029	0.029	0.028	0.028	0.030
	(15.944)**	(16.010)**	(18.969)**	(21.060)**	(23.628)**
POVERTY	-0.013				
	(-2.191)*				
UNPLOY	-0.008	-0.013			
	(-0.932)	(-1.646)			
INCOME [b]	0.0001	0.0001			
	(-1.282)	(-0.838)			
ED_HS	-0.016	-0.014	-0.025	-0.025	
	(-2.985)**	(-2.582)**	(-5.444)**	(-5.441)**	
ED_COL	-0.033	-0.032	-0.023	-0.023	
	(-5.198)**	(-4.984)**	(-4.370)**	(-4.354)**	
CRIME [b]	0.0001	0.0001	0.0001	0.0001	
	(2.809)**	(3.095)**	(4.854)**	(5.129)**	
SUICIDE	0.023	0.024	0.021	0.021	0.031
UNIVERSAL	-0.812	-0.815	-0.762	-0.773	-0.668
	(-14.171)**	(-14.205)**	(-13.441)**	(-13.761)**	(-11.789)**
PARTIAL	-0.275	-0.286	-0.252	-0.256	-0.168
	(-5.108)**	(-5.313)**	(-4.695)**	(-4.792)**	(-3.113)**
Adjusted R^2	0.619	0.618	0.612	0.6125	0.588
F-stat [c]	96.210	99.480	109.500	125.900	133.800

a Regional dummy variables were included in the regressions; all are estimated as negative and mostly significant given that the region including Hawaii was the reference region. Hawaii has the highest motorcycle fatality rate. The reference group for helmet laws is NO LAW. OLS estimates using state factor variables were also obtained and results are similar to those above (results available upon request). As noted above, we believe a time trend is an appropriate specification for the gradual improvements in technology and of permanent income, but we also estimated the OLS model using time fixed effects. Again, the results are similar to those presented in Table 3. Significance at the 5% level is indicated by * and at the 1% level by **.
b Coefficients on income and crime < .00001 but coded as .0001
c n = 1581

Figure 1: Feasible Bounds

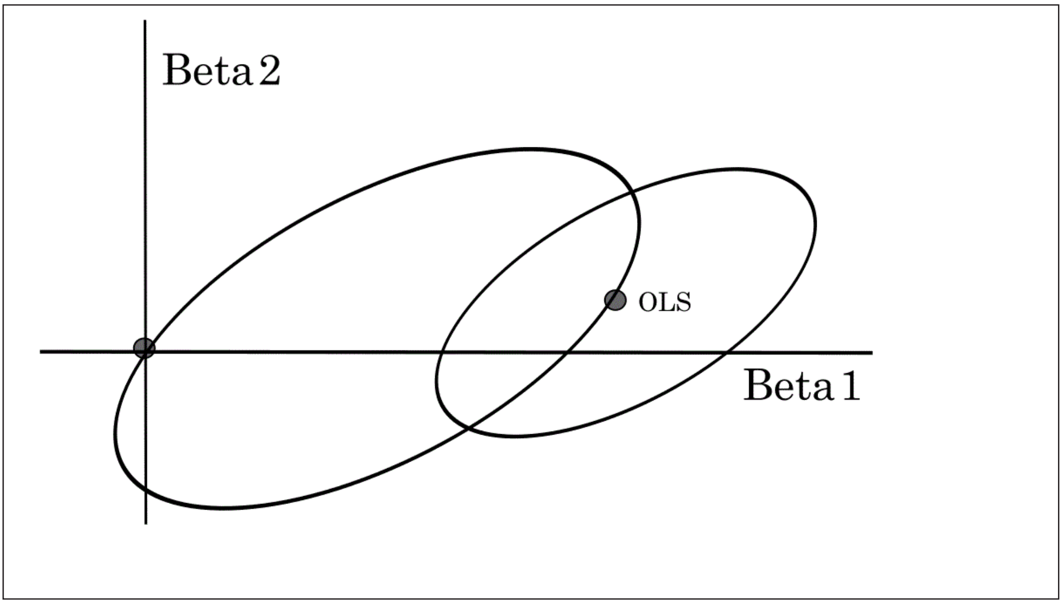
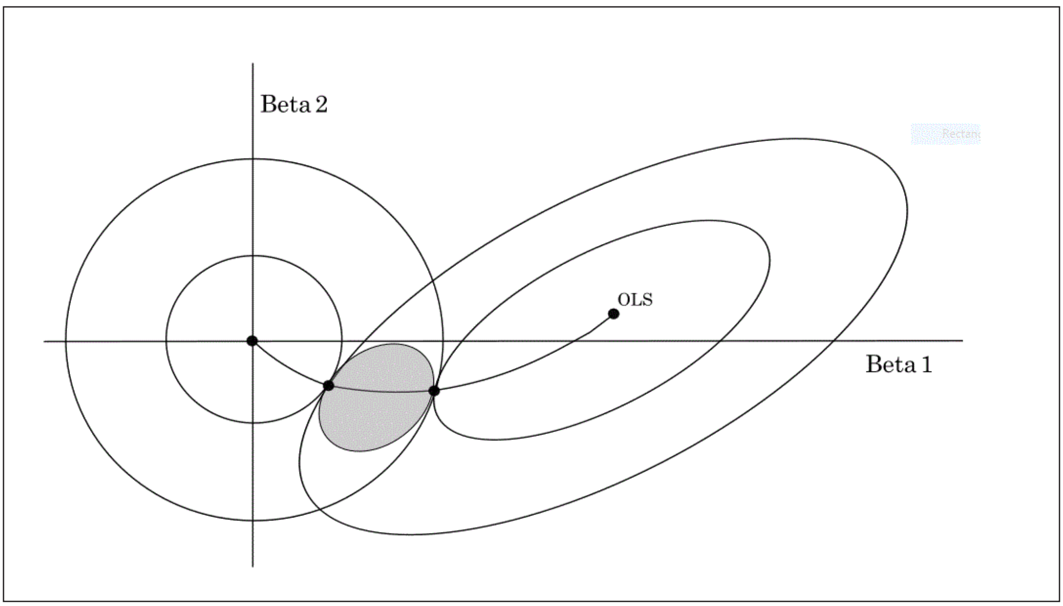


Figure 2: Prior R-square Bounds



As suggested by Leamer (2014, 2016), useful prior R-squares are associated with values of .1 to 1 (wide), .1 to .5 (pessimistic), and .5 to 1 (optimistic). A pessimistic belief is that the explanatory variables would not account for much of the variation in the dependent variable, whereas an optimistic belief is that they do and thus the prior defers to the data.[29]

Table 4 summarizes the findings for our variables of interest based on standardized data.[30] The column "Simple OLS Beta Coefficients" regresses the fatality rate on only the one specified explanatory variable and measures the pairwise correlation between the two variables. Leamer argues that these simple correlations "are a feature of the data, while the 'partial' regression coefficients are cooked up by the analyst when he or she selects the control variables."[31] A different sign in the simple correlation and the partial correlation then "requires scrutiny."[32] It is here that S-values are particularly useful. The next six columns provide lower and upper extreme values for the three specified prior variances, the first two for the wide prior (prior R-squared from 0.1 to 1), the second two for the pessimist prior (prior R-squared from 0.1 to 0.5), and the third two for the optimistic prior (prior R-square from 0.5 to 1). The ninth column, "Multiple OLS Beta Coefficients," provides the standard estimates for the complete model (the t-statistics are shown in the last column). S-values for the wide and optimistic prior are in columns 10 and 11. The shaded cells in Table 4 highlight aspects of model and parameter uncertainty. There are four variables, YEAR, BEER, MLDA, and UNIVERSAL for which all cells are shaded. For these variables, the signs of parameters are always the same, the absolute value of the S-values are greater than one, and the absolute values of the t-statistics are greater than two. These four variables exhibit the highest level of sturdiness. CELLPOP shows sturdiness on the basis of S-values and the S-values conform with t-statistics, in addition, all bounds are non-fragile. However, there is sign switching when viewing the SIMPLE correlation and the coefficient in the full model. This result is due to an aspect of falling fatality rates when cellphones became popular. Again, when other control variables are introduced, CELLPOP is regarded as a sturdy variable.

For non-Bayesians, Table 4 also demonstrates that there is agreement between calculated S-values and t-statistics.[33] Notice that the variable YOUNG has a large optimistic S value (column 11) and a small t statistic (column 12). This is because the bounds for the optimistic prior are not fragile. If one is dubious that YOUNG is an important explanatory variable, then its bounds are fragile (the wide prior) and the corresponding S-value as shown is less than 1. An important feature of this reporting style is that each reader can come to the table with his or her own attitude toward the importance of the variable shown.

These relationships from Table 4 are illustrated in Figure 3 with horizontal lines at the origin and +/- 1 and vertical lines at the origin and +/- 2. Variables in the northeast and southwest quadrants are associated with more certain and sturdy estimates.

CONCLUDING COMMENTS

One of the most important statistical problems is the task of inference in the context of parameter uncertainty and model ambiguity. This challenging task is due to the magnitude of the number of models that need to be considered, often numbering in the millions. In this paper we have looked at the determinants of motorcycle crashes focusing on five specific variables, i.e., alcohol consumption, universal helmet laws, partial helmet laws, cell phone use, and suicidal propensities, after normalizing for other vehicle, economic, and other factors commonly found in the transportation safety literature.

While the effectiveness of helmet laws has been investigated previously, this is the first study which distinguishes universal helmet laws from partial helmet laws and ranks them in importance based on strong Bayesian statistical criteria, i.e., S-values. Cell phone use, while considered in models of overall transportation safety, has not previously been examined with respect to motorcycle fatality rates. Finally, we consider the impact of suicidal propensities on these crashes along with the well-established alcohol effect.

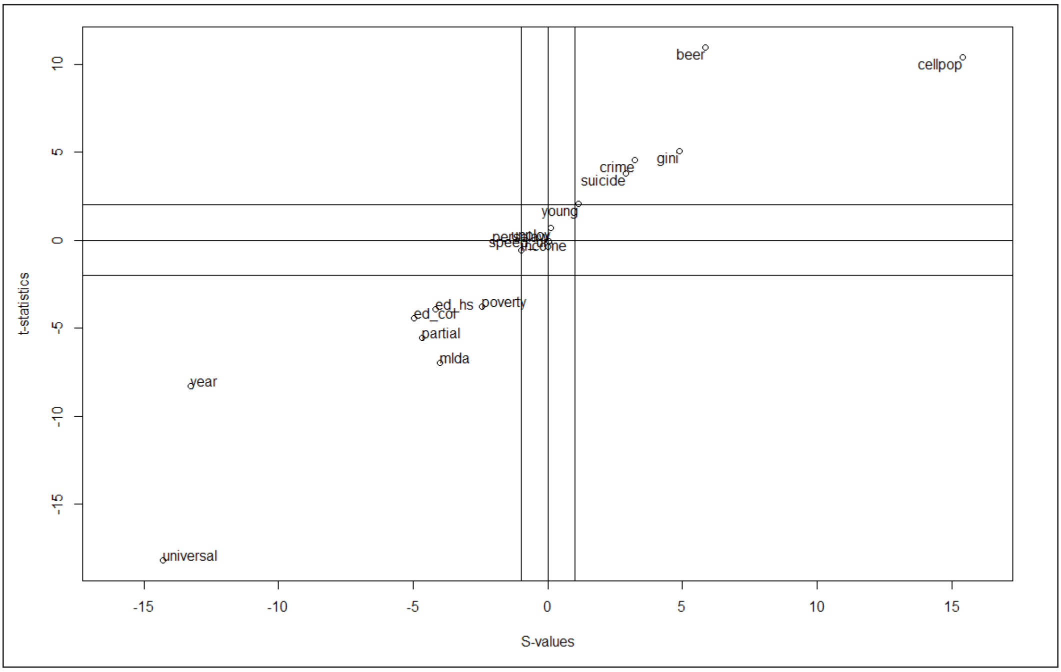
Models are proposed to examine the above factors using a new Bayesian procedure developed by Leamer (2014, 2016), i.e., S-values, along with ordinary least squares. S-values, otherwise known as sturdiness statistics, examine parameter stability among hundreds of thousands or millions of potential models. The estimates are provided in three domains: a pessimistic view of the impact of the explanatory variables on the dependent variable, an optimistic view, and an indifferent or unknowing view. The reviewer of the models can then select the prior view they hold to and compare it to other views, or simply come to some conclusion based on their own prior belief. In addition, we

Table 4: Coefficients, Bounds, and S-values for U.S. Motorcycle Fatality Rates[a]

	Simple OLS Beta Coefficients	R .1 to 1 (wide)		R .1 to .5 (pessimistic)		R .5 to 1 (optimistic)		Multiple OLS Beta Coefficients	R .1 to 1	R .5 to 1	t stat
		Lower	Upper	Lower	Upper	Lower	Upper		S-value	S-value	
YEAR	-4.24E-01	-1.14322	-0.1932	-0.96616	-0.2291	-0.97721	-0.76714	-1.15E+00	-1.40673	-8.30348	-13.2755
PERSELAW	-2.55E-01	-0.06387	0.046331	-0.0562	0.035789	-0.00961	0.008327	3.93E-03	-0.15918	-0.07137	0.041689
SPEED_UR	-1.13E-01	-0.09318	0.055941	-0.08478	0.037264	-0.01835	0.008678	1.58E-02	-0.24971	-0.35782	0.014241
BEER	3.39E-01	0.068837	0.200662	0.083893	0.193137	0.111426	0.133819	1.08E-01	2.044368	10.95176	5.862222
MLDA	-4.40E-01	-0.18508	-0.04362	-0.17988	-0.06459	-0.10451	-0.07835	-6.02E-02	-1.6166	-6.99032	-4.02307
YOUNG	2.95E-01	-0.02218	0.153478	0.005519	0.146652	0.01814	0.052644	-5.98E-03	0.747514	2.051458	1.150619
CELLPOP	-1.97E-01	0.288631	1.050289	0.311952	0.907686	0.773657	0.938028	1.09E+00	1.757903	10.41357	15.42076
POVERTY	6.04E-02	-0.16926	0.037176	-0.15311	0.017714	-0.08398	-0.04862	-5.86E-02	-0.63983	-3.74999	-2.45375
UNPLOY	2.74E-01	-0.03544	0.092132	-0.01797	0.086952	-0.00329	0.019272	-1.56E-02	0.444435	0.708197	0.094037
INCOME	-3.45E-01	-0.48659	0.424038	-0.37493	0.336205	-0.15429	0.043188	-1.07E-01	-0.06869	-0.56261	-0.97521
ED_HS	-3.46E-01	-0.49376	0.029645	-0.45774	-0.04059	-0.26185	-0.15582	-1.33E-01	-0.88672	-3.93928	-4.18701
ED_COL	-2.90E-01	-0.39925	0.056817	-0.34662	0.019582	-0.24393	-0.15412	-2.29E-01	-0.75084	-4.43204	-4.97298
CRIME	1.76E-01	-0.01788	0.197853	0.005535	0.18282	0.067745	0.106064	6.74E-02	0.834274	4.535849	3.2187
SUICIDE	2.04E-01	-0.04983	0.217488	-0.02612	0.194798	0.065006	0.111119	8.42E-02	0.627159	3.819459	2.908027
GINI	-2.48E-01	-0.03791	0.320832	-0.0139	0.27867	0.134479	0.200593	2.05E-01	0.788665	5.068143	4.89885
UNIVERSAL	-3.29E-01	-0.54115	-0.26033	-0.51031	-0.27818	-0.46371	-0.41533	-4.60E-01	-2.85404	-18.1727	-14.2902
PARTIAL	2.18E-01	-0.23208	0.038613	-0.20059	0.022223	-0.15572	-0.10803	-1.58E-01	-0.71471	-5.53049	-4.67269

[a] S-values are obtained by simply taking the ratio of sum of the upper and lower bounds to the difference between them, so the S-values for the pessimistic prior can be obtained from columns 5 and 6.

Figure 3: t-statistics & S-values



compare these Bayesian estimates with that of ordinary least squares. Surprisingly, we find strong agreement between the Bayesian and frequentist approach, given that S-values greater than “1” quite often correspond to t-values of 2 or greater, both in absolute value.

Reviewing the statistical results associated with our focus variables, we find that BEER, our alcohol variable, has a potent effect on the motorcycle fatality rate as seen from all statistics presented. The “Simple” regression result has the same sign as the OLS result. All bounds reported are non-fragile and the S-values all have values (in absolute value) greater than “1” while the t-statistics are greater than “2.” This result conforms with the result found by French et al. (2009).

The Partial Law results show a sign change between the “Simple” correlation and the partial correlation found in the OLS regression. The wide bounds and the pessimistic bounds are fragile, while the optimistic bounds are stable. Finally, the S-value for the wide bounds does not show relevance, given that its value is less than “1” in absolute value, while both the optimistic bounds and the t-statistics are favorably portrayed as having an effect on the dependent variable. These inconsistent results can be compared with those associated with the Universal Law effect. Here consistent results are found throughout. That is, the “Simple” result is of the same sign as found in the OLS model. In addition, all bounds, i.e., wide, optimistic, and pessimistic, are non-fragile and finally, the S-values reported for both the wide and optimistic bounds are greater than “1” in absolute value while the t-statistic is greater than “2” in absolute value. Clearly, there is wide support for the importance of the universal law on motorcycle fatality rates.

The statistical results associated with the suicide effect are not uniform. The “Simple” correlation conforms to the OLS results, but both the wide and pessimistic bounds are fragile. However, the optimistic bounds are stable. Only the optimistic S-value and the t-statistic conform with reason to believe SUICIDE is influential. This mixed set of results leaves one in the position of deciding the importance of this factor based on one’s prior with respect to optimism or pessimism.

Finally, the results regarding cell phone usage, i.e., CELLPOP, are almost always supportive regarding the importance of this variable. All bounds are stable and the S-values for both the wide and the optimistic bounds are greater than “1.” In addition, the t-statistic is greater than “2.”

However, the "Simple" result differs from the OLS result in terms of sign. Leamer would argue that this requires scrutiny. However, these results are expected. The negative coefficient in the SIMPLE result is due to the association between cell phones and the time trend. Over time, the number of cell phones increased exponentially. The time trend shows a strong negative association with the fatality rate as seen in the OLS result. Hence, we argue that the "SIMPLE" result in this case is not at odds with all of the other results. This suggests that cell phone usage is indeed a contributor to motorcycle fatality rates.

The statistical results, both Bayesian and classical, support potential public policies on alcohol, universal helmet laws, and cell phone usage as they impact motorcycle fatality rates. For example, they suggest stricter policing and strong fine structures be imposed on motorcyclists driving while under the influence of alcohol and perhaps funding for substance abuse treatment centers be considered by governments.[34]

In addition, we have found strong evidence that universal helmet laws are superior to partial helmet laws. This suggests that Congress or the states might consider imposing once again legislation promoting such universal helmet laws.

Cell phone usage has been found to contribute to motorcycle fatality rates. It is not unusual for motorcyclists to have the ability to use cell phones while driving along with other drivers and pedestrians. Evidence has been provided at length about the effect of cell phone use on other modes of transportation, and perhaps this is the time to investigate the appropriateness of imposing bans on cell phone use on all drivers beyond the 14 states and DC where such bans exist for hand-held devices and expanding the ban further to include hands-free devices. This could be accomplished by stricter policing of such laws and a viable fine structure.

The suicide effect was not found as significant on motorcycle fatality rates as on motor vehicle fatality rates in general.[35] However, to review, support for this variable is found with regard to the consistency of signs in the "SIMPLE" and OLS results along with stable optimistic bounds and a large S-value associated with optimistic bounds and a large t-statistic. It may prove beneficial to consider this factor further since high suicide states are also high motor vehicle fatality states.[36] In addition, suicides are a leading cause of death among young people in the United States, making it an important factor from a public health perspective.[37] Interestingly, suicides have also been found to be an area of concern with other modes of transportation, in particular with railroads.[38] It may be that suicidal propensities are measuring changes in risk taking propensities by individuals or society in general. A potential avenue of future research may be to investigate the effectiveness of posting phone numbers/help lines for those suffering from emotional or psychiatric issues who might benefit from this and/or the investment of public monies to reduce reckless or violent behaviors while driving.[39] However, it seems that suicidal propensities are not as pronounced for motorcycle fatalities as they are for automobile fatalities.

Endnotes

1. See Lin and Kraus (2009).

2. See NHTSA (2006).

3. See National Highway Traffic Safety Administration (2011).

4. An early review of the causes of motorcycle crashes along with other transportation related crashes can be found in Loeb et al. (1994).

5. The only other paper investigating these, and the other focus variables mentioned as applied to motorcycle fatalities, is that of Fowles et al. (2015). But that paper makes use of different

Bayesian techniques, i.e., Extreme Bounds Analysis (EBA) and Bayesian Model Averaging (BMA). The approach applied here extends that analysis and is heuristically more accessible.

6. The general form of the models estimated and the independent variables included in the models are based on the general work dealing with regulations suggested by Peltzman (1975), French et al. (2009) and Lin and Kraus (2009). The models take into account that motorcycle fatality rates are related to driver characteristics, road characteristics, and a host of other socio-economic factors commonly found in studies dealing with crashes.

7. Universal helmet laws require all motorcyclists to wear a helmet while partial helmet laws require only some motorcyclists to wear a helmet.

8. See National Highway Traffic Safety Administration (NHTSA), (2003) for a review of legislative history.

9. See Loeb et al. (1994) for additional reviews, some showing opposite or insignificant results.

10. See Lin and Kraus (2009, pp. 712-713) for a review of this literature.

11. See Loeb et al. (1994) for additional reviews.

12. Some preliminary work on these factors using alternative Bayesian techniques have been investigated by Fowles et al. (2015).

13. See CTIA (2011).

14. See Governors Highway Safety Association (2015) for the list of states banning cell phone use.

15. See Poysti et al. (2005, p. 50).

16. See Fowles et al. (2015) for further discussion.

17. See Lin and Kraus (2009), and Shankar (2001).

18. Between 1985 and 2003, the percentage of motorcycle owners who were 50 or older steadily grew from 8.1 to 25.1%. See Morris (2009).

19. Our method of imputing cell phone subscriptions correlates with the actual data with a correlation coefficient of .9943.

20. The per se law refers to legislation that makes it illegal to drive a vehicle at a blood alcohol level at or above the specified BAC level. BAC is measured in grams per deciliter.

21. We are interested not only in the effects of universal helmet laws and partial helmet laws, but which has a stronger and less uncertain effect on motorcycle fatality rates.

22. The use of regions mirrors the U.S. standard federal regions, but we isolate Alaska and Hawaii since they are non-contiguous. In all analyses in the paper, the regional variables are included, but results are not presented.

23. The anticipated sign for YEAR as a time trend is negative because it proxies advances in technology and possibly permanent income. Poverty is anticipated to have a positive effect as it serves as a proxy for state infrastructure, such as improved highways, traffic enforcement, and faster emergency response times. Income inequality and crime are anticipated to have positive

signs that may reflect social malaise or risk seeking behaviors. These variables are discussed in Blattenberger et al. (2013). As noted above, mixed results in previous literature are associated with young riders, so we are uncertain as to the anticipated sign of this variable.

24. See Ramsey (1974) and Ramsey and Zarembka (1971).

25. Similar models for total motor vehicle fatality rates have been investigated in prior research for specification errors of omission of variables, misspecification of the structural form of the regressors, simultaneous equation bias, serial correlation, and non-normality of the error term and found to be in compliance with the Full Ideal Conditions. See, for example, Loeb, et al. (2009). In addition, see Fowles et al. (2013) and Loeb and Clarke (2009).

26. Mathematical developments are found in Leamer (1982).

27. See, for example, Leamer (1978, 1982, 1983), Blattenberger et al. (2012, 2013), and Fowles et al. (2015).

28. The Bayesian natural conjugate model that corresponds with the classical model presented above (equations 1-3), sets the prior variance for the β's = var(β) = $v^2I_{\mathbf{kxk}}$ where I_{kxk} is the k by k identity matrix. Bounds are obtained via the scalar v^2, which is set to the minimum or maximum expected R-square divided by k. See Leamer (2014, 2016) for details. Calculations are performed in the software R (R Development Core, 2016).

29. A super pessimist prior is to exclude a variable from a regression, so the prior mean is at zero and the variance is zero as well (prior R-square zero). In this paper, we do not consider this kind of strict prior.

30. Regional dummies were included as explanatory variables but results are not shown in Table 4.

31. See Leamer (2014).

32. See Leamer (2014).

33. For the prior R-square at 1, the correlation is .9329.

34. See Chaloupka et al. (1993) and Freeborn and McManus (2007).

35. See, for example, Blattenberger et al. (2013).

36. See Blattenberger et al. (2013).

37. See Centers for Disease Control and Prevention (2012).

38. See, for example, Savage (2007).

39. See Savage (2007) and Connner et al (2001).

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Appendix 1: Data Sources

Name	Data Source
MCFATAL	Highway Statistics (various years), Federal Highway Administration, Traffic Safety Facts (various years), National Highway Traffic Safety Administration
PERSELAW	Digest of State Alcohol-Highway Safety Related Legislation (various years), Traffic Laws Annotated 1979, Alcohol and Highway Safety Laws: A National Overview 1980, National Highway Traffic Safety Administration
SPEED	Highway Statistics (various years), Federal Highway Administration
BEER	U.S. Census Bureau, National Institute on Alcohol Abuse and Alcoholism
MLDA21	A Digest of State Alcohol-Highway Safety Related Legislation (various years), Traffic Laws Annotated 1979, Alcohol and Highway Safety Laws: A National Overview of 1980, National Highway Traffic Safety Administration, U.S. Census Bureau
YOUNG	State Population Estimates (various years), U.S. Census Bureau http://www.census.gov/population/www/estimates/statepop.html
CELLPOP	Cellular Telecommunication and Internet Association Wireless Industry Survey, International Association for the Wireless Telecommunications Industry.
POVERTY	Statistical Abstract of the United States (various years), U.S. Census Bureau website http://www.census.gov/hhes/poverty/histpov19.html
UNPLOY	Statistical Abstract of the United States (various years), U.S. Census Bureau
INCOME	State Personal Income (various years), Bureau of Economic Analysis website http://www.bea.doc.gov/bea/regional/spi/dpcpi.htm
ED_HS	Digest of Education Statistics (various years), National Center for Education Statistics, Educational Attainment in the United States (various years), U.S. Census Bureau
ED_COL	Digest of Education Statistics (various years), National Center for Education Statistics, Educational Attainment in the United States (various years), U.S. Census Bureau
CRIME	FBI Uniform Crime Reporting Statistics website http://www.ucrdatatool.gov
SUICIDE	Statistical Abstract of the United States (various years), U.S. Census Bureau
GINI	University of Texas Inequality Project website http://utip.gov.utexas.edu
UNIVERSAL PARTIAL	Governors Highway Safety Association http://www.ghsa.org/html/stateinfo/laws/helmet_laws.html (accessed 6/6/2015)
REGION	US States 1: ME, NH, VT; 2: MA, RI, CT; 3: NY, NJ, PA; 4: OH, IN, IL, MI, WI, MN, IA, MO; 5: ND, SD, NE, KS; 6: DE, MD, DC, VA, WV; 7: NC, SC, GA, FL; 8: KY, TN, AL, MS, AR, LA, OK, TX; 9: MT, ID, WY, CO, NM, AZ, UT, NV; 10: WA, OR, CA; 11: AK, HI

Shippers' Changing Priorities in Port Selection Decision – A Survey Analysis Using Analytic Hierarchy Process (AHP)

by Neha Mittal and Dale McClung

This paper analyzes different criterion that shippers employ in their port selection process. It uses results from a survey conducted on regional shippers from the chemical and life sciences industries that ship full container and LCL cargo of hazardous and non-hazardous chemicals westbound (from U.S. east coast to Asia). Using an Analytic Hierarchy Process (AHP) framework and participants' comparative scores, factors affecting a shipper's port choice are prioritized. Findings suggest that port congestion and delays on the west coast ports in the U.S. and its effect on shippers' supply chains have changed their priorities; price and port characteristics are no longer their primary decision factors.

INTRODUCTION AND RESEARCH PROBLEM

Marine ports are of vital importance to modern day businesses. With extensive and complex supply chains, businesses today work in a global environment. It has become imperative for them to import/export to deliver their products to the market. Since maritime shipping provides the most economical way to transport large quantities of freight, businesses or shippers frequently make the decision to identify their port of choice.

Several previous studies and industry articles have made efforts to understand a shipper's port choice selection criterion, but the complexity and dynamic nature of international trade and logistics industry has kept this area as an ongoing research subject. Historical studies showed price and characteristics of a carrier (shipping line) as the most important criterions for shippers; a port's infrastructure or its location did not carry much significance (Slack 1985). However, these factors have changed dramatically over the years.

Selecting a port is surely a challenging task for shippers. On the other hand, port officials are under constant fear of losing their customers/ attractiveness; often not due to the deficiencies in their physical port infrastructure, but due to the shippers' constantly changing requirements and priorities. This makes it vital for the port officials and marine terminal operators to understand and adapt to the changing needs of their customers. Results and conclusions from the study provide port managers with essential information on key factors that come into the decision process of port users.

Through this paper, we intend to understand how some of the recent events and changes in the shipping industry have led to shaping a shippers' port selection decision in recent times. While the subject has been well studied, our paper adds value in terms of its timing, study analysis and interpretation of results. We present the paper as a survey of different decision factors in a port selection process, and present an AHP-based analysis on data obtained from regional shippers. The remainder of this paper is organized as follows. In the second section of the paper, we provide a chronological survey of articles on how shippers' port selection criterion has changed over time. Following the literature review, we discuss the research methodology, present the survey analysis, results, and present conclusions. We believe our study findings will serve as a set of recommendations for port officials and terminal operators.

LITERATURE REVIEW

There is a significant amount of literature on factors important to shippers' port selection process. During the survey of articles, we found that the problem of port selection is studied under two different perspectives – one where shipping lines are selecting their port of calls and another in which the shipper is making the port choice decision.

Table 1 presents a chronological survey of papers that have dealt with the problem and lists different criterions that were found important in each of those studies.

Older studies, such as by Slack (1985), established that the choice of port depends more on the price and quality of service offered by land or ocean carriers than the port's characteristics. Among the factors, such as the port's security, its size, inland freight rate, port charge, quality of custom handling, congestion, port equipment, number of trips (sailings or departures of ships at the port), and possibility of intermodal links, Slack found that while connection to inland transport services and availability of container facilities is relevant, the number of sailings or voyages from the port and the inland shipping rates were at the highest mark.

Bird (1988a and 1988b), based on his analysis of European freight forwarders, found that the frequency of ship service is the main factor in a port choice. Tongzon (1995) also confirmed that the frequency of shipping service is the major determinant of time, and time is essential in the freight forwarding industry.

Jamaluddin (1995) with reference to the Far East/Europe trade, defined the six service attributes from both the shipper and the carrier's perspective. It described that the six service factors which shippers find most important are freight rate, cargo care and handling, knowledgeability, punctuality, transit time, and service frequency. In case of carriers, the six most important service attributes are knowledgeability, freight rate, cargo care and handling, punctuality, transit time, and service frequency.

Research conducted by Tiwari et al (2003) found additional factors that influence a shipper's port choice decision. These factors included the shipper's distance from the port, the number of ship calls at the port (i.e., the number of scheduled intermediate stops by ships at the port, which determines the value of cargo that can be moved through that port), the efficiency of the port infrastructure, and the number of routes offered at the port.

Blonigen and Wilson (2006) developed a model for port choice. They estimated the impact of ocean transport rates, efficiency of ports, and internal transport systems on a shipper's port choice. Based on sample data on trade volumes between U.S. ports and several foreign countries from 1991 through 2003, the study provided strong evidence on the importance of economic factors in port choice. While distance and transport prices were found significant, unlike previous studies, it found that an individual port's efficiency plays an important role in determining its activity.

Chinonye et al. (2006) determined the service characteristics that shippers consider important when selecting a port. Based on a survey and analytic hierarchy process tool, he prioritized the characteristics according to their importance. Seven criteria for the port selection decision and four ports were identified for analysis in his study. Findings suggested that shippers consider efficiency, frequency of ship visits, and adequate infrastructure more important in their decision making process than a quick response time to port users' needs.

For determining a shipping lines' port choice factors, Tongzon and Sawant (2007) used a revealed preference approach. They found port costs and range of port services to be two significant factors. They discussed the evolving role of shipping lines in the logistics business and how they now connect a shipper with a customer in modern days, then the traditional approach of linking the shippers/freight forwarders with the ports. The study emphasized how this fact is of great importance for port officials when considering their competition with others.

Wiegmans (2008) addressed three dimensions in his study: buying decision characteristics; port choice strategy; and terminal selection. Results showed that for the port choice decision, the

Table 1: Chronological Review of Literature for Factors Influencing Port Selection

Author	Year	Perspective	Criterion found significant
B. Slack	1985	Shipper	Price and number of sailings
J. Bird	1988(a), (b)	Shipping Line	Frequency of shipping service
Tongzon	1995	Shipping Line	Frequency of shipping service
Jamaluddin	1995	Shipping Line	Freight rate, cargo care and handling, knowledgeability, punctuality, transit time, and service frequency of the shipping line
Tiwari et. al.	2003	Shipper	distance of the shipper from the port, number of ship calls at the port, efficiency of port infrastructure, and number of routes offered at the port
Blonigen and Wilson	2006	Shipper	distance and transport prices are very significant factors
Chinonye et. al.	2006	Shipper	efficiency, frequency of ship visits and adequate infrastructure
Tongzon and Sawant	2007	Shipping Line	port charges and range of port services available
Wiegmans et. al.	2008	Shipper	availability of hinterland connections; reasonable tariffs; and immediacy of consumers
Tongzon	2009	Shipper	port efficiency was the most important factor followed by shipping frequency, infrastructure and location of the port
Chou	2009	Shipper	inland freight costs and frequency of ship callings
Ruriani D.C.	2009	Shipper	Proximity to port, efficiency of workforce, infrastructure
Chou	2010	Shipper	hinterland economy, port charges, port loading/ discharging efficiency
Tang et. al.	2011	Shipper	Shipping line: port efficiency and scale economies
Fung, Sun and Bhattachariya	2013	Shipper	Their own supply chain arrangements influence their port selection
Zarei	2015	Shipping Line	Quality of products delivered (packaging, freshness), Advanced port management (Promptness of issuing document, service speed, custom services, port operation policy, port safety), and port infrastructure.

most important criteria from a carrier's perspective are: availability of hinterland connections, reasonable tariffs, and immediacy of consumers (large hinterland). In addition to these criteria, shipping lines find feeder connectivity, environmental issues, and the ports' characteristics important in their decision making. The study pointed out that port selection is not the same as terminal selection, and in case of the latter, handling speed, handling costs, reliability, and hinterland connections become more important. The analysis showed that these decisions often change based on the carrier, trade, and port type.

In a slightly different study, Tongzon (2009) evaluated factors influencing port choice decision from the freight forwarders' perspective. He focused on the Southeast Asian freight forwarders in his study. The paper highlighted the increasing role of 3PLs in the growing supply chains and why it is important to consider studying the port choice decision based on their decision-making style and port selection process. Results found that the port's efficiency (i.e., the speed and reliability of port services), shipping frequency, infrastructure, and location are the most dominant factors from the freight forwarder's perspective.

Chou (2009) developed a mathematical programming model for port choice of shippers. It highlights the fact that shippers focus on minimizing the total logistics costs, and not only the inland costs, which was ignored by many past studies. It said that the port choice of the shipper is not only dependent on the transportation costs, but also on the value of the cargoes being shipped through the port. In other words, shippers aim to not only minimize the inland freight costs but also consider the frequency of ship callings (number of ships that consider it as their "port of call"). The study proposes the model, tests it using a Taiwanese port, and concludes that the frequency of ship calling (i.e., the number of scheduled intermediate stops by ships at the port, which determines the value of cargo moved through the port), is important to shippers.

In an article, Ruriani (2009) discussed guidelines when selecting the right port from a shipper's perspective. It suggests considering the location of the port, in terms of proximity to the customer and labor availability. A port's infrastructure investment (in terms of navigation channel access, landside transportation, terminal capacity, and intermodal options) should be high on the list. Additionally, knowing the port's restrictions, Foreign Trade Zone (FTZ) access, its technological capability, and operating hours must be considered when selecting the port.

Chou (2010), discussed the choice of port callings from the shipping carrier's point of view. The study highlighted the importance of port choice decision in the international trade and transportation industry and how the optimal selection of port callings can reduce the total transportation cost. It constructed an AHP model to simulate the behaviors of carriers' port choices and identified the weight of influential factors influencing carriers' port choices in the multiple-ports region.

Tang et al. (2011) developed a network-based choice evaluation model that integrated the elements of a port service network with observational port attributes to identify important characteristics on which liner shipping companies base their port choices. Based on an empirical study, it found that port efficiency and economies of scale are the two important dimensions influencing liner shipping companies' selections in Asia.

Fung et al. (2013) examined how the supply chain arrangement of a shipper affects its port of O/D selection and vice versa. It investigated the interaction between the port of call selections of shipping lines and shippers in Australia. Based on their interviews with shipping lines, freight forwarders, and importers they found that shippers' supply chain arrangements influence their port of O/D selections, but are not considered important by shipping lines in their port of call selections. The author mentioned that this may be due to the restricted port choices of both the shippers and the shipping lines, a result of the spatial characteristics of Australia.

Zarei (2015) aimed to identify the key factors in a shipping company's port selection process. To identify and rank factors that play a role in selecting the port, it adopted a questionnaire-based survey approach. Responses from the main shipping companies' operators in Iran revealed that the level of services of supplying companies and customs rules play an important role in selecting the ports.

From this review/discussion, we can see that the existing literature reveals a considerable range of factors affecting the decision of port choice. Some of these factors are quantitative, while others are qualitative. By quantitative factors, we mean the ones that can potentially be measured and compared in an unbiased way. Qualitative factors, on the other hand include feelings and experiences of a shipper with a port. Factors such as a port's marketing efforts, its flexibility and ease in processes, cargo care, influences of port rules, and policies on shippers are subjective. Our focus in this paper is to consider a shippers' viewpoint in selecting a port. (Please note, by shipper, we mean the firms who supply or own the commodities shipped. A shipping line or carrier is a company that transports goods for the shipper; they are the vessel operators and carrier of the cargo. The decision of port selection is made by the shipper or the shipper's agents [freight forwarders].)

For a shipper in its quest to choose the right port, distinction between quantitative and qualitative factors often becomes unimportant and, in many cases, perceptions take precedence over actual performance of the port. For this reason, we adopt an AHP-based methodology in this paper. The advantage of AHP is it allows using logic, human intuition, experience, and information to estimate relative magnitudes and compare alternatives in pairs. The method decomposes the goal of the problem and builds a problem structure comprised of its criteria and alternatives. In the next section, we describe our research methodology.

RESEARCH METHODOLOGY

To meet our study purpose, we adopt the following methodology:

1. Develop a list of factors that may influence a shipper's port choice. The criterions were identified based on the literature survey and our knowledge/experience in the industry (please note the co-author of this paper works for a large freight forwarding company in Pennsylvania and serves as a shipper for large vendors).
2. Structure the problem in an AHP framework.
3. Create a survey form using an MS Excel spreadsheet for customers/shippers in the region, so the participants can input their comparative scores.
4. Analyze the data received from the survey respondents and prioritize factors important to shippers when choosing a port using an Analytic Hierarchy Process.
5. Present the results, validate them, and provide conclusions from the study.

Developing a List of Factors

Based on the literature review, interviews with local shippers, and our experience, the following factors that influence a shipper's port choice decision were identified:

- Port Infrastructure – equipment availability, adequacy of port facilities
- Cost - port charges, delivered price, cost of pilotage, towage, customs
- Port's efficiency – turnaround time and facilities for loading/unloading freight, grouping, and freight consolidation
- Congestion at the port – delays (speed of getting through ports), labor problems
- Cargo volume – total TEUs handled at the port and current volume at the port, number of sailings, average size of vessel handled at the port
- Pickup and delivery times
- Information conveyance (the action or process of transmitting and communicating information from one place to another) concerning shipments, availability of technology, and communications systems

- Intermodal/connecting links – sailing frequency of deep-sea and feeder shipping services (the service that transports shipping containers from different ports and brings them to a central container terminal where they are loaded to bigger vessels)
- Empty container management – storage and distribution
- Quality and reputation of terminal operators – their efficiency of cargo handling, and the internal competition (the nature of competition that exists among the different terminal operators within a given port)

Some additional factors were also considered in the beginning of the study, but they were left out later from the research after consulting with industry experts. These excluded factors were:

- Special freight/odd-size shipment handling capability
- Loss and damage frequency
- Port's services – on-site custom clearance, assistance in claims handling and loss & damage performance
- Port security – safety and environmental profile of the port
- Involved government bodies

Structure the Problem in AHP Framework

Analytic Hierarchy Process (AHP) is one of the multi-criteria decision-making methods (Saaty 1999). It uses a system of pair-wise comparisons that determines the dominance of one element over another, with respect to a given attribute. AHP uses qualitative and quantitative approaches to solve decision-making problems. Qualitatively, the problem is decomposed into a hierarchy of elements and then analyzed. Quantitatively, the set of attributes is prioritized to distinguish the more important alternatives from the less important ones.

To understand the applicability of AHP, let's take a simple example and then tie it to the research problem in this paper. Consider a company that aims to maximize its profit. The company is looking for a product that may fit its specific needs of easy installation, easy learning/adoption, reliability, and product safety. The company finds three different products in the market that can help increase its profits, but there is not one product that will meet all its four criteria. Each product provides the company with a unique advantage; one saves the company on energy bills, the second increases its labor productivity, and the third brings automation and increases its existing process efficiency. The company is now in a dilemma as to which product to buy. At this point, the company may adopt AHP methodology and by placing relative weights on each criterion with respect to each product, it can come to a conclusion and make a rational decision on its product choice. Similarly, this paper's goal is to identify the right port to ship a shipper's cargo. Considering the right port selection as a profit maximizing goal and different product alternatives as different port regions in the country, the two problems will carry similar AHP problem structures. The criteria (such as ease of installation, ease of adoption, product reliability, and product safety), can be compared to the criteria for the port selection decision, as listed above.

Understanding AHP Methodology

The AHP is a tool of measurement based on pairwise comparisons. It relies on the judgments of experts to derive priority scales. The process helps measure intangible factors in relative terms. The comparisons are made using a scale of absolute judgments that represent how dominant one factor is in comparison to another (Saaty 2008).

To make an organized decision, AHP requires a clear problem definition. Once the problem is defined, a structural hierarchy of the decision from top to the bottom is created. The goal of the decision (problem statement) is at the top, followed by the intermediate levels (criteria and sub-criteria), to the lowest level (which usually are alternatives).

AHP uses a set of pairwise comparison matrices, where each element in an upper level is compared with the elements in the level immediately below. First, priorities are derived for the criteria in terms of their importance to achieve the goal. Then priorities are derived for the performance of the alternatives on each criterion. To make comparisons, AHP provides a scale of numbers that indicates how many times one element is more important than another with respect to the criterion to which they are compared. A weighting and adding process is used to obtain overall priorities for the alternatives as to how they contribute to the goal. With the AHP, a multidimensional scaling problem is thus transformed to a unidimensional scaling problem.

Step-by-Step AHP Process

Step 1. Develop a pairwise comparison matrix for a criterion by rating the relative importance between each pair of decision alternatives. In our case, these comparative scores are provided by the survey respondents (shippers). Respondents are provided with the standard AHP scale (Table 2 below) to fill the relative scores in the matrix.

Table 2: The Fundamental AHP Scale of Absolute Numbers (Saaty 1999)

Intensity of Importance	*Definition*	*Explanation*
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

Step 2. Develop a normalized matrix by dividing each number in a column of the pairwise comparison matrix by its column sum.

Step 3. Develop the priority vector (weight) for the criterion by averaging each row of the normalized matrix.

Step 4. Measure the consistency of the inputs in the matrix by calculating a consistency ratio (explained below). A consistency ratio of less than 10% is preferred, while up to 20% is acceptable.

Step 5. Summarize the results in the priority matrix by listing the decision alternatives horizontally and the criteria vertically.
Step 6. Repeat steps 2–5 to develop a similar matrix with another criterion.
Step 7. Lastly, construct an overall priority vector by multiplying the priority matrix (from step 5) by the criteria priority vector (from step 6).

Steps in Calculating the Consistency Ratio

Step 1. For each row of the pairwise comparison matrix, determine a weighted sum by summing the multiples of the entries by the priority of its corresponding (column) alternative.
Step 2. For each row, divide its weighted sum by the priority of its corresponding (row) alternative.
Step 3. Determine the average (known as lambda-max) of the results of step 2.
Step 4. Compute the consistency index, Cl, by using CI = (lambda max - n)/(n -1), where n = number of criterion in a given matrix.
Step 5. Determine the random index, RI using the standard table (Table 3) provided by Saaty (1999).

Table 3: Saaty's Standard Random Index (RI) Scale

Number of Decision Alternatives (n)	2	3	4	5	6	7	8
Random Index, RI	0.16	0.58	0.9	1.12	1.24	1.32	1.41

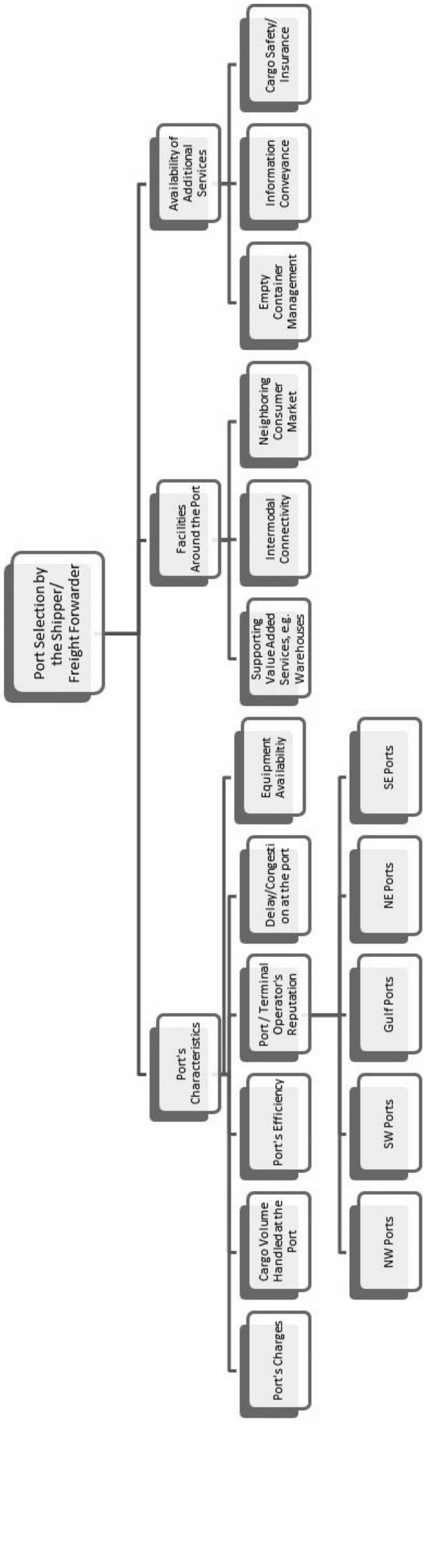
In our paper, the goal is to determine the shipper's choice of port. The criterion and sub-criterion illustrate factors that influence a shipper's port choice decision, and the alternatives are different port regions in the country. Priorities and weights are provided by industry experts (shippers or freight forwarders). For this study, a hierarchy is built with the goal, criteria, sub-criteria, and alternatives, as shown in Figure 1. The goal is to identify some of the critical factors that influence a shippers' port choice.

Table 4 provides a clear list of all criteria and sub-criteria used in this study's AHP framework.

Table 4: AHP Framework for Port Selection Decision

Criteria	Sub-criteria
	Port's charges Cargo volume handled at the port Port's efficiency Port/terminal operator's reputation Delay/congestion at the port Equipment availability
Facilities Around the Port	Supporting value-added services (warehousing) Intermodal/hinterland connectivity Neighboring consumer market
Availablity of Additional Services	Empty container management Information conveyance (EDT) Cargo safety and insurance

Figure 1: AHP Structured Problem on Shipper's Port Selection



Survey

After developing the AHP framework, an Excel-based survey was created for regional shippers. The participants in this survey are involved in the chemical and life sciences industries in the northeast region of the United States. They represent mid- and high-volume containerized cargo shippers in the chemical industry. Lower volume shippers may be more “anchored” to a smaller group of ports due to a limited capability to control transportation costs. The sourcing and logistics management teams from these companies were asked to complete the survey. The responses came from clients’ sourcing teams along with feedback from clients’ logistics specialists and 3PL supply chain analysts. The decision to use mid- and high-volume shippers was based on the belief that there would be a more agnostic response to the survey if we targeted audiences that have the resources and capabilities to choose ports that best fit their commercial needs.

Survey participants move both package and bulk liquid cargo internationally. They range in annual global volume shipped from 20,000 to 60,000 containers shipped annually. Approximately 80% of the cargo is non-hazardous and 20% is hazardous. The majority of the products are bulk commodity chemicals with a smaller portion (approximately 10%) being specialty chemicals. A variety of equipment types are used in this industry group with standard, dry 20-ft and 40-ft containers making up a large portion of shipments. This includes the use of refrigerated and other temperature controlled containers. Products reach the ports of export by truck, rail, and intermodal operation. Bulk commodities leaving the U.S. tend to move via rail and intermodal to reduce the transportation costs. Specialty and smaller volume products tend to move via truck to reduce the uncertainty of transit times and risk of delayed arrival to port. The shippers’ overseas markets of the shipments are in China, Europe, and Latin America.

In all, 14 surveys were sent to different clients, of which five responses were obtained. While the number of responses (35%) received were low, the respondent weights and relative scores were close enough to run the analysis and validate the survey results. Respondents were asked not to consider bulk vessel transportation when considering their response to the questions. We also asked to only consider recent (past year) performance from ports and to take an objective approach in their evaluation.

Data Analysis

After receiving the raw relative scores on each criterion and sub-criterion from our survey respondents, we started performing the AHP analysis. Our complete analysis in an Excel worksheet can be found at this link: http://sites.temple.edu/nmittal/2016/05/06/port_selection/

Factors under the first criterion of “Port’s Characteristics” are analyzed first. Table 5 shows the subjective assessment of the importance of one factor over another; these comparative scores are provided by the survey respondents.

In this table, a value of “3” between cargo handled at port and port’s changes indicates that shippers consider volume handled by the port to be three times more important than the charges at the port when making their port selection decision. The value of “1/3” (reciprocal) indicates that for the comparative pair, shippers consider port charges as three times less important than the cargo (volume) handled at the port. Survey respondents were asked to fill values only in the upper triangular matrix since the lower left is only a reciprocal of the upper triangular matrix.

Table 5: Raw Relative Scores Received on "Port Characteristics"

	Cargo Handled at Port	Port's Charges	Port's Efficiency	Operator's Efficiency	Delay/ Congestion	Equipment Availability
Cargo Handled at Port	1	3	1	5	1/9	1/8
Port's Charges	1/3	1	1/8	1/6	1/9	1/8
Port's Efficiency	1	8	1	3	1/9	1/8
Operator's Efficiency	1/5	6	1/3	1	1/9	1/8
Delay/ Congestion	9	9	9	9	1	9
Equipment Availability	8	8	8	8	1/9	1

The next step is to normalize the scores. We calculate the overall weight that the respondent assigns to each criterion by taking each entry and divide it by the sum of the column it appears in. We then average the normalized quantities (row-wise) to come up with weight for each sub-criterion (such as Cargo Handled at Port, Port's Charges, Port's Efficiency, Operator's Efficiency, Delay/ Congestion, and Equipment Availability) within the "Port Characteristics" criterion. By averaging across each row, we correct for any small inconsistencies in the decision-making process. This average is between 0 and 1, and the total weights add up to 1. At each stage, the values are checked for consistency ratio. Table 6 shows the average normalized weights (importance) of factors under "Port Characteristics."

Table 6: Weightage on Sub-Criterion Under "Port Characteristics"

Factors	Weight
Cargo Handled at Port	9.0%
Port's Charges	2.6%
Port's Efficiency	10.3%
Operator's Efficiency	6.2%
Delay/ Congestion	43.3%
Equipment Availability	28.5%

This suggests that the Delay or Congestion at the port at 43.3% is the most important sub-criteria for shippers, followed by equipment availability at 28.5%, within the "Port Characteristics."

Our next step is to evaluate all sub-criterion separately within 'Port Characteristics' to determine their choice of a port region (NW, SW, Gulf, NE, and SE). For instance, if we take "Cargo Handled at Port," we determine if the shippers prefer one region over another, based on that particular factor. Similarly, the weights are calculated for each sub-criterion under the "Port Characteristics" criterion. Table 7 shows the summarized evaluation of port regions based on all sub-criterions within the "Port Characteristics."

Table 7: Evaluation of Port Regions Based on "Port Characteristics"

NW ports	SW ports	Gulf ports	NE ports	SE ports
0.200	0.213	0.305	0.089	0.192

Results show that with 30.5%, Gulf port region is the most preferred port region by our survey respondents. Similar analysis is performed on the other two criterions – "Facilities around the port" and "Additional services available at Port," as shown in Tables 8, 9, 10 and 11.

Table 8: Weightage Calculated on Sub-Criterion Under "Facilities Around the Port"

Factors	Weight
Nearby Warehousing Services	0.26
Intermodal Connectivity	0.92
Consumer Market	0.08

Table 9: Evaluation of Port Regions Based on 'Facilities Around the Port'

NW	SW	Gulf	NE	SE
0.043	0.058	0.532	0.147	0.220

Considering "Facilities Around the Port," at 53.2% Gulf port region is most preferred, followed by Southeast, Northeast, Southwest and Northwest port regions.

Table 10: Weightage Calculated on Sub-Criterion Under "Additional Services"

Factors	Weight
Empty Container Management	6.9%
Information Conveyance	29.8%
Cargo safety/ Insurance Policy	63.2%

Table 11: Evaluation of Port Regions Based on "Additional Services"

NW ports	SW ports	Gulf ports	NE ports	SE ports
0.1357	0.1380	0.3544	0.1832	0.1887

Considering "Additional Services," at 35.44% Gulf port region is most preferred.

After individually evaluating all the sub-criterion for port selection criterion, analysis was summarized using the relative importance among the three primary criterion. After normalization, the weightage on three primary criterions is calculated and results are shown in Table 12.

Table 12: Weightage on Port Selection Decision-Making Criterion

Criterion	Weight
Port Characteristics at Port	0.723506
Facilities Around the Port	0.193186
Additional Services at Port	0.083308

After calculating the weights and relative importance of each criterion and sub-criterion in the problem, final calculations are made by multiplying priority weights for each criterion in Table 12, by their criterion-based weights in Table 7, Table 9, and Table 11. These final values highlight the port region that is most attractive to our survey respondents (shippers who are shipping both full container and LCL cargo of hazardous and non-hazardous chemicals westbound – from U.S. to Asia). Table 13 shows the final results.

Table 13: Evaluation of Port Regions Based on Port Selection Criterion

Region	NW ports	SW ports	Gulf ports	NE ports	SE ports
Weight	16.5%	17.7%	35.3%	10.8%	19.7%

RESULTS INTERPRETATION AND VALIDATION

Let us now understand the results from above tables and see if they can be validated using our knowledge and industry literature. Table 6 above shows that within the Port Characteristics, delay/ congestion at the port (with 43.3% weightage) is the most important factor for shippers in recent times. Ports play a significant role in goods movement and any delay in a product's transportation increases costs and disrupts its sales and inventory levels for all players (supplier → manufacturer → retailer/ customer). While Table 6 highlights the importance of delay at the ports, Table 7 identifies ports in the Gulf region as most preferred to shippers. Industry articles (Garrett 2016) highlight this pattern and report that West Coast ports have lost their market share to eastern and Gulf ports in the last two years due to problems with delays and congestion at the port. The article estimates that east and Gulf ports receive approximately 34% of containerized imports from Asia today, compared to 29%, just two years ago.

Table 8 shows that among all different sub-criterion within the "Facilities Around the Port," "intermodal connectivity" is of utmost importance to shippers. By intermodal connectivity, we mean the capability of the port to move cargo inland using trains and trucks. Table 9 indicates the preference of Gulf ports over other port regions. This result can be validated given the massive public and private investment in the Gulf port region for hinterland connectivity and their improved links (Federal Maritime Commission 2015).

Table 10 highlights the importance of safe cargo to shippers when compared with the empty container management or conveyance of information at the port terminals. With rising security risks, cargo safety stood out to be an important factor for shippers. Table 11, again indicates the preference for Gulf ports (at 35.44%) over eastern and western port regions under the criterion of "Additional Services."

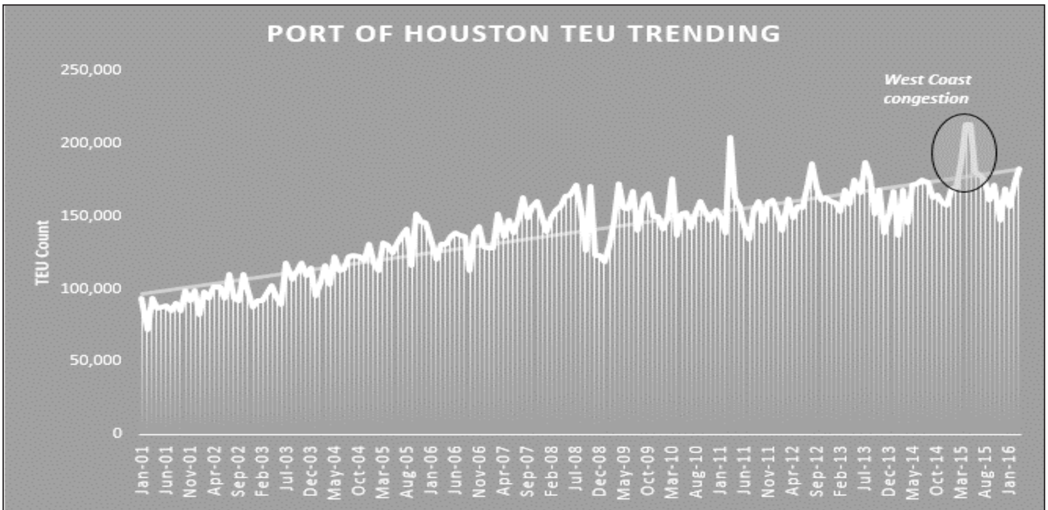
Table 12 shows the weightage of individual three criteria, indicating that "Port Characteristics" is most important to shippers when compared against "Facilities Around the Port" and "Additional Services." Within "Port Characteristics," we found that Delay/ Congestion is most important to the shipper, and not the volume handled or cost or efficiency of the port. Table 13 shows the final decision; at an overall weightage of 35.3%, Gulf ports are the most preferred.

We infer from this analysis that port regions can lose their competitive advantage and market leadership if they are unable to keep up with increasing demands of trade. The unsettled scene at West Coast ports in the latter part of 2014 and early 2015 has changed the shipper's criterion for port selection and "congestion at the port," has become foremost important of all factors that decide a shipper's port of export today.

We found that these findings are synchronous with some of the recent industry news reports and surveys that showed an increased attractiveness of Gulf ports due to the congestion at West Coast ports. In February 2015, National Public Radio (Northan 2015) reported that "The ongoing disruptions at the West Coast seaports are forcing companies to put on more ships and reroute them." It also indicated that while the first inclination to divert the cargo was toward the West Coast ports of Canada, but soon due to the insufficient rail and road network in that region, U.S. shippers leaned toward using alternatives in ports of Mexico and along the Gulf Coast.

During the same period, a *Journal of Commerce* (Szakonyi 2015) article also noted that 65% of shippers in its own survey expressed an interest in diverting their cargo from West Coast. Of this, nearly 23% of the shippers said the majority of their freight would head to U.S. Southeast ports, which experienced virtually no congestion over the recent past, while 16% said they would move the majority through U.S. Gulf Coast ports. In our case, since the shippers moved cargo westbound, Gulf ports were more attractive than the eastern region. In another article from August 2015 (Mongelluzzo 2015), it was reported that East and Gulf Coast ports experienced double-digit increases in container volumes due to cargo diversions from the West Coast. Figure 2 below shows the surge in TEU-volume at the Port of Houston.

Figure 2: Container Volume Surge at Port of Houston due to West Coast Congestion



Source: PHA Marketing and External Communications based on raw data from PHA Accounting. Date: April 14, 2016. Unaudited data. Contains some estimates. May not match other sources. May containe miscellaneous other errors. Note: Only includes containers handled at Port of Hourston Authority-owned facilities (including Bayport Terminal, Barbours Cut Terminal, APM Houston). These facilities handle the vast majority of Houston-area containers. Does not include a small number of containers handled at private terminals in the Houston area. http://www.portofhouston.com/static/gen/business-development/Origination/Container_Volume_TEU_stats_in_depth_March_2016.pdf

In October 2016, Food Logistics (Garrett 2016) reported that due to the Panama Canal expansion, the increases in the Gulf are anticipated and planned for. Studies predict as container shipping lines adjust their schedules and services to include post-Panamax ships, Gulf ports' cargo share will see cargo increases in the range of 8% to 12% in 2017.

Congestion at all major gateways on the West Coast grew worse in early 2015 when the Pacific Maritime Authority retaliated by withholding lucrative night and weekend work opportunities from longshoremen. This occurrence changed the dynamics for the global maritime shipping industry, and a significant change was noticed in the shipper's behavior and their port selection criterion.

CONCLUSION

This research study focuses on how shippers' port choices are influenced by maritime events and disruptions in their supply chains. The survey and presented analysis emphasizes the dynamic nature of international trade and shipping.

Shippers' port choice decision is a well-studied subject in the literature. However, to the best of our knowledge, this paper is the first of its kind that indicates the impact of delays and port congestion on shippers' priorities when making a port selection decision. Traditionally, only price and port characteristics were the two primary decision factors. Operationally, this finding can help terminal operators and port authorities strategize their resources and gain a competitive advantage for their port. Maritime industry is an ever changing industry, and with higher reliance on just-in-time delivery and lean inventory management in addition to our complex and elongated supply chains, transportation delays can be very expensive for shippers and their customers.

The paper finds that shippers now view their global supply chains with ever increasing clarity. Evolving changes in ocean transportation, such as the widening of the Panama Canal, ocean carriers adding larger vessels to their fleet, and global maritime policy changes such as SOLAS, can now be built into risk and supply chain models, helping the shipper determine the impact to supply chain performance and their expenditure spend. Shippers are using these risks and spend models along with the current imbalance of vessel space supply and demand, low bunker (ship fuel) rates, and carrier alliances to optimize their transportation lanes and ocean port selections. While the results obtained in this study could be a special case because of the nature of the products shipped, it is important to understand that in today's competitive environment, it is imperative that port managers develop the ability to determine the critical port selection factors their users desire and form policies that support their objective.

LIMITATION AND FUTURE WORK

AHP is a concise analytical method for decision making, but often considered subjective. To ensure the reliability of the results, a comparison of results from different methods may be observed to explain the superiority of the chosen method. Another research direction could look into a correlation analyses between influencing factors and shippers' selection decision.

Notwithstanding the caveats to our results due to the underlying model selection and formulation, we feel this analysis will be very valuable to port managers and planning authorities in strategically creating and implementing viable and effective policies for attracting shippers. In an era of intense port competition, where it has become essential for port authorities, port managers, and terminal operators to have a thorough understanding of the factors that influence shippers' port choice, this article helps them recognize and understand the factors that have recently become more significant and directly affect their (port) performance and viability.

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Investigating Mixed Logit Analysis of Critical Headways at a Single-Lane Instrumented Roundabout

by Alex Hainen

This paper examines 29,403 entering vehicles that rejected two or more headways for a total of 69,123 rejected headways. A detailed series of temporal parameters was established and used to estimate a mixed binary logit model and understand rejection/acceptance decisions. This technique allows for the parameter estimates to vary across the population and across the set of decisions that drivers made and suggests that drivers may modify their critical headway as they wait at the yield bar. The results from this paper indicate that future consideration of capacity using a dynamic critical headway could be useful in modeling and capacity estimation.

INTRODUCTION

Roundabouts have gained much popularity and usage in the United States over the past decade. As designers and planners start to consider them as an alternative, much effort has been spent in capacity analysis during the design phase. One popular analysis technique is to use microsimulation. Microsimulation involves running a virtual model of the intersection or facility under user defined conditions and recording the observed performance. The critical headway is a very important setting for microsimulation. Critical headway is the minimum amount of time between circulating vehicles that a driver entering the roundabout will choose to proceed.

Critical headway at roundabouts has been studied for decades. Some of the earliest work on the subject was conducted in the 1970s in the UK and has evolved over time (Kimber 1980). Other work over time has included studies by Troutbeck (1992), Wu (2012), Raff and Hart (1950), Siegloch (1973), Polus et al. (2005), Pimentel et al. (2013), and Gazzari et al. (2012). One of the popular methods that emerged was the logit analysis, which predicts the probability of accepting a headway as $P_a = \exp(U_a) / (1 + \exp(U_a))$ where U_a is a utility function based on the circulating headway and the waiting time at the yield bar (Hewitt 1983). These equations can be calibrated in the field and the critical headway is then identified as the headway that is acceptable to half the drivers. In other words, the critical gap is identified when $P_a = P_r$ (where P_r is the probability of rejecting a headway, or $P_r = 1 - P_a$). This model can also be extended with a more robust mixing formulation discussed further in the methodology section.

Another popular critical headway estimation technique is the maximum likelihood approach (Tian, et al. 1999). This method identifies each driver's critical headway by comparing the largest rejected headway and the accepted headway by assuming a probabilistic distribution. Troutbeck (1992), Brilon et al. (1999), and Weinert (2000) have studied the impact of different distributions in their works. Another analysis by Wu (known as equilibrium of probabilities) is also used to estimate the critical headway. The equilibrium of probabilities uses a macroscopic model that doesn't need an *a priori* assumption about the distribution as required in the maximum likelihood method. Each of these techniques have numerous papers by their authors.

The fundamental challenge with the critical headway is that it cannot be directly measured and is, instead, a latent value that must be estimated using various techniques. The critical headway has been traditionally estimated as a fixed value and does not accommodate change by driver or by headway sequence. In other words, the critical headway for drivers does not change as drivers wait at the yield bar to enter the roundabout even though the drivers are likely assembling short-term observations to calibrate their own critical headway. However, drivers waiting at the yield bar may be subject to several sequential headways where they will learn and change their decision making on accepting or rejecting a headway. To accommodate this phenomenon, mixed logit analysis is used in this paper to understand additional factors and reveal information about the driver decision-making process.

OBJECTIVE

The objective of this paper is to understand how the critical headway may be changing as drivers wait to enter a roundabout and variations across the sample population. As drivers wait at the yield line, each sequential headway is an opportunity for drivers to calibrate themselves to current traffic flow. This paper examines how drivers are using observations and other pieces of information to adjust their critical gap. Technological advances allowed a single-lane roundabout to be instrumented and observe a large sample of nearly 100,000 acceptance and rejection decisions of headways over six weeks. Mixed binary logit analysis is used to further support the notion that critical headways change as drivers wait at the yield bar. This analysis will help shape future estimation of critical headways using contemporary modeling techniques. The characteristics identified in the model can be considered by researchers within a simulation environment to enhance microsimulation analysis at roundabouts.

DATA COLLECTION

The single-lane roundabout at W 106th St, Spring Mill Rd in Carmel, IN, was instrumented with 12 wireless magnetometers to provide vehicle detection at the entrance, exit, and circulating path of each of the four approaches (Hainen, et al. 2013). This roundabout has been in operation for over 10 years and the driver population is considered experienced with roundabouts (Carmel, IN, is a community with over 70 roundabouts). The sensor layout is shown in Figure 1, where the two-letter label indicates (1) the approach and (2) the sensor position (for example, "We" indicates the west approach entering sensor). Sensors were field-located and installed between the wheel tracks of the vehicle paths (redundant sensors were placed wide outside of the wheel tracks, but not necessarily based upon matching data with the primary sensors more than 99.5% of the time). Detection records were recorded over six weeks from mid- July to late August, 2012. The roundabout is in a residential area and video data for the first two weeks were analyzed to confirm minimal truck traffic (much less than 1%). Due to the expensive equipment and complex installation, this was the only roundabout instrumented for this study.

The wireless magnetometers work similarly in logical operation to a traditional inductive loop detector. When a vehicle occupies the detector, an "on" state is noted and logged to the nearest millisecond. When the vehicle leaves the detector, an "off" state is noted and also logged to the nearest millisecond. (There are a few other detector diagnostic statuses in the data, but the "on" and "off" records are all that are required for the analysis in this study.) Figure 2 shows an actual field-documented and recorded example where vehicle E1 is waiting to enter the roundabout. Vehicle E1 rejected five headways (including the arrival headway) and accepted on the sixth headway. This indicates that a headway of 3.77 seconds was larger than the critical headway for driver E1 where the driver determined there was enough room to enter the roundabout. Figure 3 shows this particular example as synthesized with video data. It is important to note that the video was not used for data reduction as in many past studies and that the video is only used to confirm the detector data. The sample sensor data are shown in Table 1. These data are then reduced to a series of headways and decisions.

Figure 1: Sensor Layout at the Roundabout at Spring Mill Rd @ W 106th St

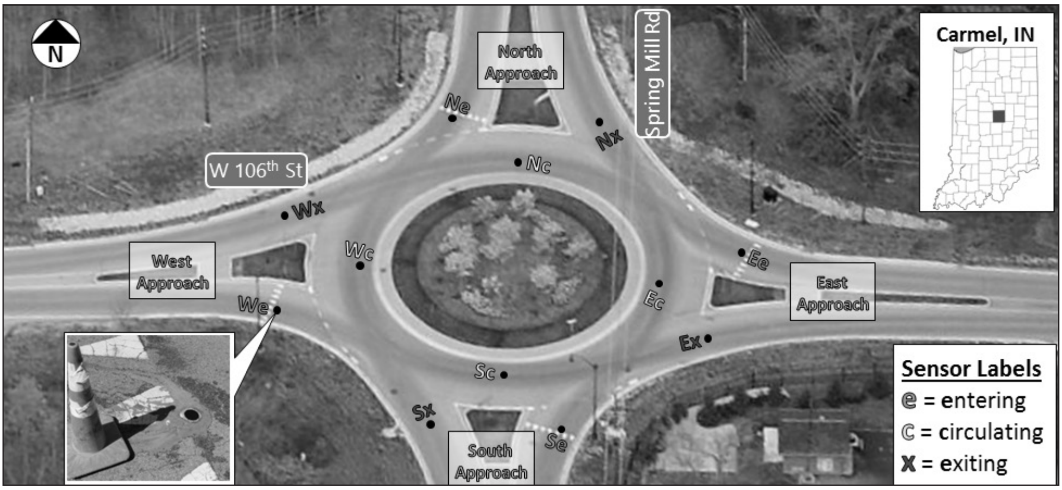
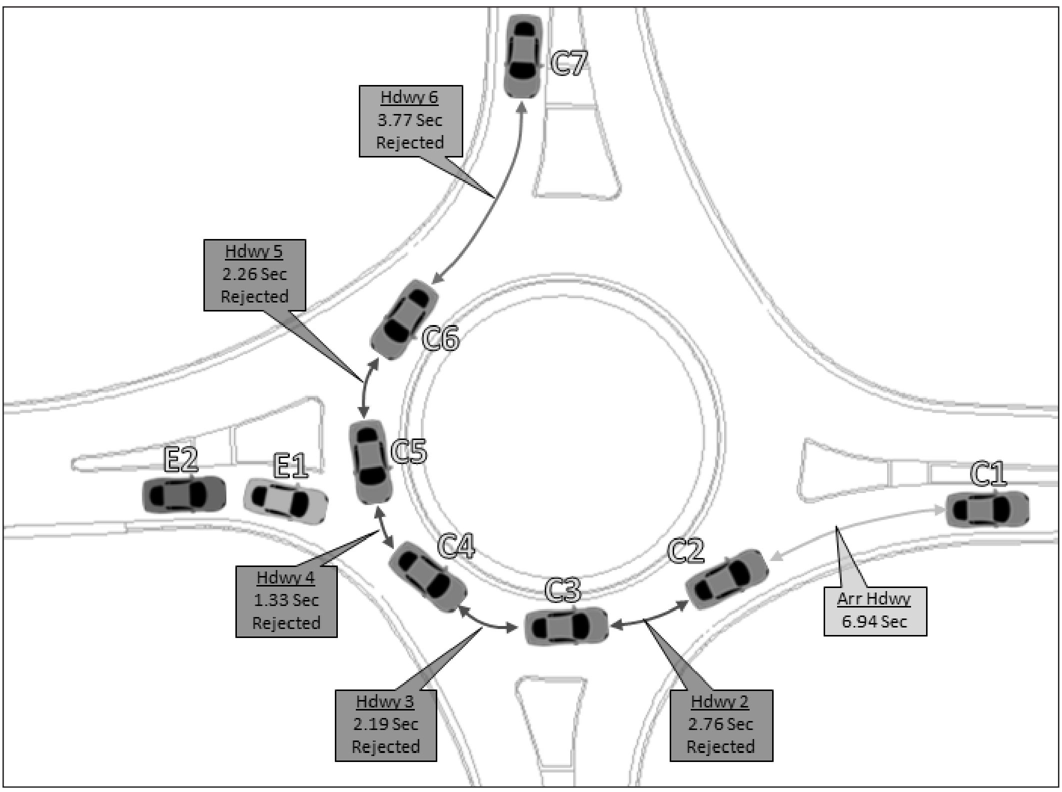


Figure 2: Example of a Vehicle Waiting to Enter the Roundabout



One important note for the examples in Figure 2 and Figure 3 is that the arrival time was also likely larger than the critical headway. For this particular case, the driver arrived at the yield bar at nearly the same time as the first circulating vehicle (C1 in Figure 2) arrived and thus the entering vehicle E1 had to yield. This dynamic of arriving vehicles and circulating vehicles is dependent on many parameters. Since the aim of this paper is to evaluate how critical headway is changing over time, the final reduced set of data used in the models only considers vehicles that, at a minimum, rejected headway #2. This ensures that each entering vehicle came to a stop and that drivers assessed a minimum of two headways before accepting. Since the first rejected headway upon arrival is unbounded, it was not used in the data set. The second rejected headways for these vehicles were used along with subsequent rejected headways to build the final data set.

Figure 3: Video Observation of Example Vehicle Waiting to Enter the Roundabout

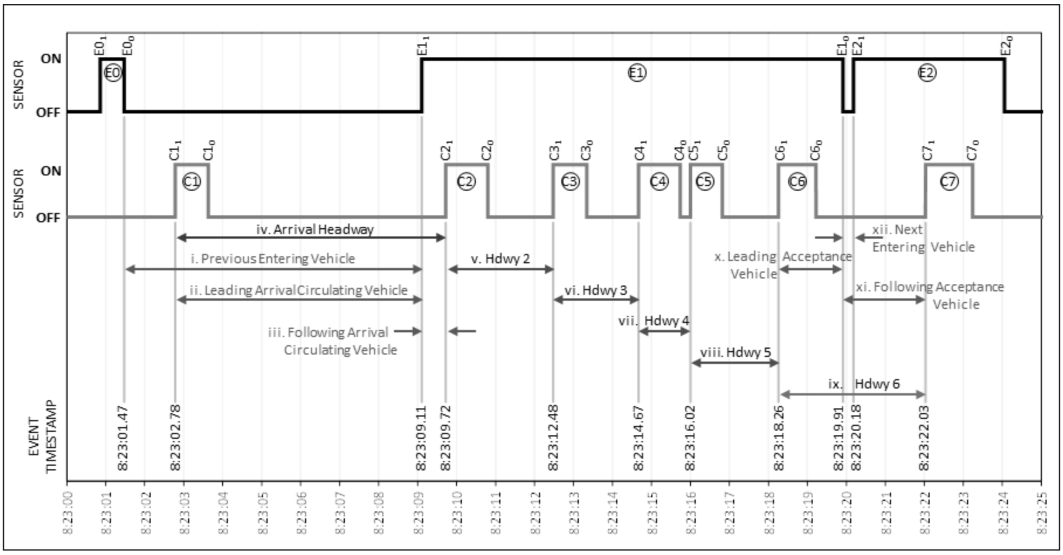
Table 1: Sample Sensor Data from Example Vehicle Waiting to Enter the Roundabout

SENSOR	STATUS	VEH-ID	CODE	TSTAMP
Entering	ON	0	E01	7/12/2012 08:23:00.86
Entering	OFF	0	E00	7/12/2012 08:23:01.47
Circulating	ON	1	C11	7/12/2012 08:23:02.78
Circulating	OFF	1	C10	7/12/2012 08:23:03.63
Entering	ON	1	E11	7/12/2012 08:23:09.11
Circulating	ON	2	C21	7/12/2012 08:23:09.72
Circulating	OFF	2	C20	7/12/2012 08:23:10.80
Circulating	ON	3	C31	7/12/2012 08:23:12.48
Circulating	OFF	3	C30	7/12/2012 08:23:13.34
Circulating	ON	4	C41	7/12/2012 08:23:14.67
Circulating	OFF	4	C40	7/12/2012 08:23:15.74
Circulating	ON	5	C51	7/12/2012 08:23:16.02
Circulating	OFF	5	C50	7/12/2012 08:23:16.82
Circulating	ON	6	C61	7/12/2012 08:23:18.26
Circulating	OFF	6	C60	7/12/2012 08:23:19.22
Entering	OFF	1	E10	7/12/2012 08:23:19.91
Entering	ON	2	E21	7/12/2012 08:23:20.18
Circulating	ON	7	C71	7/12/2012 08:23:22.03
Circulating	OFF	7	C70	7/12/2012 08:23:23.24
Entering	OFF	2	E20	7/12/2012 08:23:24.06

Assembly of Records for Modeling

The raw sensor data were turned into a series of variables that could be used for modeling. An example of the reduced data for vehicle E1 is shown in Figure 4. The upper square wave shows the ON/OFF status for the entering sensor and the lower square wave shows the ON/OFF status for the circulating sensor. By referencing key times, a series of temporal variables is established to generate a series of records for each rejected/accepted headway. Headway was calculated as the time from the “on” event of vehicle n to the “on” event of vehicle n+1 for the circulating sensors (items “iv” to “ix” in Figure 4). The delay of the entering vehicle was calculated from the “on” time to the “off” time of the entering sensor for each entering vehicle. By pairing both the entering and circulating records, the number of headways each entering vehicle rejected was observed along with the magnitude of each headway. From this set, each headway could be used to build a cumulative average, minimum, and maximum rejected headways. These are important variables that summarize the decisions that a driver made while waiting.

Figure 4: Visualization of Sensor Data and Temporal Variables Used for Modeling



Other key temporal variables include the position of the entering vehicle in time relative to both of the *circulating* vehicles for the arrival headway (items “ii” and “iii” in Figure 4) and both of the *circulating* vehicles for the acceptance headway (items “x” and “xi” in Figure 4). Lastly, temporal variables describing the entering vehicle E1 position relative to leading and following *entering* vehicles were compiled. Item “i” in Figure 4 shows that substantial time had passed between the previous entering lead vehicles E0 and E1. This indicates that vehicle E1 was not waiting in a queue (this is important since queued vehicles may be pre-calibrated by observing headways of the leading entering vehicle as they wait in the queue). Also, item “xii” in Figure 4 shows the time between vehicle E1 entering the roundabout and the next entering vehicle arriving at the yield bar. This information indicates that, in this example, E1 had vehicle(s) queued behind waiting. This was hypothesized to add to driver distraction (realizing that vehicles were pulling up behind) and also driver pressure as they felt more urgent to accept a headway on behalf of entering for queued vehicles. This move up time is discussed in detail in NCHRP Report 572 (2001).

The final record set is summarized in Table 2. Each headway is a record and includes temporal information from some of the other headways experienced by the driver for a set. These data were also combined with entering, exiting, and circulating volumetric information, which is also pertinent information that drivers will leverage while making rejection/acceptance decisions.

Table 2: Assembly of Data Records for Example Vehicle Waiting to Enter the Roundabout

Observation Vehicle	Headway Number	Headway (Seconds)	Accepted headway indicator (1 = true, 0 = otherwise)	i. Time between previous entering vehicle (seconds)	ii. Time between leading arrival circulating vehicle (seconds)	iii. Time between the following arriving circulating vehicle (seconds)	iv. Arrival Headway (Seconds)	Cumulative average rejected headway from headway 2 to headway i-1 (seconds)	Cumulative maximum rejected headway from headway 2 to headway i-1 (seconds)	Cumulative minimum rejected headway from headway 2 to headway i-1 (seconds)	Cumulative delay (seconds)	ix. Accepted headway (seconds)	x. Time between the following the leading acceptance headway vehicle and entering the roundabout (seconds)	xi. Time between entering the roundabout and the following acceptance headway vehicle (seconds)	xii. Time between entering the roundabout and the next entering vehicle arrival at the yield bar (seconds)
E1	2	2.76	0	7.64	6.32	0.62	6.94	--	--	--	3.37	3.77	0.92	2.85	0.27
E1	3	2.19	0	7.64	6.32	0.62	6.94	2.76	2.76	2.76	5.56	3.77	0.92	2.85	0.27
E1	4	1.35	0	7.64	6.32	0.62	6.94	2.47	2.76	2.19	6.89	3.77	0.92	2.85	0.27
E1	5	2.24	0	7.64	6.32	0.62	6.94	2.10	2.76	1.35	9.15	3.77	0.92	2.85	0.27
E1	6	3.77	1	7.64	6.32	0.62	6.94	2.14	2.76	1.35	10.06	3.77	0.92	2.85	0.27

** Small Roman numerals (i., ii., ...) correspond to figures. Not all variables available for modeling.*

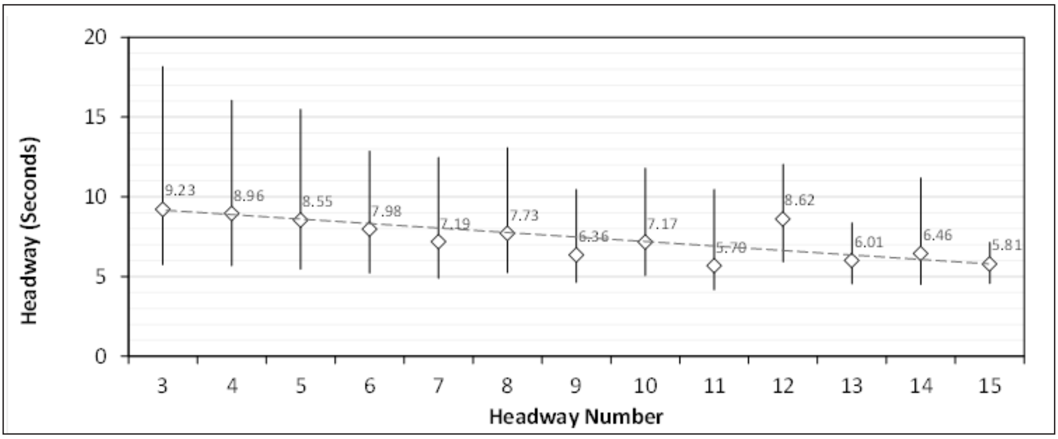
ANALYSIS AND RESULTS

Starting with empirical observations, stock plots based on the field-measured data for both the accepted and rejected headways are shown by headway sequence number (Figure 5). Each vertical bar represents the spread of the 25th and the 75th percentile headways, and the diamond marker represents the median headway. These figures provide some very intuitive evidence that the headways, by sequence, decrease as drivers wait. Since headway #2 was only considered for vehicles that rejected a minimum of two headways, the headways sequence starts on the third headway.

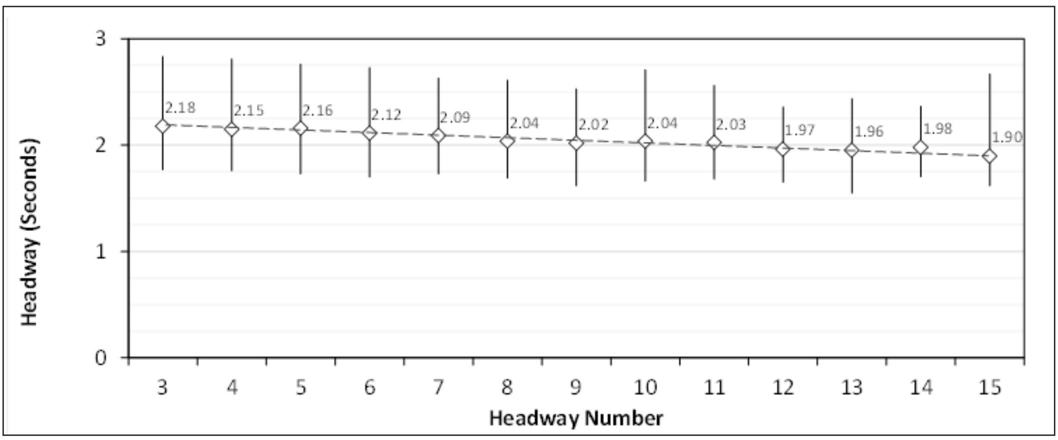
Decreasing acceptance headways (Figure 5a) means that drivers are willing to lower their critical headways a bit after rejecting several headways. This is also dependent on prevailing conditions at the roundabout where, under lighter conditions, drivers are able to accept larger headways in the earlier sequences, whereas drivers will feel forced to accept a much smaller headway during busy periods as they wait (this was clearly observed in the raw detector data and thus reflected in the model estimation).

With regards to the rejected headway decisions, the average rejected headway as drivers wait through a sequence of headways also decreases as sequence number increases (Figure 5b). This means that drivers are more discerning when they adjust their critical headways and only the tightest headways (headways that are now known to the driver to be extremely close to the critical headway) are rejected later on. This first-order magnitude, empirical analysis demonstrates that both the accepted and rejected headways are decreasing as the headway sequence increases.

Figure 5: Empirical Stock Chart Distributions (Quartiles 1, 2, and 3) of Headways by Headway Sequence (with Frequency Table)



a) Decreasing Mean and Interquartile Range of Accepted Headways



b) Decreasing Mean and Interquartile Range of Rejected Headways

Headway	2	3	4	5	6	7	8	9	10	11	12	13	14	>=15
Reject	15,152	7,568	4,016	2,267	1,376	886	608	424	313	230	178	136	102	77
Accept	N/A	7,584	3,237	1,586	809	439	252	156	104	71	49	37	31	88

c) Count of Rejected and Accepted Headways in the Final Dataset

As previously mentioned, the critical headway is recognized to be a latent value that cannot be directly observed. Turning again to Figure 5, the difference in the median accepted headway for headway sequence number 3 (9.23 seconds in Figure 5a) and the median rejected headway for headway sequence number 3 (2.18 seconds in Figure 5b) encompasses the actual critical headway. As the headway sequence increases, the difference between the median accepted headway and median rejected headway decreases. For example, the median accepted headway for headway sequence number 15 (5.81 seconds in Figure 5a) and the median rejected headway for headway sequence number 15 (1.90 seconds in Figure 5b) start to converge around the traditionally estimated critical headway value of 3.5 to 4.5 seconds. Traditional estimation techniques from Troutbeck (1992) and Wu (2012) may be used to estimate the critical headway, but this dataset lends itself to further analysis for understanding the driver decision-making process.

Mixed Binary Logit Analysis

In past estimation approaches by other researchers, binary logit analysis was an early technique used to estimate the critical headway. A binary logit model uses parameters to predict the probability of a driver making a discrete choice to either accept or reject a headway. Again, a utility function can be defined as:

(1) $U_n = \beta_i X_{in} + \varepsilon_n$

where X_{in} is a vector of data that characterizes the circumstances of a particular headway decision making instance. β_i is a vector of estimable parameters and is an error term. The estimation of β_i is done using maximum likelihood (Washington, Karlaftis, and Mannering 2011). The multinomial logit model (generalized formulation of the binary logit model) is based on McFadden's assumption that the error term ε_n in the utility function is distributed as a type 1 generalized extreme value, sometimes referred to as the Gumbel distribution (McFadden and Train 2000). The formula for a generalized multinomial logit then becomes:

(2) $$P_{in} = \frac{e^{\beta_i x_{in}}}{\sum_{\forall I} e^{\beta_i x_{in}}}$$

For the reduced binary decision case where only two choices are available (to accept headway or reject a headway), the model can be reduced to the binary logit form shown below. The equation for the binary logit shown below also includes a mixing function:

(3) $$P_{in} = \int \frac{1}{1 + e^{\beta_i x_{in}}} f(\beta|\varphi) d\beta$$

Where P_{in} is the mixed logit probability, which is a weighted average about the density function $f(\beta|\varphi)d\beta$ over varying parameter estimates (McFadden and Train 2000). For the mixing function, the β is the mean and the φ is the standard deviation of the parameter distribution. This mixing function allows the parameter estimates to vary over the sample data set instead of being fixed for all samples. A normal distribution was used for estimation in this analysis, but a variety of distributions could be used as the analyst determines is appropriate. Model estimation based on maximum likelihood was conducted using Halton draws or quasi-random selection for generating search space efficiently (Halton 1960).

Mixed Binary Logit Results

The mixed binary logit model was estimated using simulation-based maximum likelihood, and the results are shown in Table 3. Statistically significant variables were added based on the results of models that used different subsets of the variables. While models were estimated using the full 6-week dataset, a reduced dataset of 47,975 records was used to estimate the distributions of the random parameters due to software limitations (the difference in the distribution of variables was statistically insignificant, so consistent parameter estimates hold true). Estimates for fixed parameters are shown along with their t-statistics. It should be noted that large t-statistics are a function of large sample size (which is also the reason that all parameter estimates are significant at the α=1% level). For the random parameters, the means and standard deviations of the mixing distributions are included. The elasticities (and pseudo-elasticities for indicator variables) are shown in Table 4. These indicate the change in the probability of accepting a headway for a 1%

change (or one-unit change for indicator variables) in the independent variables (these are average values and will vary for the random parameters across the population). Variables were added and removed in a forward-selection fashion.

Table 3: Mixed Binary Logit Estimation Results for Headway Acceptance

Variable	Parameter estimate (Standard Deviation)	*t*-Statistic
Constant	-19.44	-47.84
Headway (seconds)	3.16 (1.61)	53.43 (52.12)
Headway sequence number (*number of rejected headways – 1*)	0.35	23.13
Cumulative yield bar delay greater than 10-seconds (*1=true, 0=otherwise*)	-2.77	-27.45
Previous one-minute circulating volume in front of the approach	0.035	4.82
Previous one-minute entering volume for the entire roundabout	0.029	5.83
Previous one-minute circulating volume at the upstream approach	0.039	4.82
Cumulative average rejected headway (*from headway 2 to headway*$_{n-1}$)	1.59	43.97
Time (in seconds) between arriving at the yield bar and the previous entering vehicle leaving the yield bar	-0.028	-11.63
Time (in seconds) between leaving the yield bar and the next entering vehicle occupying the yield bar	0.020	6.34
Time (in seconds) between the entering vehicle arriving at the yield bar and the first circulating vehicle passing in front of the approach	-0.021 (0.36)	-8.01 (15.19)
PM peak-hour indicator (*1=true, 0=otherwise*)	0.64	7.80
Weekday (Monday-Friday) indicator (*1=true, 0=otherwise*)	0.38 (0.18)	2.10 (4.31)
Sample size, *n (reduced set for distribution estimation)*	47,975	
Log-likelihood	-7990.06	

Turning to variable analysis, a positive parameter estimate indicates that drivers are less likely to reject a headway, and a negative sign suggests that a driver is more likely to reject a headway. The most pertinent information drivers use during the accept/reject decision-making process is (1) the size of the headway under consideration, (2) how many headways have been rejected, and (3) how long the driver has been waiting. The parameter for headway (in seconds) intuitively indicates that larger headways are more likely to be accepted. The random parameter aspect suggests that there are many other factors that will change the way a given headway looks to drivers depending on how long they've been waiting, how many headways they've rejected, and many other factors further discussed in the model. The fact that this variable has a distribution strongly indicates that a dynamic process of adjusting a driver's critical headway is evident, and the additional model variables help to identify some of these mechanisms. For item (2), as the number of rejected headways increases, the probability of accepting a headway increases. This is intuitive as drivers perceive each rejection as a unit that cumulatively increases the probability of accepting a headway. Also, drivers will be able to leverage the information from each rejected headway to better calibrate themselves where they'll be more likely to accept a headway. Finally, for item (3), sensitivity analysis was used to identify that a binary indicator variable of waiting more than 10 seconds at the yield bar was found to be highly significant for drivers where they will be less likely to accept a given headway. This may be due to conservative drivers who are willing to wait longer for an acceptable headway, or perhaps drivers who may have had sufficient time to identify a more acceptable headway further upstream where they desire to wait for a desirable headway.

Table 4: Elasticities for Mixed Binary Logit Model of Headway Acceptance

Variable	Elasticity
Headway (seconds)	0.0387
Headway sequence number (*number of rejected headways – 1*)	0.00433
Cumulative yield bar delay greater than 10-seconds (*1=true, 0=otherwise*)	-0.0339
Previous one-minute circulating volume in front of the approach	0.00043
Previous one-minute entering volume for the entire roundabout	0.00036
Previous one-minute circulating volume at the upstream approach	0.00048
Cumulative average rejected headway (*from headway 2 to headway*$_{n-1}$)	0.0195
Time (in seconds) between arriving at the yield bar and the previous entering vehicle leaving the yield bar	-0.00034
Time (in seconds) between leaving the yield bar and the next entering vehicle occupying the yield bar	0.00024
Time (in seconds) between the entering vehicle arriving at the yield bar and the first circulating vehicle passing in front of the approach	-0.00262
PM peak-hour indicator (*1=true, 0=otherwise*)	0.00783
Weekday (Monday-Friday) indicator (*1=true, 0=otherwise*)	0.00467

Looking at volumes, when the previous one-minute circulating volume in front of the approach is higher, drivers are more likely accept a headway. During heavy traffic conditions, drivers likely feel added stress about how busy the roundabout is, and increased traffic causes drivers to be more observant and discerning where they will be more likely to accept a headway that could be questionable close to their critical headway.

The previous one-minute entering volume for the entire roundabout is another variable that contributes to the probability of a driver accepting a headway. The higher the previous one-minute total entering volume, the more likely a driver will accept a headway. There are a few mechanisms driving this. First, a higher previous entering volume at the roundabout indicates an increased ability of vehicles in general to enter the roundabout. This is somewhat tricky because more entering vehicles at other approaches can also become circulating vehicles in front of the approach under consideration. However, relatively higher upstream circulating volumes can be useful to help drivers calibrate their perception of headways as discussed in the previous paragraph and in the next paragraph.

The variable for previous one-minute circulating volume at the upstream approach suggests that higher upstream circulating volume increases the probability of accepting a headway. (This is in contrast to higher upstream entering volume, which was not significant). The difference is that drivers waiting to enter the roundabout are able to better observe the circulating headways further out and have a longer time to observe the headway as they are presented with the option to accept. Also, it may be easier to gauge an exiting decision of a circulating vehicle.

Another very important finding is that a higher cumulative average rejected headway increases the probability of accepting a headway. This suggests that if drivers have accumulated a relatively large cumulative average rejected headway, they are more likely to recognize headways where they could have entered and thus will be more prone to accept the current headway under consideration. This makes sense from a driver perspective where rejecting a few large (and possibly acceptable) headways will cause the driver to be more likely to accept a headway as they calibrate and lower their critical headway.

The variables for the time between two entering vehicles at a given approach are also important. The more time (in seconds) between arriving at the yield bar and the previous entering vehicle leaving the yield bar, the less likely the probability of accepting a headway. This shows that drivers waiting in a queue tend to observe the headways of the car they're waiting behind. This is an opportunity for driver's to calibrate their headway observations before they're waiting at the yield bar. If the time is large (indicating that the driver wasn't in a queue), then they won't have information ahead of time (this was the case shown in Figure 4 with vehicle E0 preceding vehicle E1 with a relatively large amount of time, where E1 is unlikely to have spent time waiting in queue behind E0).

A second variable relating sequential entering vehicles is the time (in seconds) between leaving the yield bar and the next entering vehicle occupying the yield bar (or move-up time according to NCHRP 572). The more time between the next following entering car, the more likely that a driver will accept a headway. This information shouldn't be used directly for analysis since this can't be known at a given headway *n*, but it can be used as a proxy for the probability that the entering vehicle was in front of a queue and had entering vehicles queued behind (an example is shown in Figure 4 with E2 following very closely behind E1). Such a queue could cause the driver to feel more pressure and distraction than if there was no queue.

Another variable that is an important spatial relationship is the time (in seconds) between the entering vehicle arriving at the yield bar and the first circulating vehicle passing in front of the approach (item "iii" in Figure 4). If there is more time between arrival at the yield bar and the first circulating vehicle passing in front of the approach, this will be seen by the driver as an instance where they might have been able to enter. This is really their first frame of reference for observing time and headways at a roundabout, so it's important for the initial adjustment of a critical headway, and the magnitude will depend on each vehicle's relative positioning.

Finally, two time of day/week variables were found to be significant. An indicator for the PM peak-hour was estimated and shows that drivers are more likely to accept a given headway during these conditions. While at first this may seem only attributable to heavier volumes, most of the decision-making component related to volumes is captured in other variables and this PM peak-hour may be capturing other driver behavior during a stressful period. Also, a binary indicator variable for weekdays was found to be significant and, on average, increased the probability of accepting a headway. This is likely due to heavier traffic and a higher value of time during the work week (Monday-Friday) period where drivers are less likely to accept a headway during the weekend period (or rather stated that drivers tend to have a higher critical headway).

CONCLUSIONS

This paper provides very important insight about the critical headway and the decision making process drivers face when accepting or rejecting headways at a single lane roundabout. The data collection process, a major advancement over past studies, used video collection over a limited time frame. This data collection process observed 29,403 vehicles 24-hours a day over six weeks.

1. Based on empirical observations and traditional critical headway estimation techniques, there is evidence that the critical headway changes across drivers and headways as a driver waits at the yield bar. This is important information that can be used to enhance existing models.
2. The median accepted headway shows a consistent trend of decreasing over time. This suggests that drivers' critical headway value is changing based on each additional rejected headway they sit through. The median rejected headways confirms that drivers eventually reduce their critical gap and are less likely to reject longer headways as they wait.

3. Mixed binary logit analysis was used to assess different variables that affect drivers' decisions. Each of these variables could be included in microsimulation to better predict the acceptance/rejection decision for headways.
4. By using a dynamic critical headway, microsimulation and other modeling approaches could cause capacity analysis to be improved. Using a more accurate estimate of critical headway over time spent waiting at the yield bar has implications of additional capacity at roundabouts. Drivers could be modeled as accepting a headway earlier in the circulating stream sequence based on lowered critical headways.

The discussions and conclusions identified by the model are important findings for traffic engineers. Future work will include incorporating these results into calibration of a microsimulation model and also exploring other yield situations where similar technology and methodology can be used. In particular, multilane roundabouts should be examined but will require additional data reduction techniques from the sensors.

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Hazardous Materials Transportation with Multiple Objectives: A Case Study in Taiwan

by Ta-Yin Hu and Ya-Han Chang

Hazardous material (hazmat) transportation has been an important issue for handling hazardous materials, such as gases and chemical liquids. In the past, researchers have made great efforts to develop policies and route planning methods for hazmat transportation problems. In 2014, Kaohsiung City in Taiwan suffered a gas pipeline explosion at midnight; 32 people were killed, and hundreds of people were injured. After the incident, policies and routing strategies for hazardous materials (hazmat) transportation in Kaohsiung were initiated to avoid pipeline transportation. Although methodologies for hazmat transportation have been proposed and implemented to minimize potential risks, multiple objectives need to be considered in the process to facilitate hazmat transportation in Taiwan.

In order to consider both government and operators' aspects, a multi-objective formulation for the hazmat problem is proposed and a compromise programming method is applied to solve the problem with two objectives: travel cost and risk. The path risk is defined based on risk assessment indexes, such as road characteristics, population distribution, link length, hazardous material characteristics, and accident rates. An aggregate risk indicator is proposed for roadway segments. The compromise programming approach is developed from the concept of compromise decision and the main idea is to search the compromise solution closest to the ideal solution. The proposed method is applied to Kaohsiung City, Taiwan. The results show that two conflicting objectives keep making trade-offs between each other until they finally reach a compromise solution.

INTRODUCTION

In 2014, Kaohsiung City in Taiwan suffered a gas pipeline explosion at midnight on August 1; 32 people were killed, and hundreds of people were injured. After the incident, policies and routing strategies for hazardous materials transportation were initiated to avoid pipeline transportation. In order to fulfill the needs of chemical production, numerous hazmat cargo tanks are required, but those hazmat cargo tanks on roads pose huge dangers to citizens. Although methodologies for hazmat transportation have been proposed and implemented to minimize potential risks, multiple objectives might still need to be considered in the process to facilitate hazmat transportation in Taiwan.

In order to consider both government and operators' aspects, a multi-objective formulation for the hazmat problem is proposed and a compromise programming method is applied to solve the problem with two objectives: travel cost and risk. Due to the incidents in Kaohsiung, the government wishes to minimize possible risk; in the meantime, operators wish to minimize travel cost. Therefore, two objectives, including travel cost and risk, are selected for illustration purpose in this study.

The path risk is defined based on risk assessment indexes, such as road characteristics, population distribution, link length, hazardous material characteristics, and accident rates. An aggregate risk indicator is proposed for roadway segments. The compromise programming approach is developed from the concept of compromise decision and the main idea is to search the compromise solution closest to the ideal solution. The empirical study based on Kaohsiung City is conducted to illustrate the proposed algorithm.

The rest of this paper is organized as follows. The second section reviews related literature in this research. The third section describes the model formulation and solution algorithm. The fourth section studies the cases in a real-world network, followed by the conclusions and suggestions.

LITERATURE REVIEW

Some relevant literature of hazmat transportation is briefly described, including hazmat transportation, risk models, multi-objective programming models, and the compromise programming approach.

Hazardous Material Transportation

Based on the UN Recommendation on the Transport of Dangerous Goods (UNRTDG) formulated by the United States Department of Transportation (DOT) and the United Nations Economic and Social Council (ECOSOC), the definition of hazardous materials is solids, liquids, or gases that can harm people, other living organisms, property, or the environment. The hazmat can be classified into nine classes, including explosives, gases, flammable liquids, flammable solids, oxidizing substances, organic peroxides, toxic and infectious substances, radioactive material, corrosive substances, and miscellaneous dangerous substances and articles (UNRTDG 2011 p.49-50). The U.S. DOT defined hazardous material as any substance or material that could adversely affect the safety of the public, handlers, or carriers during transportation. The Pipeline and Hazardous Materials Safety Administration (PHMSA) was established to protect people and the environment from the risks of hazardous materials transportation.

List et al. (1991) classified hazmat research into three categories: risk analysis, routing/ scheduling and facility location. Risk analysis considers the appropriate ways to assess transport risk, including assessment of incident probabilities and degrees of incidents' consequences. Routing/scheduling problems focus on finding suitable routes under a variety of objectives, such as minimizing cost and risk. Facility location problems consider the locations of facilities and locations that accept hazmat wastes. The problem addressed in this research is mostly related to routing and scheduling problem.

Transportation Risk Assessment

Risk assessment is an important issue of the hazmat transportation problem, and there is plenty of research on risk analysis. Erkut et al. (2007) provides a comprehensive review on risk analysis and pointed out that quantitative risk assessment involves the following key steps: hazard and exposed receptor identification, frequency analysis, consequence modeling, and risk calculation. For more detail, the readers can refer to the comprehensive review. Some related studies are briefly reviewed as follows.

Chang (1990) proposed a set of measurement standards for risk assessment in Taiwan, proposed measures for path risk, and evaluated consequences and routing strategy with sensitivity analysis. Erkut and Verter (1998) provided an overview of risk models for risk assessment of hazardous material transportation, including traditional risk model, population exposure model, incident probability model, and perceived risk model. They also define societal risk as the product of link length, accident rate, conditional release probability, population density, and impact radius.

Chen et al. (2011) applied the concept of risk assessment matrix to determine the risk of hazmat and proposed the feasible options and supporting measures to reduce the risk of hazardous materials transportation. Kang et al. (2014) applied the concept of value-at-risk (VaR) to the assessment of hazardous materials transportation routing strategies to determine routes that minimize the global VaR value in a realistic multi-trip multi-hazmat type framework.

Multi-objective Approach

A multi-objective optimization problem means a problem with more than one objective. While a single-objective problem is looking for an optimal solution, a multi-objective problem is searching for compromise solutions among conflicted objectives. As a result, a variety of multi-objective optimization algorithms are proposed and applied in different fields. In hazmat transportation problems, cost, risk, travel time, and potential exposure are often chosen to be objectives. Objectives and methodologies applied in hazmat transportation problems are reviewed.

Abkowitz et al. (1992) put minimizing incident probability and population rate in the multi-objective schemes. Current and Ratrick (1995) proposed a multi-objective function to minimize total transportation risk, minimize total facility risk, minimize maximum transport exposure, and minimize total operating costs. Erkut and Verter (1998) viewed the risk minimizing problem as a bicriterion optimization problem. They also mentioned that traditional risk is a combination of incident probability and population rate. Finally, they suggested finding the compromise solution for the two criteria and other attributes such as cost and length.

Li and Leung (2011) developed a novel methodology based on the concept of the compromise programming approach for determination of optimal routes for dangerous goods transportation under conflicting objectives. Li et al. (2013) proposed a model based on multi-objective optimization, which takes transportation risk, route, and freight into consideration. Li and Jiang (2013) developed a multi-objective genetic algorithm (MOGA) to determine optimal routes for hazmat transportation under conflicting objectives.

Compromise Programming Approach

The compromise programming approach is developed from the concept of compromise decision (Yu and Leitmann 1973). The main idea of compromise programming is to search the compromise solution closest to the ideal solution. That is, the decision maker will tend to lower the target of each objective when facing numerous conflicting objectives until the solution becomes feasible.

A multi-objective optimization problem is briefly described below. When each objective is minimized independently, the optimal value of each objective can be obtained. The combination of optimal value for each objective is defined as the ideal solution for the problem.

$$\min_{x} \boldsymbol{Z}(\boldsymbol{x}) = [\boldsymbol{Z_1}(\boldsymbol{x}), \boldsymbol{Z_2}(\boldsymbol{x}), \dots, \boldsymbol{Z_n}(\boldsymbol{x})]$$

s.t $\mathbf{x} \in$ **feasible region**
ideal solution = $(\boldsymbol{Z_1^*}, \boldsymbol{Z_2^*}, \dots, \boldsymbol{Z_n^*})$

The distance between the ideal solution and a compromise solution is defined by the following function.

$$\boldsymbol{d_p} = \left[\sum_{i=1}^{n} \lambda_i^p (\boldsymbol{x_i} - \boldsymbol{Z_i^*})^p\right]^{1/p}, \quad 1 \le p \le \infty$$

λ_i^p is the weight of objective i, which can be viewed as the preference of the decision maker or the unit adjustment between objectives. Distance parameter p gives a different measure of the distance from the compromise point to the ideal point.

$\boldsymbol{d_1}$ (p=1) is the city-block distance, which is also known as the Manhattan-block distance. In this situation, all deviations are weighted equally. $\boldsymbol{d_2}$ (p=2) is the Euclidean distance, which is the linear distance the between compromise point and ideal point. $\boldsymbol{d_\infty}$ (p= ∞) is the one-dimension distance, which is also known as the Chebyshev distance. As p approaches, the problem becomes a min-max problem, which aims to minimize the maximum distance from dimensional aspect.

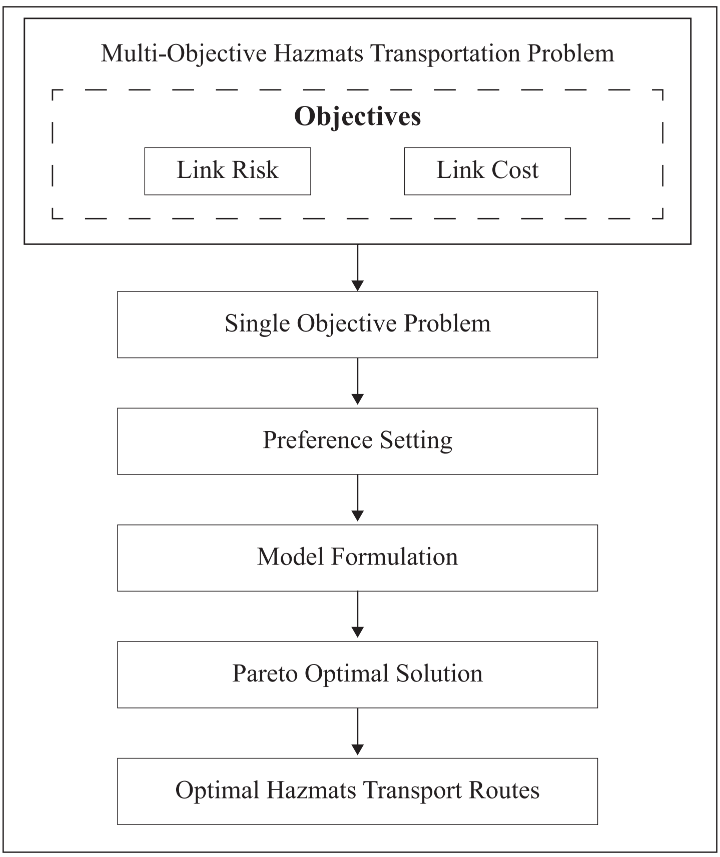
By setting the weights between objectives and fixing the distance parameter p, decision makers can choose the most appropriate solution based on the distance function.

RESEARCH METHODOLOGY

Given a directed network G = (N, A), which includes the set of nodes N and the set of arcs A. Each arc (i,j) is associated with the travel time (C_{ij}) and the transport risk (SR_{ij}). The origin node is s and the destination node is t. A multi-objective compromise programming approach with two conflict objectives, including path cost and risk, is developed. Assumptions of this research include (1) only single hazmat is considered; (2) functional speed for links is assumed to be the speed limit.

The conceptual framework of the hazardous materials transportation problem, as shown in Figure 1, includes five procedures: multiple objectives for hazardous materials transportation, single objective problem for each individual objective, preference setting for each objective, compromise programming model formulation with two objectives, finding the Pareto optimal solution and obtain the optimal transport paths.

Figure 1: Conceptual Framework



Model Formulation

Two objectives considered in this research are path risk and path cost. The notations of the formulation are listed in Table 1. Multi-objective hazardous material transportation routing problem is formulated as follows:

Table 1: Notations of the Formulation

Notation	Definition
Set	
N	The set of nodes.
A	The set of arcs.
P	The set of intermediate nodes.
Variable	
x_{ij}	If the arc (i, j) is selected into the optimal path, x_{ij} is equal to 1. Otherwise, x_{ij} is equal to 0.
SR_{ij}	The total societal risk of the optimal path.
C_{ij}	The total travel cost of the optimal path.
Parameter	
v_{ij}	The functional speed on arc (i, j).
l_{ij}	The length of arc (i, j).
d_{ij}	The population density in the neighborhood of arc (i, j).
r	The impact radius of the hazardous material.
AR_{ij}	The accident rate on arc (i, j).
CR_{ij}	The conditional release probability on arc (i, j).

Objectives:

Path Risk

(1) $Min \sum_{i \in N} \sum_{j \in N} SR_{ij} * x_{ij}$

Path Cost

(2) $Min \sum_{i \in N} \sum_{j \in N} C_{ij} * x_{ij}$

subject to

(3) $\sum_{i \in N} x_{i,j} = 1 \; (i \in origin)$

(4) $\sum_{i \in N} x_{j,i} - \sum_{i \in N} x_{i,j} = 0 \quad (i \in P)$

(5) $\sum_{i \in N} x_{j,i} = 1 \; (i \in destination)$

(6) $SR_{ij} = l_{ij} * AR_{ij} * CR_{ij} * d_{ij} * (\pi)\,(r)^2 \quad \forall\, (i,j) \in A$

(7) $C_{ij} = l_{ij} / v_{ij} \quad \forall\, (i,j) \in A$

(8) $x_{ij} = 0 \; or \; 1 \quad (i, j \in N)$

Two objectives are described in equations (1) to (2). Objective (1) minimizes the total path risk and objective (2) minimizes the total path cost. Equations (3) to (5) are flow conservation equations. Equation (6) is to calculate the societal risk, which is the product of link length, accident rate, conditional release probability, population density, and impact radius. Accident and release probability are determined by the road type. The size of impact radius depends on the hazmat under consideration. Equation (7) is to calculate the travel cost, which is estimated as length of arc divided by functional speed. Equation (8) is the 0-1 constraint.

Solution Algorithm

Based on Erkut and Verter (1998), the societal risk is the expected number of people to be impacted in one trip of the hazmat truck on that link. The societal risk of each arc is estimated as follows:

Societal risk = length of link (km) *accident rate on the link (per km) *conditional release probability of the link *population density in the neighborhood of the link (people/km-sq) *(π) (impact radius)^2 (km-sq)

The expected travel time of each arc is estimated as follows:

Travel time = length of link / functional speed,

The goal of the multi-objective hazardous material transportation routing problem is formulated as follows:

(9) $\min_{w} Z(w) = [Z_1(w), Z_2(w)]$

Subject to

(10) $Z_1(w) = \text{Path cost objective} = Min \sum_{i \in N} \sum_{j \in N} C_{ij} * x_{ij}$

(11) $Z_2(w) = \text{Path risk objective} = Min \sum_{i \in N} \sum_{j \in N} SR_{ij} * x_{ij}$

w $\in$ feasible region

Ideal solution = (Z_1^*, Z_2^*)

The distance between ideal solution and compromise solution is defined as follows:

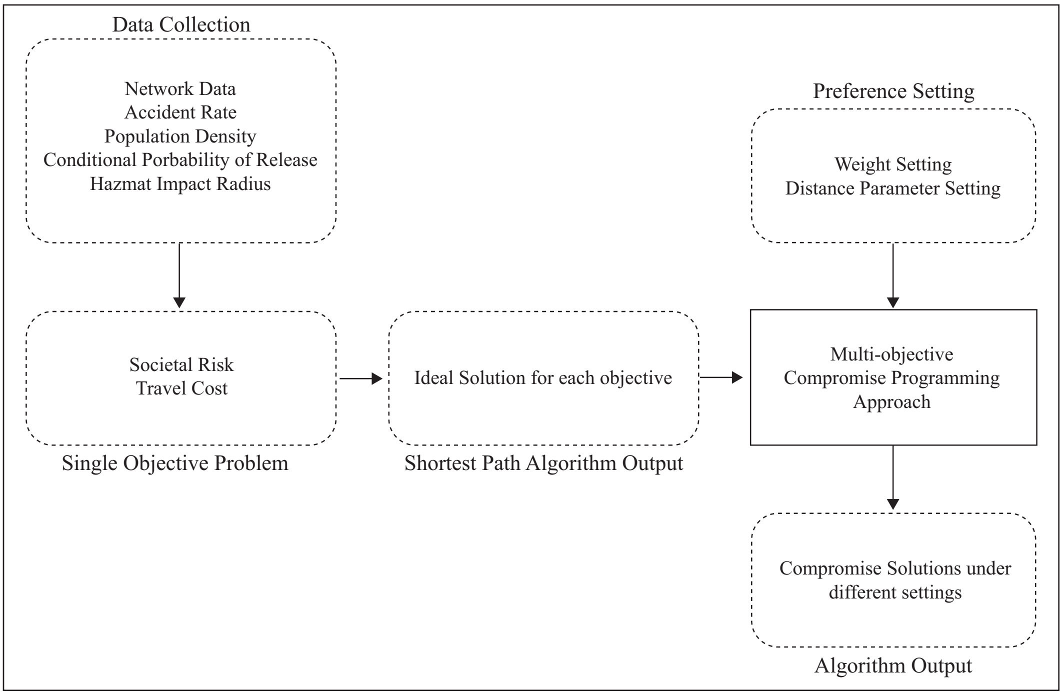
(12) $d_p = \left[\lambda_1^p (w_1 - Z_1^*)^p + \lambda_2^p (w_2 - Z_2^*)^p\right]^{1/p}, 1 \le p \le \infty$

By setting the distance parameter p, solutions under different situations are obtained. Distance parameter p represents different measures of the distance from the compromise point to the ideal point. When p = 1, all deviations are weighted equally. When p = 2, the linear distance between compromise point and ideal point is used. As p approaches ∞, the problem aims to minimize the maximum distance from dimensional aspect. By setting the weights between objectives and fixing the distance parameter p, decision makers can choose the most appropriate solution based on the distance function.

ALGORITHM FRAMEWORK

As shown in Figure 2, the algorithm is constructed in three parts: data collection, shortest path algorithm, and compromise programming approach. The data collected in the first part will be the input data for shortest path algorithm, and the output data from shortest path algorithm will be the input data for the compromise programming approach.

Figure 2: The Algorithm Framework

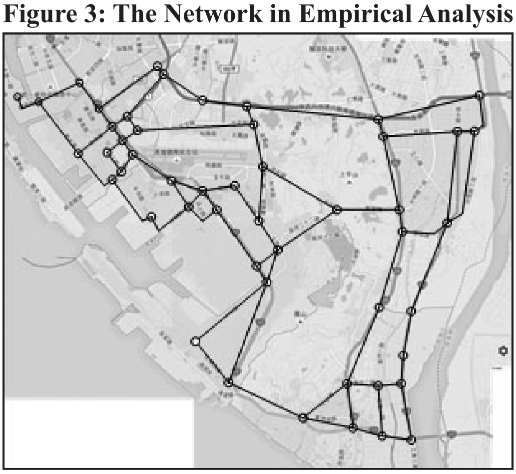


EMPIRICAL ANALYSIS

Basic Data of Experimental Network

The proposed approach is tested in Kaohsiung City shown in Figure 3. The network consists of 50 nodes and 144 links. The links consist of freeways, expressways, and arterial streets with real road characteristics. The origin node is China General Terminal & Distribution Corporation (CGTD) and the destination is Lin Yuan Industrial Zone.

Figure 3: The Network in Empirical Analysis



Accident Rate

Domestic data for hazmat cargo tanks, such as traffic information and accident information, are insufficient. Therefore, the accident information of trucks and freight vehicles are used in the study. The data for Year 2013 are summarized in Table 2, where A1 is defined as the injured persons who died within 24 hours of the accident and A2 is defined as non-fatal traffic accidents.

Table 2: A1+A2 Accident Data in 2013

Road type	A1+A2 accidents	Truck	Freight vehicle	Total
General roads	278,388	18818	3749	22567
Freeways	1233	281	181	462

In order to calculate the total traveled distance of truck and freight vehicles on general roads, we retrieved the domestic cargo transport data from the Directorate General of Highways, MOTC. Total traveled distance of all operating vehicles (Lc) is 4,171,633,457 km, and is used as the total travel distance while calculating accident rate. The average accident rate of trucks and freight vehicles on general roads per car per unit traveled distance is calculated as follows:

(13) $f = \frac{\text{number of } A1 \text{ } and \text{ } A2 \text{ } accidents \text{ } (X)}{total \text{ } traveld \text{ } distance}$, accident per km

Year 2013, A1+A2: $f = \frac{(X)}{Lc} = \frac{22567}{4{,}171{,}633{,}457} = 5.41 \times 10^{-6}$ accident/km

Highway data are obtained from different sources, including Taiwan Area National Freeway Bureau and Directorate General of Highways. The average accident rate of trucks and freight vehicles on national freeways per car per unit traveled distance is estimated as:

(14) $= \frac{A1 \text{ } and \text{ } A2 \text{ } accidents \text{ } of \text{ } freeways \text{ } (Y)}{total \text{ } traveld \text{ } distance}$, accident per km

Year 2013, A1+A2: $f = \frac{(Y)}{Lc} = \frac{462}{5{,}301{,}545{,}312} = 8.71 \times 10^{-8}$ accident/km

Table 3: Accident Rate

	A1+A2 accident (accident/million km)
General Road	
National Freeway	

Population Density

Village is used as the basic unit in estimating population density. Village area and link length are obtained through Google Maps. Based on the statistics data from the Civil Affairs Bureau of Kaohsiung City Government, the population density data of each village can be computed as follows:

Population density on link j = $\frac{\sum_i \textbf{village population}}{\sum_i \textbf{village area}}$ (people per km-sq),

where i represent the villages link j pass through, j represent the links in network

Conditional Release Probability

Conditional release probability is the probability of a hazmat release given an accident involving a hazmat-carrying truck. Since there is no related research and appropriate data of release probabilities in Taiwan, the data of release probability for use in hazmat routing analysis from Harwood et al. (1993) is adopted and presented in Table 4.

Table 4: Release Probability for Use in Hazmat Routing Analysis

Area Type	Roadway type	Probability of release given an accident
Rural	Two-lane	0.086
	Multilane	0.082
	Freeway	0.090
Urban	Two-lane	0.069
	Multilane	0.062
	Freeway	0.062

(Source: Harwood et al., 1993)

Hazmat Impact Radius

In this research, we selected styrene monomer as our hazmat to be transported. The hazard modeling program, ALOHA 5.4.4, is used to estimate hazmat impact radius. ALOHA is a software that allows us to enter details about a real or potential chemical release, which can estimate threat zones associated with different types of hazardous chemical releases. Parameters based on Kaohsiung City are set in ALOHA, and the worst case scenario is simulated. Through the simulation, the fireball diameter is 145 yards, or, 0.13km. Thus, 0.13km is used as impact radius if an accident occurred in Kaohsiung.

Experiment Design

The objective is to obtain an optimal path of hazardous materials transportation under the consideration of trade-off between minimizing travel cost and travel risk. Each scenario includes a different weight λ_i^p and different distance parameter p. Eleven scenarios of different weights and distance parameters are experimented with to observe how the trade-off between conflicting objectives and the setting of distance parameters influences the optimal path decision, as shown in Table 5. Scenarios 1 and 2 are single-objective problems and scenarios 3 to 11 are multi-objective problems. The results of scenarios 1 and 2 are also the ideal solutions for the two objectives.

We standardize the risk and cost of each link for data simplification and unit adjustment, the data standardization method is expressed as: $x_i' = x_i / \bar{x}$.

Table 5: Experiment Scenarios

Scenario	p	λ_c	λ_r	Scenario	p	λ_c	λ_r
1	x	1	0	**7**	2	0.25	0.75
2	x	0	1	**8**	2	0.75	0.25
3	1	0.5	0.5	**9**	∞	0.5	0.5
4	1	0.25	0.75	**10**	∞	0.25	0.75
5	1	0.75	0.25	**11**	∞	0.75	0.25
6	2	0.5	0.5				

The results of Scenarios 1 and 2 are summarized in Table 6. Scenario 1 minimizes the travel cost, and Scenario 2 minimizes the risk. The optimum paths of Scenarios 1 and 2 are illustrated in Figure 4.

Table 6: Results of Scenarios 1 and 2

Scenario	p	λ_c	λ_r	Path (in terms of nodes)	Total cost	Total risk
1	-	1	0	1→2→3→4→8→11→15→20→22 →23→27→30→32→44→46→50	10.165	-
2	-	0	1	1→2→9→8→7→6→16→17→33→35 →38→39→40→42→43→48→47→50		3.832

Figure 4(a): Min Travel Cost

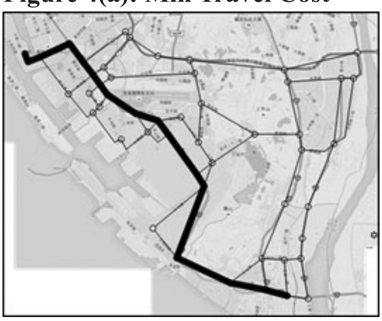
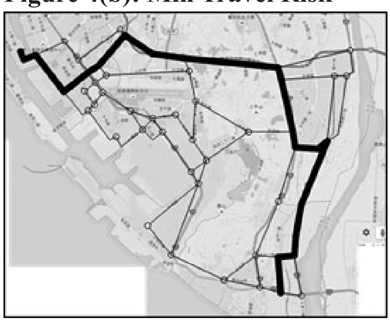


Figure 4(b): Min Travel Risk



The ideal solutions for the two objectives are [*cost**, *risk**] = [10.165,3.832]. For other scenarios, our goal is making the compromise solution as close to the ideal solution as possible. The results are summarized in Table 7, and the optimum paths are illustrated in Figures 5 to 8.

Table 7: Results of Scenarios 3 to 11

Scenario	p	λ_c	λ_r	Path	Distance to Ideal point	Cost	Risk
3	1	0.5	0.5	1→2→9→8→7→6→16→17→33→35 →38→39→40→42→43→48→49→50	1.5995	13.272	3.924
4	1	0.25	0.75	1→2→9→8→7→6→16→17→33→35 →38→39→40→42→43→48→49→50	0.84575	13.272	3.924
5	1	0.75	0.25	1→2→3→4→8→7→6→16→17→33 →35→38→39→41→45→46→50	1.7685	11.255	7.636
6	2	0.5	0.5	1→2→3→4→8→7→6→16→17→33→35 →38→39→40→42→43→48→49→50	1.387429	12.43	5.435
7	2	0.25	0.75	1→2→9→8→7→6→16→17→33→35 →38→39→40→42→43→48→49→50	0.77981	13.272	3.924
8	2	0.75	0.25	1→2→3→4→8→7→6→16→17→33 →35→38→39→41→45→46→50	1.2541	11.255	7.636
9	∞	0.5	0.5	1→2→3→4→8→7→6→16→17→33→35 →38→39→40→42→43→48→49→50	1.1325	12.43	5.435
10	∞	0.25	0.75	1→2→9→8→7→6→16→17→33 →35→38→39→41→45→47→50	0.749	13.161	4.705
11	∞	0.75	0.25	1→2→3→4→8→7→6→16→17→33 →35→38→39→41→45→46→50	0.951	11.255	7.636

Figure 5: Scenarios 3,4,7

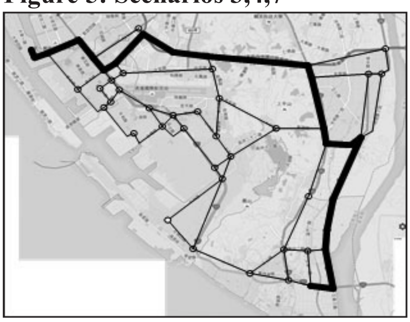


Figure 6: Scenarios 5,8,11

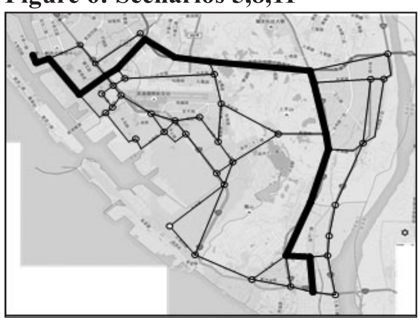


Figure 7: Scenarios 6,9

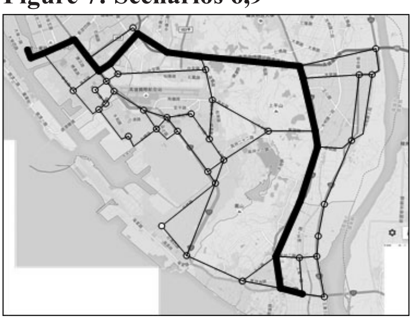


Figure 8: Scenario 10

When considering only the cost minimization, the optimal path includes the usage of the expressway 17th, which has a higher speed limit and shorter travel distance. When considering only the risk minimization, due to the lower accident risk on highways and expressways and also the lower population density, expressway 88th and the Sun Yat-sen Freeway are chosen to be the optimal path in this scenario. When it comes to the multi-objective experiments, we can find that due to the Sun Yat-sen Freeway and expressway 88th have the highest speed limit and the lowest accident rate in the research network, hence all scenarios choose them as the optimal compromising paths.

When considering the impact of distance parameter settings, the results show that while p is set to be infinite, the distances to the ideal point is smaller than those of p are set to 1 or 2. When the values of p are the same, the distance between compromise solution and ideal point will be the smallest while the weights between cost objective and risk objective is set to be 0.25:0.75, which are scenarios 4, 7, and 10. Under this weight, we can obtain the minimum distance to ideal point while p = 2.

CONCLUSION

The main contribution of this research is to apply the compromise programming algorithm to design an optimal path for hazardous material transportation of Kaohsiung city under the consideration of travel cost and travel risk. The numerical results show that optimal paths under different objectives tend to be different. With the compromising approach, a variety of compromise solutions could be identified based the distance parameter p. The numerical analysis illustrates positive advantages of the compromise programming approach, and other objectives might be able to be considered in the future.

Future research directions include a multi-OD hazmat framework and weight decisions. The former represents a more general framework for the hazmat transport problem in a network, and the latter represents how to choose the distance parameter p. In practice, how to decide appropriate weights for objectives is important, so does the distance parameter p. There are some methods for weighting such as AHP and TOPSIS. How to define the most appropriate method needs to be discussed in the future.

As for the hazmat problem in practice, data are very important to evaluate risk as well as cost. The accuracy and quality of the data could have significant impact on the result. Currently, data for hazmat transportation in Taiwan are insufficient and incomplete. Future research directions include how to establish sufficient databases, how to validate the proposed algorithm, and how to conduct demonstration projects.

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An Assessment and Measurement of Risks in the International Airline Industry: A Study of the ICAO Carriers Over the Period, 1990-2013

by Carl Scheraga and Richard D. Gritta

A prior study by one of the authors (Gritta, et. al. 2006) published in the Journal of the Transportation Research Forum*, examined the extent of operating, financial, and total leverage facing the major U.S airlines, those carriers with total revenues of $1.0 billion or more. The study found that the vast majority of the carriers were highly leveraged at both the operating and financial levels and that this resulted in highly unstable profitability and increased the dangers of bankruptcy.*

The global airline industry has always been highly cyclical and somewhat fixed-cost driven. Airlines are thus high in what financial analysts refer to as operating leverage. In addition, the many airlines have followed aggressive debt strategies; that is, they have chosen to use large amounts of long-term debt finance to purchase assets. This results in a high degree of financial leverage. In the past, the resulting combined leverage has created severe financial problems for major carriers, both domestically and internationally.

The current study seeks to examine a sample of foreign carriers in order to measure the extent of risks on the international level. In doing so, comparisons will be made to the large U.S. carriers. If possible, the authors will use the same time horizon as in the published paper, although in some cases carriers are too new to have such a history.

INTRODUCTION

The profitability of the global airline industry has always been highly volatile. Periods of high profits have usually been followed by periods of significant losses. The causes of the instability of this industry are manifold; the vulnerability to economic cycles, the price elasticity of demand, the relative high fixed costs of the carriers, the debt burdens taken on by carriers, the periods of both high interest rates and low oil prices (and vice versa), the intense competition in many domestic and international markets, the regulation of carriers, and other variables. Some of these variables are inherent in the nature of the business itself, while others are the direct result of carrier management decision making. All industries face three levels of risk. They are business risk, financial risk, and total or combined risk. Business risk is caused by the cyclical nature of demand, the presence of fixed costs, the degree of competition faced by competing firms in the industry, and government regulation. Financial risk has but one cause-interest on debt. Combined risk, it will be shown in this paper, is the multiplicative (not additive) interaction of both business and financial risks.

The purpose of this paper is to define and measure these risks quantitatively and demonstrate the causes of this inherent volatility. The period covered in this study is 1990-2013. The sample includes 37 carriers that are members of International Civil Aviation Organization (ICAO) and for which complete data were available for the entire period. The methodology utilized is that ingrained in leading finance textbooks and in the finance literature (for example; Moyer, et. al 2014). It is the same as that used to document the instability of the U.S. airline industry in earlier domestic carrier studies (Gritta et. al 1998; Gritta et. al 2006).

The first section of the paper will define the risks facing all carriers. The second will derive statistical measures to gauge these risks over time. The third will apply these measures to the sample of ICAO carriers. The conclusion of the paper will then outline the implications for air carrier management.

DEFINING INDUSTRY RISKS

All firms, regardless of industry type, face three types of risk. These three risks are commonly identified in financial theory as business risk, financial risk, and combined risk. (for example, Moyer, et al. 2014). Business risk can be defined as the variability in a firm's operating profit, often referred to as earnings before interest and taxes (EBIT), over time. It is attributable to the inherent nature of the firm's operations and the environment within which it operates. This type of risk is driven primarily by the firm's cost structure, product demand characteristics, and intra-industry competitive position. Some companies may face high business risk solely because of external, and therefore largely uncontrollable, factors such as high-fixed costs, the cyclical nature of its business, government regulation, and intense competition. However, high business risk can also be the result of poor cost controls, low productivity, or pricing practices that dilute revenues. The airline industry is high in business risk on virtually all these factors.[1]

Financial risk is generally defined as the added variability in earnings available to a firm's common shareholders due to the use of long-term debt to finance the acquisition of assets. It often represents the increased probability of insolvency that comes with excessive debt finance because interest on debt must be paid (unlike common stock dividends, which are paid at management's discretion). High financial risk may indicate that high interest charges are overwhelming a business enterprise, forcing it in some cases to seek court protection. Unlike business risk, financial risk is not primarily the product of the environment within which a company operates, but rather it results directly from a firm's conscious decision to use financial leverage (i.e., long-term debt or preferred stock) over time instead of issuing common stock to raise funds.

Combined (or total) risk, as the name suggests, refers to the risk that results from the interaction of both operating and financial risk. It is important to note that the interaction of the two risk types has a multiplicative, rather than an additive, effect. The impact of the combined effect can be extremely powerful, as will be evident from the discussion and statistical analysis that follows.

MEASURING RISK

One of the principal measures of a firm's business risk is its degree of operating leverage (DOL). (Moyer et al. 2014) Operating leverage generally refers to the firm's incurrence of fixed operating costs, i.e., costs which do not vary as output changes. As a general rule, high fixed costs create higher and more unstable DOLs.[2]

As an elasticity measure borrowed from microeconomic theory, DOL actually measures the responsiveness of operating profits (often referred to as EBIT, or earnings before interest and taxes) to changes in operating revenue. (Moyer et al. 2014). That is, it directly measures the X% change in operating profits that would be induced by a 1% change in operating revenues. As an elasticity measure, DOL can be defined as the percentage change in operating profits (OP or EBIT) divided by percentage change in operating revenues (OR). Operating revenues can be defined as price per unit of output *times* output (pq) and variable costs (V) equal variable cost per unit times output (vq), or q(p-v). Since fixed costs are fixed by definition, if the values of p and v remain relatively constant, the only change in OP is the change in quantity times the difference between the price and variable cost per unit (i.e., Δq[p-v]). DOL can then be derived as,

$$(1)\quad \text{DOL} = \frac{\%\Delta OP}{\%\Delta OR} = \frac{\dfrac{\Delta q(p-v)}{q(p-v)-F}}{\dfrac{\Delta qp}{qp}} = \frac{\Delta q(p-v)}{q(p-v)-F} x \frac{q}{\Delta q} = \frac{q(p-v)}{q(p-v)-F} = \frac{R-V}{R-V-F}$$

where R (pq) is operating revenue and V (vq) and F are variable and fixed costs (respectively).

The sign and the magnitude of DOL are both important indicators of risk. For example, consider a situation in which a firm's operating revenues (R) are \$500, its variable costs (V) are \$100, and its fixed costs (F) are \$150. In this case

$$\text{(2)} \quad \text{DOL} = \frac{500 - 100}{500 - 100 - 150} = +1.6$$

Since revenues (R) exceed the sum of variable plus fixed costs (V+F) here, the firm is above its operating breakeven point and DOL is positive. The positive DOL indicates that as R increases, operating profits will increase (and vice versa). In this case, a 1% increase in revenues will produce a 1.6% increase in operating profits; a 1% decrease in revenues will produce a 1.6% decrease in operating profits. In general, when R exceeds the sum of (V+F), DOL will take on a value between +1 and +∝. The relatively small positive value for DOL indicates a relatively low business risk (i.e., low variability in operating profit), since changes in revenue will induce relatively small changes in operating profits. In contrast, had fixed costs (F) been higher relative to (R-V), say \$350 rather than \$150, DOL would increase (to +8.0), indicating a significantly higher level of business risk. If the firm has no fixed costs; that is, if F = 0, that firm has no operating leverage. Thus business risk would be low and DOL would equal +1.0.

Should costs (V + F) exceed operating revenues, operating profit would be negative and the picture changes. Suppose, for example, that: R=\$500, V= \$400 and F=\$110. Here the firm is below its operating breakeven and

$$\text{(3)} \quad \text{DOL} = \frac{500 - 400}{500 - 400 - 110} = -10$$

The implication here is that a 1% change in operating revenues will induce a 10% change in operating profits or, more accurately, in operating losses. The negative sign indicates that when revenues *increase*, operating *losses* will decrease (and vice versa). The relatively large absolute value for DOL implies a relatively high degree of variability in operating profits (losses), which can be dangerous since the firm is operating below its breakeven point. However, such large negative values can actually be interpreted as less serious than very low negative numbers, since large absolute values indicate that current losses are relatively small and that a small increase in operating revenues can be expected to cut deeply into operating losses. Had fixed costs (F) been larger relative to (R - V), say \$600 rather than \$110, DOL would have remained negative—again indicating an operating loss—but its absolute value would have been substantially smaller. (In this case, DOL would have been -.2.) This smaller absolute value would be especially alarming since (1) it reflects the large size of current operating losses, and (2) it implies that positive changes in operating revenues will have only a minimal effect on reducing those losses. Negative DOL values will be between 0 and -∝.

Although fixed costs are generally seen as the key to determining the value of DOL, inefficient management policies affecting variable costs or gross revenues can also contribute to high business risk. In the airline industry, for example, factors such as poor cost controls or inefficiencies in a carrier's route structure can produce unfavorable DOLs. Reduced revenues caused by aggressive fare wars may have a similar effect.

A firm's financial risk can be measured by its degree of financial leverage (DFL). This interest (I) driven measure reflects the responsiveness of net profit (NP) to changes in operating profit. The lever here is interest on debt, which is a fixed charge. More specifically, DFL measures the percentage change in net profit (NP) given a percentage change in EBIT or:

$$\text{(4)} \quad \text{DFL} = \frac{\%\Delta NP}{\%\Delta EBIT} = \frac{\dfrac{\Delta NP}{NP}}{\dfrac{\Delta EBIT}{EBIT}}$$

Since NP=R-V-F-I and EBIT (OP) = R-V-F, this means that

$$(5)\quad \text{DFL} = \frac{\dfrac{\Delta(R-V)}{R-V-F-I}}{\dfrac{\Delta(R-V)}{R-V-F}} = \frac{R-V-F}{R-V-F-I} = \frac{\text{Operating Profit}}{\text{Operating Profit} - \text{I}}$$

In this latter form, the roles of both F and I can readily be seen. Like DOL, DFL is an elasticity measure, here measuring the X% change in net profit (R-V-F-I) that would be produced by a 1% change in operating profits. It is usually assumed that tax rates are relatively constant, so that net profits before and after taxes will vary in unison. As in the case of DOL, both the sign and the magnitude of DFL are significant. To illustrate, suppose operating profit is $90, since R-V-F is 500-400-10. If interest is $10, then

$$(6)\quad \text{DFL} = \frac{90}{90-10} = +1.125$$

This indicates that a 1% change in operating profit will produce a 1.125% change in net profit. The positive sign reflects the fact that the firm is above its financial breakeven (i.e., operating profits exceed interest). It also indicates that when operating profits increase, net profits will increase; when operating profits decrease, net profits will decrease. The relatively small value of DFL here means that (1) net profit is relatively large (relative to operating profit) and (2) variability in net profit (i.e., risk) is relatively small.

Had interest been higher, the positive value of DFL would increase (so long as interest did not exceed operating profit). For example, if interest (I) were $88, DFL would equal +45. A 1% change in operating profits here would produce a 45% change in net profit. The firm would still be operating above financial breakeven (hence the plus sign), but there would be significant variability (risk) in net profits. For positive DFLs, values will range from +1 (when the firm is debt-free, i.e., when I= 0) to +∝ (when interest = operating profit).

When interest exceeds operating profit, the firm is showing a net loss and DFL is negative. This negative DFL means that an increase in operating profit will lead to a *decrease* in the firm's net loss and vice versa. As in the case of negative DOLs, small absolute values for negative DFLs are especially serious since they indicate (1) large net losses for the firm, and (2) a lack of net loss responsiveness to improvements in operating profits. Negative DFL values will range from -∝ to 0. It should also be noted that if operating profits are negative, DFL will be reported as negative irrespective of the value of I.

A firm's combined (or total) risk—the product of its business and financial risks—can be measured by its degree of combined leverage (DCL). The multiplicative effect of business and financial risks in the calculation of DCL means that the core causes of risk—interest and fixed costs—magnify total risk to a degree that exceeds their simple sum. Similar to the effect of levers in physics, it is as though one lever (interest) is magnifying what another lever (fixed costs) has already magnified. Specifically,

$$(7)\quad \begin{aligned} \text{DCL} &= \text{DOL} \times \text{DFL} \\ \text{DCL} &= \frac{\text{R}-\text{V}}{\text{R}-\text{V}-\text{F}}\, x\, \frac{\text{R}-\text{V}-\text{F}}{\text{R}-\text{V}-\text{F}-\text{I}} = \frac{\text{R}-\text{V}}{\text{R}-\text{V}-\text{F}-\text{I}} \end{aligned}$$

As defined here, DCL measures the X% change in net profit that would be produced by a 1% change in operating revenues.

If revenue (R) is greater than total costs (V+F+I), the firm is operating above its total breakeven point and DCL will be positive. In such a case, smaller DCL values indicate relatively low combined risk since fixed costs and interest would be relatively low when compared to revenue. In the extreme, if DCL is +1, combined risk is minimal since fixed costs and interest would necessarily be 0.

When total costs (V + F + I) exceed revenue, the firm is operating *below* its combined breakeven point and DCL will be negative. Low absolute values for DCL are especially alarming here since they indicate that (1) losses are large and, (2) responsiveness to improvements in revenue will be sluggish. Insolvency is more likely and the firm has a long way to go to restore profitability (Gritta et al. 2006). If either DOL is negative or DFL is negative, or if *both* DOL and DFL are negative, DCL will be reported as negative. It is the absolute value that is important for reasons that will be explained shortly.

Critically, the multiplicative interaction that produces combined risk highlights the danger of employing debt finance when a company faces a high-risk DOL. To illustrate, assume two companies face the same large positive DOL, meaning that a very small decline in revenue can precipitate a very large decrease in net profits. In this case, assume DOL for both companies is +10. Company A, perceiving the business risk it faces and wary of any downturn in the economy, decides to use no debt in its capital structure, and thus has a DFL of +1. Its resulting DCL is 10 x 1 = +10. Company B, on the other hand, chooses to ignore the incremental risk associated with debt financing and, as the result of interest on its debt, faces a DFL of +4. DCL for this firm is a far more dangerous +40 (10 x 4). Should the industry experience a slowdown in activity or face a recession, Company B is clearly more seriously exposed. A 5% reduction in revenue will cause a 50% reduction in Company A's net profits (5% x 10), a serious enough drop, but B's net profits will plummet by 200% (5% x40).

The situation is even worse in cases where DCL values are negative with small absolute values, especially where such conditions persist over a long period of time. (As suggested earlier, this is because the base of losses is so large that the financial solvency of the enterprise in the long run is severely threatened.)

Because of the multiplicative effect of business and financial risks, most companies and industries try to balance risk. That is, a company high in business risk will tend to avoid significant long-term debt finance. A company low in business risk will be more likely to use debt finance since it will tend not to threaten the firm's basic stability.[3]

AIR CARRIER RISK ANALYSIS

Values for the leverage measures described in the previous section were calculated for the entire sample of the 37 ICAO airlines for which adequate data were available. Table 1 shows the ICAO carriers in the sample.

Table 1: Carriers in the Study

Aero Mexico	AMX	Korean Air	KAL
Air Canada	ACA	Lan Chile	LAN
Air Europa	ARA	LOT	LOT
Air France	AFR	Lufthansa	DLH
Air India	AIC	Malaysian	MAS
Air Nostrum	ANE	Monarch Airlines	MON
All Nippon Airways	ANA	Oman Air	OMA
Avianca	AVA	Philippine Airlines	PAL
British Airways	BAW	Pakistani International Air	PIA
Cathay Pacific	CPA	Royal Jordanian	RJA
Czech Airlines	CSA	Scandinavian Airlines	SAS
EasyJet	EZY	Singapore Airlines	SIA
El Al	ELY	Spanair	JKK
Ethiopian	ETH	SriLankan	ALK
Flybe British European	BEE	TAP Air Portugal	TAP
Iberia	IBE	Thai Airways	THA
Iran Air	IRA	Turkish Airlines	THY
Jet2	EXS	Virgin Atlantic	VIR
Kenya Airways	KQA		

The detailed results for all the carriers are summarized in Table 2. In the computation of these values, variable costs (V) are defined as the sum of flying operations, maintenance, passenger service, and air traffic costs. Fixed costs (F) are the summation of promotion and sales expenses, general and administrative costs, depreciation and amortization expenses, and various transportation related costs.[4] The Appendix to the paper shows the actual figures for each carrier for the years 1990-2000 and 2001-2013.

As can be seen from the table, many of the carriers had negative combined leverage (DCLs) for the study time horizon. On the excessive leverage side, Aero Mexico, Air Canada, Air India, Air Nostrun, Iberia, and Jet2 really stand out, and several of these carriers have had severe problems. To some extent, this analysis understates the situation since there were missing data for a few years for some of the carriers. Only a few airlines had moderate levels of risk; Kenya Airways, Ethiopian, and Thai Airways are examples. The difficult and volatile financial situation faced by the majority of the carriers is clearly evident. While the carriers' negative DOLs were certainly an important part of the problem, the biggest factor was the large number of carriers having negative DFLs during the 23-year time horizon.

The volatile nature of the industry is also apparent in some of the dramatic extremes shown in the Appendix. Such extraordinarily large positive values are typically produced when the base of profits is so small that a relatively small *absolute* change in value represents a very large *percentage* change. The tables in the Appendix also show a large number of cases in which negative levels of DFL are alarmingly small (in absolute value)—an indication that these carriers have followed financial strategies which are inappropriate in an industry characterized by high business risk. (As already discussed, very small negative values often result when the base of losses is so large that a significant absolute increase in revenue or profits has little effect in *percentage* terms.) While many of the carriers are subsidized by their governments, the record is still appalling.[5 6]

Table 2: Number of Years with Negative Leverage, 1990-2013

CARRIER	DOL	DFL	DCL		CARRIER	DOL	DFL	DCL
AMX	12	18	18		LOT	12	15	15
ACA	9	17	17		LDH	9	15	15
AIC	13	16	16		MAS	11	12	12
ANE	6	17	17		MON	3	6	6
ANA	4	11	11		OMA	8	10	10
AVA	8	14	14		PAL	8	9	9
BAW	3	6	6		PIA	8	11	11
CPA	2	6	6		RJA	3	5	5
CSA	5	11	11		SAS	8	10	10
EZY	0	7	7		SIA	1	14	14
ELY	5	9	9		JKK	7	7	7
ETH	2	3	3		ALK	11	14	14
BEE	10	11	11		TAP	10	13	13
IBE	10	15	15		THA	0	0	0
IRA	8	8	8		THY	11	17	17
EXS	3	18	18		VIR	6	8	8
KQA	0	0	0		Source: Cumulated from tables in the Appendix.			
KAL	2	9	9					
LAN	0	3	3					

The penalty of these financing patters is detailed in Table 3. The table shows the ROA (the return on assets), ROE (the return on equity), and the standard deviations around the ROA and ROE for a subset of the IOCA carriers.

Table 3: Return Characteristics: Reduced Sample (2002-2013)

	YR	ROA AVG	ROA SD	ROA MED	ROE AVG	ROE SD	ROE MED	NDOL (%)	NDFL (%)	NDCL (%)
AEA	11	0.0589	0.0548	0.0615	-0.0220	1.0347	0.3350	18.18	18.18	18.18
AFR	9	0.0043	0.0312	0.0089	-0.0622	0.4273	0.0428	33.33	33.33	33.33
ANE	11	-0.0210	0.1343	0.0063	-0.2110	1.0050	0.1653	45.45	36.36	45.45
ANA	11	0.0239	0.0271	0.0323	0.0211	0.0812	0.0526	27.27	27.27	27.27
BAW	11	0.0317	0.0273	0.0370	0.0538	0.1947	0.1119	18.18	18.18	18.18
CPA	10	0.0146	0.0341	0.0209	0.0567	0.1027	0.0915	20.00	30.00	30.00
CSA	12	-0.0494	0.1282	0.0090	-3.2622	10.6174	-0.0361	41.67	58.33	66.67
EZY	12	0.0600	0.0377	0.0560	0.1213	0.1428	0.0688	0.00	0.00	0.00
BEE	11	-0.0141	0.0567	-0.0127	-0.5882	2.2708	0.0412	63.64	72.73	72.73
EXS	12	0.0275	0.0571	0.0306	-0.0014	0.8628	0.1891	16.67	16.67	16.67
DLH	12	0.0053	0.0133	0.0043	0.0668	0.1561	0.1032	33.33	75.00	75.00
MAS	11	-0.0376	0.0899	-0.0117	-0.1458	0.7572	0.0559	54.55	54.55	63.64
MON	11	-0.0128	0.0663	0.0121	-0.0997	0.4068	0.0453	36.36	27.27	36.36
OMA	10	-0.0604	0.0879	-0.0178	-0.5514	0.8301	-0.1185	60.00	80.00	80.00
PAL	9	0.0203	0.0464	0.0450	-0.5484	1.9440	0.1039	33.33	33.33	33.33
RJA	9	0.0100	0.0871	0.0261	-0.1904	0.7831	0.1284	33.33	33.33	33.33
SAS	10	-0.0019	0.0462	-0.0113	-0.0334	0.1065	-0.0446	60.00	70.00	70.00
SIA	11	0.0263	0.0209	0.0313	0.1521	0.1964	0.0919	9.09	9.09	9.09
VIR	11	-0.0065	0.0530	0.0119	-0.1957	1.1603	0.1244	27.27	18.18	27.27

Note that in too many cases, the average ROAs and ROEs are exceeded by the standard deviations around those returns. Finally, Table 4 shows the frequent inverse correlations that have existed between ROAs and ROEs and the standard deviations around those means.

Table 4: Correlation Analysis: Reduced Sample (2002-2013)

	ROA AVG	ROA SD	ROA MED	ROE AVG	ROE SD	ROE MED	NDOL	NDFL	NDCL
ROA AVG	1								
ROA SD	-0.6479	1							
ROA MED	0.8649	-0.3473	1						
ROE AVG	0.5409	-0.6009 (.0065)	0.2127	1					
ROE SD	-0.4413	0.5698	-0.1199	-0.9868	1				
ROE MED	0.6591	-0.1323	0.6589	0.3715	-0.2453	1			
NDOL	-0.8050 (.0000)	0.4855	-0.8618 (.0000)	-0.3101	0.2148	-0.5441 (.0160)	1		
NDFL	-0.7257 (.0004)	0.2807	-0.8174 (.0000)	-0.3540	0.2600	-0.5844 (.0086)	0.8744	1	
NDCL	-0.8039 (.0000)	0.3828	-0.8569 (.0000)	-0.4088 (.0822)	0.3174	-0.5829 (.0088)	0.9027	0.9862	1

Carriers generally recognized to be financially troubled do stand out. In general, the data suggest an alarming pattern of reliance on debt finance in the face of significant business risk. The leverage situation is not unlike evidenced in the U.S. airline industry during roughly the same period (Gritta et al. 1998 and Gritta et al. 2006).

CONCLUSION

This paper has defined airline industry risks and quantitatively measured the degrees of operating, financial, and total leverage facing major ICAO carriers, using elasticity measures borrowed from microeconomics. The findings of this research are quite revealing. The international airline industry has long been noted as one high in business risk with a variability in operating profits over time. The result of the analysis confirmed this observation. The study also, however, detailed the extremely high financial leverage persistent in the industry. It was argued that firms facing high business risk should moderate their exposure to financial risk (by employing relatively low levels of financial leverage). The majority of the carriers did not and the penalty for that strategy was confirmed in the high volatility documented in Tables 2, 3, 4, and in the Appendix.

Given the data presented, it seems clear that the long-term operating and financial performance of the international industry airline industry has been poor. Historically high-risk levels, as measured by the DOL, DFL, and DCL indicators, and chronically low rates of return, bode ill for an industry that has had more than its share of obstacles to overcome during the past three decades. Largely closed off to debt financing because of already worrisome leverage positions, and offering little in the way of reward to potential investors, some of the carriers may have to turn to selling assets, trading labor concessions for equity, finding new partners with whom to share the risk, or even merging with one another, if they are to survive the next 20 years.

One last question in this analysis remains. Has the situation facing/faced by the airlines been different from other industries, or is the situation fairly common across many different industries? While this paper's purpose is not to explore the research internationally, there is an answer in the case of the domestic U. S. airlines. Research has shown that the domestic airline industry has been unique (Gritta et al. 2005). In a sample of 35 different industrial groups, the U.S. domestic carriers ranked not only first in business risk and also first in financial risk, resulting in very high levels of total or combined risk. Furthermore, almost all of the industrial groups balanced risk (that is, those high in business risk, employed low levels of debt, and vice versa), thus conforming to the sound principle of finance that dictates that firms high in business risk should/must take on less financial risk (Moyer et al. 2014). The failure to balance risk has greatly increased the risk of financial stress/bankruptcy (Gritta et al. 2006). The lesson in the United States is conclusive evidence of this. The list of major U.S. airlines filing under the U.S. bankruptcy codes since deregulation in 1982 includes American, Continental, Delta, Northwest, TWA, United, as well as former major carriers such as Braniff, Eastern, National, PanAm, and Western, which have ceased operations or been merged to forestall the inevitable. History does provide strong support for the above mentioned sound principle of finance.

Endnotes

1. Frederick (1961) and Caves (1962) were the first airline writers/economists to discuss carrier cost structure and its effect on business risk. Dogainis (Dogainis 2002) provides a more recent and excellent discussion of airline operating cost structures and their effects on operating profit instability. Bijan Vasigh (Bijan Vasigh et al. 2010) also discusses the extremely cyclicality of carrier profits and discusses some of the measures utilized in this paper.

2. Brigham (Brigham et al. 1993) has noted that airlines must invest heavily in fixed assets, which results in high DOLs, other things being equal. As noted, this is a situation that lies largely outside of management's control.

3. The need to balance business and financial risk is a principle advanced in virtually all finance textbooks. See, for example, Moyer (2014), Brigham and Gapenski (1993), and Bijan (Bijan et al. 2010). Gritta et al. (2005) found this to be true in an empirical study contrasting levels of business, financial, and total risk in the airline industry with risk levels in other industries.

4. The accounts used are the standard account lines presented in the publication, ICAO. One further point must be noted here: To the extent that some airline variable costs, such as fuel, are "sticky" or "constant" in the economic lexicon (or, as accountants would say, they are step-variable in nature), the analysis of the DOL presented in this paper actually *understates* the true level of risk in the airline industry. Caves (1962), a prominent airline economist, argued that to a large extent, costs which might appear to be structurally quite variable, may be in fact far less so in the airline industry. As traffic declines, classical variable costs, such as fuel, cannot be cut immediately in response. Hence, they behave in a sticky manner, increasing operating leverage. The accounts used are the standard account lines presented in the publication, ICAO.

5. As described earlier, the most severe conditions a carrier can face are (1) small negative DOLs, DFLs, and DCLs, the latter being the most severe; and (2) volatile DOLs, DFLs, and DCLs over time. There are several reasons for this. First, very small negative DCLs indicate considerable financial distress since net profits (EBIT-I) are strongly negative and the carrier could default on loan payments (interest, principal, and lease obligations. Several bankruptcy studies (Gritta, et al. 2006) clearly demonstrate the effect of excess leverage on U.S. carrier solvency, one quite early on in the pre-deregulation era. Second, volatility (extreme variability) is abhorrent to stockholders and other investors, unless compensated by commensurably higher rates of return. Investors, ex-post, must perceive that they will be rewarded for assuming risk. Ex-ante, their expectations may not be fulfilled.

6. As noted earlier, if either DOL or DFL is negative, then DCL must also be negative since DCL is the product of the two values. Less obviously, should *both* DOL and DFL be negative, DCL will also be reported as negative. In every case, the absolute values of DOL and DFL that are multiplied, with the sign applied appropriately to the resulting product.

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Table 5: DOL, DFL, DCL (2013-2002)

		2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002
AMX	DOL	NA	11.64	5.74	5.13	-4.56	-2.97	-2.67	-7.83	53.71	94.40	-6.08	-11.67
	DFL	NA	-2.16	1.86	1.76	-0.59	-0.70	-0.75	-0.81	3.06	3.39	-0.84	0.86
	DCL	NA	-25.18	10.67	9.02	-2.70	-2.08	-2.02	-6.30	164.17	319.61	-5.13	-10.06
ACA	DOL	NA	NA	23.56	14.97	-9.42	116.02	7.37	30.59	11.95	-52.10	-3.39	-11.90
	DFL	NA	NA	-1.57	-4.04	-0.50	-0.18	1.20	0.81	0.64	-0.10	-0.68	-0.76
	DCL	NA	NA	-37.03	-60.50	-4.67	-20.86	8.88	24.81	7.60	-5.15	-2.31	-9.07
AEA	DOL	5.74	-234.04	-61.72	9.79	13.72	379.47	14.05	71.53	68.29	12.01	19.32	30.32
	DFL	1.36	-4.61	-1.71	0.93	0.91	0.17	1.17	1.22	15.66	0.93	0.58	0.47
	DCL	7.80	-1078.96	-105.79	9.11	12.51	64.13	16.39	87.41	1069.32	11.11	11.11	14.33
AFR	DOL	NA	NA	-8.87	-16.25	-3.65	-24.40	9.16	8.33	14.18	88.70	42.33	29.72
	DFL	NA	NA	-1.25	-0.44	-0.77	-0.23	0.97	0.96	0.46	0.65	1.06	1.44
	DCL	NA	NA	-11.07	-7.19	-2.82	-5.63	8.90	7.98	6.47	57.85	44.79	42.74
AIC	DOL	-1.70	-1.20	NA	-1.21	NA	-0.56	-2.15	-1.68	-7.44	-16.43	-22.48	-12.12
	DFL	0.44	0.49	NA	-0.53	NA	-0.76	-0.79	-0.84	-0.83	-0.84	-0.74	-0.72
	DCL	-0.75	-0.59	NA	-0.65	NA	-0.43	-1.69	-1.40	-6.15	-13.86	-16.73	-8.70
ANE	DOL	-3.04	-2.38	-4.02	-520.35	-7.22	89.20	12.69	NA	9.13	8.05	4.79	3.74
	DFL	-0.89	-0.93	-0.90	-0.60	1.03	0.55	0.92	NA	1.09	1.22	1.59	1.04
	DCL	-2.70	-2.21	-3.62	-313.90	-7.42	49.06	11.61	NA	9.93	9.84	7.62	3.89
ANA	DOL	34.70	5.31	5.63	7.94	-5.83	-645.22	8.12	7.77	7.51	7.86	15.89	-49.55
	DFL	0.99	1.23	1.27	1.45	-0.78	-0.05	1.22	1.21	1.30	1.32	2.99	-0.32
	DCL	34.48	6.55	7.15	11.54	-4.53	-30.94	9.95	9.38	9.72	10.34	47.47	-16.04
AVA	DOL	NA	NA	NA	NA	22.54	11.53	2.81	NA	NA	NA	-3.71	-2.41
	DFL	NA	NA	NA	NA	1.82	0.96	0.85	NA	NA	NA	-0.98	-0.93
	DCL	NA	NA	NA	NA	40.94	11.12	2.40	NA	NA	NA	-3.65	-2.24
BAW	DOL	4.99	9.78	4.49	NA	-8.64	-14.41	3.74	5.58	4.60	5.63	7.04	10.20
	DFL	2.32	0.84	1.30	NA	-0.41	-0.37	1.28	1.23	1.40	1.57	1.78	8.59
	DCL	11.61	8.24	5.83	NA	-3.51	-5.34	4.80	6.85	6.45	8.82	12.52	87.62
CPA	DOL	9.29	-314.10	9.31	NA	NA	-0.90	4.60	5.75	6.63	4.15	19.28	4.30
	DFL	1.66	-0.06	1.42	NA	NA	-0.91	1.12	1.12	1.20	1.19	-13.07	1.24
	DCL	15.41	-19.76	13.26	NA	NA	-0.82	5.16	6.44	7.97	4.92	-252.00	5.34
CSA	DOL	-4.19	-9.42	-2.59	63.82	-1.23	27.80	34.44	48.32	-61.36	7.78	9.15	5.09
	DFL	1.00	-0.89	-0.95	17.57	-0.96	-27.61	-2.97	-2.00	-0.40	1.18	1.47	1.63
	DCL	-4.19	-8.43	-2.47	1120.95	-1.18	-767.34	-102.28	-96.58	-24.50	9.15	13.47	8.29
EZY	DOL	2.60	4.17	2.74	1.56	8.67	4.47	3.01	3.78	7.14	6.92	6.78	3.27
	DFL	1.06	1.20	1.08	1.05	1.10	1.17	0.85	0.90	0.72	0.81	1.00	0.95
	DCL	2.76	4.99	2.98	1.63	9.52	5.24	2.55	3.41	5.12	5.62	6.78	3.12
ELY	DOL	19.11	97.82	NA	7.84	-7.07	-62.95	NA	NA	7.35	10.13	18.45	23.93
	DFL	1.80	-0.67	NA	1.25	-0.77	-0.21	NA	NA	1.37	1.37	5.84	-3.04
	DCL	34.37	-65.18	NA	9.79	-5.46	-13.32	NA	NA	10.04	13.89	107.85	-72.81

Table 5: continued

ETH	DOL	NA	6.29	20.69	NA	NA	NA	12.32	8.49	5.00	6.00	10.09	9.21
	DFL	NA	1.50	3.71	NA	NA	NA	5.36	2.88	1.29	1.21	1.37	1.55
	DCL	NA	9.42	76.80	NA	NA	NA	66.07	24.41	6.47	7.23	13.85	14.31
BEE	DOL	-28.29	-6.91	-43.03	-82.96	19.13	-13.56	22.88	23.55	-308.81	7.69	-3.74	69.78
	DFL	-2766.50	-0.93	-0.65	-0.51	1.76	-0.72	1.94	1.00	-0.07	1.41	-0.92	-2.46
	DCL	-78263.00	-6.46	-27.84	-42.67	33.72	-9.81	44.28	23.55	-21.60	10.80	-3.42	-171.86
IBE	DOL	-8.84	NA	-21.19	-66.40	-4.01	-645.82	9.30	17.57	29.48	13.33	17.57	11.01
	DFL	-0.96	NA	-1.20	-0.97	1.01	0.05	0.65	0.90	0.89	0.90	0.92	1.11
	DCL	-8.51	NA	-25.34	-64.17	-4.05	-33.00	6.06	15.90	26.28	12.00	16.18	12.22
IRA	DOL	NA	NA	NA	NA	-1.76	-3.55	-6.15	-5.33	-4.51	-32.36	NA	-1.73
	DFL	NA	NA	NA	NA	-0.97	-0.98	-0.94	-0.92	-0.93	-0.73	NA	-0.98
	DCL	NA	NA	NA	NA	-1.70	-3.48	-5.77	-4.90	-4.17	-23.54	NA	-1.69
EXS	DOL	7.04	7.78	9.70	6.64	8.17	4.22	-3.41	-5583.80	19.52	6.77	24.92	37.76
	DFL	1.27	0.93	0.95	0.98	0.98	0.91	-1.27	-0.0029	0.50	0.82	0.69	0.63
	DCL	8.91	7.27	9.26	6.52	8.00	3.86	-4.34	-16.11	9.81	5.52	17.20	23.69
KQA	DOL	NA	NA	NA	NA	16.49	NA	4.21	3.59	3.41	3.27	5.96	16.41
	DFL	NA	NA	NA	NA	5.19	NA	1.34	1.27	1.16	1.13	1.24	1.94
	DCL	NA	NA	NA	NA	85.65	NA	5.64	4.57	3.96	3.70	7.36	31.83
KAL	DOL	NA	NA	NA	4.49	28.99	-39.53	6.69	7.66	NA	9.82	11.37	12.49
	DFL	NA	NA	NA	1.91	-0.35	-0.17	3.01	5.54	NA	0.49	-3.47	3.26
	DCL	NA	NA	NA	8.58	-10.13	-6.70	20.12	42.41	NA	4.84	-39.44	40.74
LAN	DOL	NA	9.10	5.17	3.92	NA	NA	NA	NA	10.22	7.44	9.32	15.17
	DFL	NA	1.93	1.37	1.32	NA	NA	NA	NA	1.42	1.26	1.54	2.83
	DCL	NA	17.56	7.10	5.16	NA	NA	NA	NA	14.48	9.40	14.32	42.89
LOT	DOL	NA	-8.84	-5.77	-6.25	NA	NA	19.80	-29.89	14.60	-63.50	269.87	-24.39
	DFL	NA	-0.57	-0.66	-0.85	NA	NA	1.00	-0.35	1.71	-0.22	1.00	-0.43
	DCL	NA	-5.03	-3.81	-5.29	NA	NA	19.80	-10.42	24.89	-13.77	269.87	-10.43
DLH	DOL	40.64	-11.70	-29.70	36.48	-11.38	23.18	9.43	13.50	103.51	41.99	-191.28	10.62
	DFL	-0.62	-0.55	-0.35	-0.64	-0.56	-24.52	1.49	3.25	-0.27	-0.67	-0.07	58.84
	DCL	-25.09	-6.45	-10.51	-23.51	-6.33	-568.15	14.07	43.81	-27.83	-28.04	-13.20	624.88
MAS	DOL	-6.62	NA	-1.24	35.74	-7.01	16.23	8.68	-11.47	-1.73	16.80	24.19	-54.77
	DFL	0.63	NA	-0.93	-4.23	-0.85	1.29	1.09	-0.89	-1.00	1.0004	1.00	-1.00
	DCL	-4.18	NA	-1.15	-151.08	-5.96	20.88	9.42	-10.17	-1.73	16.80	24.19	-54.77
MON	DOL	41.18	-3.90	-1.91	-122.67	-8.19	79.69	14.96	7.46	14.90	22.65	8.18	NA
	DFL	1.81	1.00	-0.93	-0.27	-0.86	60.76	2.92	1.55	3.14	1.87	1.16	NA
	DCL	74.40	-3.90	-1.79	-33.20	-7.01	4841.99	43.65	11.57	46.73	42.44	9.51	NA
OMA	DOL	-1.09	-1.29	-0.83	-1.20	NA	NA	15.09	12.09	95.57	90.22	-21.92	-13.90
	DFL	-0.91	-0.89	-0.90	-0.88	NA	NA	2.00	2.04	-0.18	-0.29	-0.52	-0.72
	DCL	-1.00	-1.15	-0.75	-1.05	NA	NA	30.20	24.69	-16.82	-26.04	-11.44	-10.06

Table 5: continued

PAL	DOL	NA	-9.24	-8.54	10.98	-13.74	NA	11.22	NA	9.61	6.92	8.59	7.10
	DFL	NA	-0.69	-0.76	1.67	-0.54	NA	5.14	NA	4.55	2.34	8.07	8.14
	DCL	NA	-6.41	-6.45	18.32	-7.42	NA	57.70	NA	43.75	16.17	69.35	57.80
PIA	DOL	NA	NA	NA	NA	12.92	-2.71	-3.59	-1.55	-5.80	10.62	3.89	3.04
	DFL	NA	NA	NA	NA	-0.44	-0.48	-1.00	-0.64	-0.52	-6.77	1.92	1.63
	DCL	NA	NA	NA	NA	-5.73	-1.29	-3.59	-1.00	-3.01	-71.86	7.46	4.96
RJA	DOL	-6.70	26.62	-3.39	15.91	7.27	23.40	10.52	-78.14	6.45	NA	NA	NA
	DFL	-0.81	1.96	-0.94	1.18	1.08	1.84	1.27	-0.28	1.20	NA	NA	NA
	DCL	-5.40	52.08	-3.19	18.85	7.88	43.10	13.34	-22.24	7.72	NA	NA	NA
SAS	DOL	NA	NA	15.15	-11.01	-5.88	-45.75	8.42	8.82	87.76	-15.21	-8.32	-35.29
	DFL	NA	NA	1.67	-0.72	-0.86	-0.93	1.14	1.56	-0.32	-0.65	-0.74	-0.44
	DCL	NA	NA	25.29	-7.94	-5.09	-42.74	9.57	13.77	-28.12	-9.84	-6.14	-15.46
SIA	DOL	NA	20.44	21.26	5.46	-92.12	5.34	3.19	4.22	5.97	5.42	19.29	15.23
	DFL	NA	1.16	1.10	1.02	-0.96	0.97	0.96	1.05	0.99	1.09	1.00	1.00
	DCL	NA	23.69	23.31	5.59	-88.45	5.18	3.05	4.42	5.88	5.91	19.29	15.23
JKK	DOL	NA	NA	NA	NA	-0.97	-2.01	-18.27	12.82	-73.46	NA	NA	-4.85
	DFL	NA	NA	NA	NA	-0.97	-0.88	-0.54	1.91	-0.28	NA	NA	-0.84
	DCL	NA	NA	NA	NA	-0.94	-1.78	-9.85	24.48	-20.54	NA	NA	-4.07
ALK	DOL	-0.17	-0.78	-0.75	-5.16	-2.87	-1.73	-8.48	-15.68	56.93	-31.79	8.00	11.30
	DFL	-0.91	-0.94	-0.94	-0.89	-1.00	-1.02	-1.16	-1.10	1.47	-0.75	1.09	14.54
	DCL	-0.15	-0.73	-0.71	-4.59	-2.87	-1.76	-9.84	-17.23	83.48	-23.77	8.69	164.34
TAP	DOL	16.07	15.61	NA	8.12	10.40	-3.10	7.58	14.86	NA	-13.45	22.42	12.25
	DFL	2.61	3.97	NA	1.25	0.76	-1.27	1.41	2.74	NA	-1.00	1.00	1.00
	DCL	41.98	61.90	NA	10.18	7.93	-3.93	10.70	40.65	NA	-13.45	22.42	12.25
THA	DOL	NA	NA	NA	5.76	5.98	NA	4.91	6.67	4.99	3.05	3.29	3.07
	DFL	NA	NA	NA	1.96	2.65	NA	1.59	2.07	1.59	1.26	1.30	1.42
	DCL	NA	NA	NA	11.26	15.86	NA	7.82	13.84	7.95	3.84	4.28	4.35
THY	DOL	NA	NA	54.97	9.17	5.58	NA	NA	NA	-29.32	18.77	NA	10.95
	DFL	NA	NA	0.30	0.78	0.84	NA	NA	NA	-4.69	0.65	NA	0.84
	DCL	NA	NA	16.62	7.20	4.66	NA	NA	NA	-137.47	12.26	NA	9.21
VIR	DOL	-54.40	-4.96	NA	24.59	-2.53	50.88	42.68	43.64	11.85	45.25	113.54	12.84
	DFL	0.73	-0.94	NA	1.27	-0.94	0.29	0.50	0.53	0.80	1.95	0.34	0.84
	DCL	-39.96	-4.65	NA	31.18	-2.37	14.81	21.15	23.33	9.43	88.28	38.97	10.80
AMX	DOL	-10.50	11.96	10.52	12.05	6.36	7.95	16.21	-33.24	-55.04	-22.82	-450.26	-151.53
	DFL	-0.95	0.94	0.96	0.91	0.95	1.70	-0.30	-0.23	-0.18	-0.45	-0.05	-0.54
	DCL	-9.98	11.21	10.09	10.95	6.06	13.52	-4.88	-7.76	-9.80	-10.20	-22.59	-81.40
ACA	DOL	-5.14	81.10	7.34	26.01	6.98	10.64	8.23	9.74	-19.02	-5.74	-5.37	-37.42
	DFL	-0.72	-0.34	1.59	-1.89	1.45	3.23	6.64	-1116.09	-0.32	-0.59	-0.72	-0.46
	DCL	-3.67	-27.54	11.70	-49.10	10.12	34.34	54.61	-10875.21	-6.16	-3.40	-3.86	-17.29

Table 5: continued

AEA	DOL	184.74	224.42	28.13	30.01	29.43	15.97	NA	NA	NA	NA	NA	NA
	DFL	0.24	-0.76	0.93	1.04	1.12	1.01	NA	NA	NA	NA	NA	NA
	DCL	44.89	-170.25	26.05	31.16	33.09	16.15	NA	NA	NA	NA	NA	NA
AFR	DOL	22.11	10.38	12.32	14.99	7.20	14.24	15.26	-11.69	-5.56	-21.02	-36.14	-8.36
	DFL	2.12	1.21	1.77	1.08	1.98	14.70	-0.99	-0.34	-0.54	-0.35	-0.26	-0.61
	DCL	46.96	12.56	21.76	16.23	14.28	209.23	-15.03	-4.00	-2.99	-7.34	-9.43	-5.06
AIC	DOL	-37.66	697.21	-99.13	47.92	-126.50	-4.69	-7.31	21.43	10.65	4.50	6.32	11.08
	DFL	-0.26	-0.01	-0.09	-0.18	-0.06	-0.74	-0.56	-0.69	0.92	0.93	1.30	8.19
	DCL	-9.68	-8.83	-8.49	-8.85	-7.29	-3.47	-4.07	-14.81	9.78	4.17	8.22	90.77
ANE	DOL	7.86	11.96	7.86	8.70	13.93	-1.87	NA	NA	NA	NA	NA	NA
	DFL	1.93	1.45	1.08	0.97	0.95	-0.96	NA	NA	NA	NA	NA	NA
	DCL	15.18	17.38	8.50	8.47	13.24	-1.79	NA	NA	NA	NA	NA	NA
ANA	DOL	19.39	6.15	18.02	-26.25	551.18	19.28	12.74	19.94	54.61	18.62	9.07	12.22
	DFL	-302.43	1.48	5.28	-0.29	-0.02	-1.30	-2.97	-0.64	-0.15	-0.86	5.33	6.54
	DCL	-5864.10	9.14	95.20	-7.66	-12.33	-24.98	-37.78	-12.76	-8.11	-15.99	48.36	79.95
AVA	DOL	-1.53	-1.84	-9.58	-16.79	100.13	17.84	12.93	386.27	-13.67	-7.26	-6.09	-5.53
	DFL	-0.84	-0.81	-0.51	-14.78	-0.30	2.85	2.20	-0.11	-0.68	-0.76	-0.57	-0.50
	DCL	-1.28	-1.50	-4.89	-248.21	-29.75	50.83	28.43	-42.82	-9.29	-5.54	-3.47	-2.77
BAW	DOL	-26.66	10.37	37.40	8.49	7.78	5.01	4.56	5.04	5.82	8.02	7.06	13.30
	DFL	-0.30	3.08	-0.29	7.14	1.50	0.80	1.40	1.48	1.42	1.46	1.34	1.27
	DCL	-8.06	31.95	-10.78	60.63	11.67	4.02	6.39	7.48	8.27	11.72	9.48	16.83
CPA	DOL	130.28	3.54	6.78	13.20	6.13	3.43	2.77	5.05	5.28	3.15	3.19	3.74
	DFL	-0.25	1.07	1.93	1.45	1.24	1.10	1.16	-2.57	-1.52	4.17	2.80	2.81
	DCL	-32.27	3.79	13.05	19.09	7.61	3.79	3.20	-12.99	-8.01	13.15	8.95	10.51
CSA	DOL	7.54	3.59	5.26	3.70	6.45	11.82	11.72	39.86	-6.60	NA	NA	NA
	DFL	5.22	1.93	3.13	1.73	5.10	-1.47	-1.55	-0.13	-0.37	NA	NA	NA
	DCL	39.38	6.93	16.47	6.39	32.93	-17.42	-18.14	-5.10	-2.44	NA	NA	NA
EZY	DOL	3.55	4.29	-5.70	18.71	NA	NA	NA	NA	NA	NA	NA	NA
	DFL	0.95	1.00	-1.09	0.65	NA	NA	NA	NA	NA	NA	NA	NA
	DCL	3.37	4.29	-6.20	12.10	NA	NA	NA	NA	NA	NA	NA	NA
ELY	DOL	-15.17	-8.47	36.96	15.85	42.39	-9.30	NA	NA	NA	NA	NA	NA
	DFL	-0.41	-0.60	-1.21	1.85	-2.61	-0.73	NA	NA	NA	NA	NA	NA
	DCL	-6.23	-5.11	-44.59	29.26	-110.49	-6.82	NA	NA	NA	NA	NA	NA
ETH	DOL	16.46	-5.67	-21.29	8.12	19.38	5.63	NA	6.78	8.40	5.91	5.58	NA
	DFL	5.96	-0.70	-0.34	4.43	-0.73	4.67	NA	2.87	8.10	2.94	2.74	NA
	DCL	98.14	-3.95	-7.28	35.98	-14.19	26.32	NA	19.47	68.07	17.39	15.31	NA
BEE	DOL	-3.85	-5.13	25.30	8.02	10.63	12.77	-5.92	NA	-5.83	NA	NA	NA
	DFL	-0.91	-0.91	1.98	1.19	1.23	1.02	-1.03	NA	-1.05	NA	NA	NA
	DCL	-3.51	-4.65	50.03	9.57	13.07	13.04	-6.08	NA	-6.10	NA	NA	NA

Table 5: continued

IBE	DOL	-95.75	62.26	64.65	8.24	6.15	5.51	7.23	26.69	-9.25	-13.81	-8.15	-14.44
	DFL	1.83	2.36	0.41	1.09	0.87	1.60	4.13	-0.43	-0.39	-0.41	-0.47	-0.40
	DCL	-175.06	147.11	26.76	8.98	5.33	8.82	29.88	-11.37	-3.59	-5.72	-3.85	-5.79
IRA	DOL	NA	NA	3.25	4.76	4.28	16.28	8.12	-9.62	3.85	6.21	8.29	23.29
	DFL	NA	NA	1.00	1.00	1.00	1.00	10.67	-1.00	1.00	1.00	1.00	1.00
	DCL	NA	NA	3.25	4.76	4.28	16.28	86.65	-9.62	3.85	6.21	8.29	23.29
EXS	DOL	11.77	9.16	6.44	4.80	7.36	5.69	6.14	NA	25.00	8.63	NA	NA
	DFL	0.86	0.84	0.85	0.95	1.14	0.99	0.94	NA	0.97	1.09	NA	NA
	DCL	10.17	7.73	5.49	4.59	8.37	5.64	5.80	NA	24.14	9.42	NA	NA
KQA	DOL	10.04	NA	NA	8.69	NA	NA	NA	3.01	NA	NA	NA	NA
	DFL	1.23	NA	NA	0.74	NA	NA	NA	1.18	NA	NA	NA	NA
	DCL	12.32	NA	NA	6.46	NA	NA	NA	3.55	NA	NA	NA	NA
KAL	DOL	-15.14	141.95	16.63	8.79	6.73	98.37	7.26	8.97	7.69	12.42	NA	7.55
	DFL	-0.39	-0.08	-1.35	-2.74	3.80	-0.13	2.83	2.70	1.81	4.70	NA	3.03
	DCL	-5.97	-12.06	-22.50	-24.08	25.60	-12.59	20.57	24.22	13.90	58.39	NA	22.87
LAN	DOL	16.24	11.90	NA	15.46	7.76	NA	9.52	21.30	17.98	21.40	12.32	-8.72
	DFL	2.47	1.70	NA	1.44	1.10	NA	0.93	0.85	2.72	1.94	2.18	-1.19
	DCL	40.07	20.27	NA	22.34	8.58	NA	8.87	18.16	48.91	41.56	26.87	-10.41
LOT	DOL	-1.72	NA	-19.56	6.58	17.15	6.53	5.94	-2.95	-4.00	-9.17	-3.84	8.02
	DFL	-0.97	NA	-0.70	8.93	-0.62	-8.05	-2.92	-1.00	-1.00	-1.00	-1.00	1.00
	DCL	-1.66	NA	-13.64	58.75	-10.69	-52.53	-17.35	-2.95	-4.00	-9.17	-3.84	8.02
DLH	DOL	-23.52	7.44	28.73	5.54	8.60	19.61	20.44	18.87	-888.22	-13.95	-21.14	-30.72
	DFL	-0.31	1.68	-1.64	1.27	1.02	1.27	2.19	1.86	-0.03	-0.62	-0.51	-0.54
	DCL	-7.22	12.48	-47.22	7.02	8.77	24.96	44.69	35.18	-30.69	-8.66	-10.78	-16.72
MAS	DOL	-4.94	-2.04	-5.77	-5.50	-7.38	20.35	18.38	6.67	10.96	NA	13.39	-37.36
	DFL	-1.00	-1.00	-1.00	-1.00	-1.00	1.00	1.00	4.63	8.72	NA	4.03	-0.24
	DCL	-4.94	-2.04	-5.77	-5.50	-7.38	20.35	18.38	30.85	95.61	NA	53.92	-9.15
MON	DOL	78.63	33.07	9.45	10.60	9.10	12.41	NA	10.18	7.54	7.82	18.51	6.21
	DFL	82.44	1.45	1.03	0.81	0.85	0.79	NA	0.94	1.08	1.10	17.99	2.48
	DCL	6482.61	48.03	9.75	8.54	7.73	9.75	NA	9.58	8.16	8.64	333.04	15.37
OMA	DOL	-6.38	-12.16	16.51	17.07	8.66	7.53	NA	6.29	NA	NA	NA	NA
	DFL	-0.82	-1.00	1.00	1.00	1.00	1.00	NA	1.00	NA	NA	NA	NA
	DCL	-5.25	-12.16	16.51	17.07	8.66	7.53	NA	6.29		NA	NA	NA
PAL	DOL	9.33	NA	NA	-8.46	-7.95	-33.75	-6.11	-25.88	27.33	8.08	6.28	7.15
	DFL	-2.47	NA	NA	-0.20	-0.43	-0.21	-0.58	-0.34	1.52	1.24	2.29	7.92
	DCL	-23.03	NA	NA	-1.70	-3.42	-7.22	-3.58	-8.90	41.66	10.00	14.38	56.66
PIA	DOL	47.92	-5.16	-17.72	7.46	-176.61	9.40	7.06	8.38	13.98	5.32	-61.38	10.59
	DFL	-0.20	-0.62	-0.36	4.34	-0.05	7.81	5.73	5.21	4.28	1.62	-0.27	2.30
	DCL	-9.50	-3.22	-6.31	32.42	-8.27	73.41	40.46	43.71	59.87	8.63	-16.83	24.34

Table 5: continued

RJA	DOL	NA	NA	NA	NA	NA	35.93	7.13	12.69	4.47	4.07	NA	NA
	DFL	NA	NA	NA	NA	NA	-0.10	-0.93	-0.32	-3.97	-2.41	NA	NA
	DCL	NA	NA	NA	NA	NA	-3.58	-6.66	-4.06	-17.76	-9.81	NA	NA
SAS	DOL	-10.00	25.67	76.72	13.80	10.20	11.55	7.43	19.25	-61.73	12.28	9.77	8.82
	DFL	-0.85	1.44	2.17	1.02	1.06	1.03	1.02	1.91	-0.22	-13.75	3.06	1.22
	DCL	-8.53	36.96	166.63	14.04	10.76	11.87	7.60	36.69	-13.49	-168.90	29.88	10.74
SIA	DOL	6.69	4.66	5.34	8.78	4.69	5.09	4.41	4.11	6.06	4.90	3.81	3.61
	DFL	1.11	1.05	0.89	0.82	0.90	0.87	0.90	0.90	0.84	0.81	0.80	0.78
	DCL	7.41	4.88	4.73	7.16	4.22	4.44	3.99	3.71	5.10	3.98	3.07	2.81
JKK	DOL	-7.68	-13.35	26.49	28.85	19.63	33.62	19.07	NA	NA	NA	NA	NA
	DFL	-0.79	-0.85	1.09	1.08	1.07	1.63	3.75	NA	NA	NA	NA	NA
	DCL	-6.04	-11.28	28.87	31.23	21.00	54.96	71.59	NA	NA	NA	NA	NA
ALK	DOL	-3.63	-1.57	52.71	NA	3.14	5.60	5.43	4.67	9.20	10.82	13.59	10.28
	DFL	-0.62	-0.64	-0.10	NA	4.84	-1.03	-3.23	15.71	23.22	5.63	29.94	5.22
	DCL	-2.24	-1.01	-5.06	NA	15.20	-5.79	-17.51	73.31	213.71	60.91	406.85	53.70
TAP	DOL	NA	NA	-4.84	331.02	-7696.56	12.54	-7.93	-3.46	-2.01	-2.37	-22.89	-13.67
	DFL	NA	NA	-0.76	-0.08	-0.01	-6.56	-0.72	-0.83	-0.95	-0.88	-0.46	-0.84
	DCL	NA	NA	-3.67	-27.95	-50.67	-82.27	-5.68	-2.89	-1.90	-2.09	-10.57	-11.41
THA	DOL	4.63	4.28	3.54	4.31	5.01	4.62	4.47	4.48	7.11	6.39	7.36	3.71
	DFL	2.46	1.78	1.54	2.33	2.64	1.85	1.73	1.93	8.77	3.46	3.98	1.27
	DCL	11.37	7.61	5.43	10.03	13.21	8.53	7.74	8.67	62.34	22.11	29.28	4.73
THY	DOL	-5.15	-3.80	-2.48	-33.14	-41.11	14.09	26.87	-17.47	-3.71	-9.26	-4.05	-4.76
	DFL	-0.93	-0.93	-0.91	-0.77	-0.68	1.80	-1.15	-0.42	-0.75	-0.56	-0.63	-0.55
	DCL	-4.78	-3.53	-2.27	-25.55	-27.92	25.37	-30.93	-7.30	-2.78	-5.19	-2.55	-2.61
VIR	DOL	-108.44	9.92	10.01	4.74	5.94	9.66	7.29	-17.41	-13.74	-9.57	32.18	9.74
	DFL	-0.29	1.28	1.14	1.01	0.96	0.88	1.05	-0.80	-0.70	-0.79	6.92	1.31
	DCL	-31.07	12.69	11.43	4.76	5.70	8.52	7.68	-13.99	-9.60	-7.59	222.70	12.71

Table 6: ROA, ROE 2013-2002

		2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002
AMX	ROA	NA	0.0343	0.0872	0.1319	-0.1005	-0.1844	-0.2215	-0.0670	0.0140	NA	-0.0969	-0.0584
	ROE	NA	-0.0639	0.2878	3.5663	NA	NA	NA	-0.3337	0.0997	NA	-0.5393	-0.2794
ACA	ROA	NA	NA	0.0180	0.0275	-0.0333	0.0026	0.0367	0.0085	0.0305	-0.0071	-0.1213	-0.0536
	ROE	NA	NA	NA	0.0947	-0.0195	-1.7983	0.1515	-0.0238	0.1382	-4.2692	NA	NA
AEA	ROA	0.1727	-0.0041	-0.0161	0.0914	0.0704	0.0030	0.0928	0.0340	0.0133	0.0949	0.0615	0.0477
	ROE	0.7069	-2.8697	-0.9363	0.4742	0.4390	0.1847	0.4780	0.2478	NA	0.3350	0.3260	0.3726
AFR	ROA	NA	NA	-0.0316	-0.0153	-0.0612	-0.0113	0.0344	0.0429	0.0229	0.0040	0.0089	0.0133
	ROE	NA	NA	NA	0.2125	-1.0649	-0.4300	0.1541	0.2143	0.2400	0.0326	0.0383	0.0428
AIC	ROA	-0.0684	-0.0800	NA	-0.0981	NA	-0.1623	-0.0919	-0.1281	-0.0602	-0.0370	-0.0241	-0.0368
	ROE	NA	NA	NA	NA	NA	NA	NA	NA	0.0603	0.4137	NA	NA
ANE	ROA	-0.2427	-0.2426	-0.1314	-0.0011	-0.0684	0.0063	0.0509	0.0674	0.0674	0.0740	0.1308	0.1260
	ROE	-2.9921	-0.8974	-0.1750	0.2537	-0.2239	0.0000	0.1653	NA	0.2769	0.2953	0.3951	0.5816
ANA	ROA	0.0259	0.0443	0.0461	0.0323	-0.0341	-0.0004	0.0434	NA	0.0462	0.0477	0.0183	-0.0069
	ROE	-0.0082	0.0591	0.0526	0.0472	-0.1263	-0.0048	0.1279	NA	0.0867	0.0528	0.0684	-0.1228
AVA	ROA	NA	NA	NA	NA	0.0254	0.0546	NA	NA	NA	NA	-0.1554	-0.2242
	ROE	NA	NA	NA	NA	0.0268	-0.0573	NA	NA	NA	NA	NA	-3.5640
BAW	ROA	0.0430	0.0180	0.0370	NA	-0.0161	-0.0146	0.0718	0.0465	0.0555	0.0466	0.0367	0.0244
	ROE	0.1479	0.1337	0.2771	NA	-0.2720	-0.3177	0.2170	0.0095	0.2353	0.1119	0.0640	-0.0151
CPA	ROA	0.0134	-0.0004	0.0155	NA	NA	-0.0716	0.0357	0.0262	0.0275	0.0473	0.0075	0.0453
	ROE	0.0416	0.0160	0.0983	NA	NA	-0.2104	0.1384	0.0894	0.0936	0.1344	0.0420	0.1240
CSA	ROA	-0.2452	-0.0648	-0.1790	0.0089	-0.3200	0.0193	0.0127	0.0091	-0.0077	0.0619	0.0440	0.0686
	ROE	-1.4923	-0.3118	-0.6271	-0.0498	-36.9456	0.0355	0.0267	-0.0223	-0.0626	0.1046	0.1019	0.0966
EZY	ROA	0.1048	0.0571	0.0602	0.1560	0.0164	0.0327	0.0626	0.0550	0.0302	0.0381	0.0429	0.0640
	ROE	0.4663	0.3401	0.1320	-0.0569	0.0629	0.0704	0.1307	0.0974	0.0507	0.0521	0.0427	0.0673
ELY	ROA	0.0222	0.0043	NA	0.0513	-0.0448	-0.0057	NA	NA	0.0520	0.0368	0.0182	0.0136
	ROE	0.1414	-0.1431	NA	0.2305	-0.6164	-0.3532	NA	NA	0.2366	0.1810	NA	-0.1034
ETH	ROA	NA	0.0395	0.0131	NA	NA	NA	0.0262	0.0323	0.0556	0.0511	0.0449	0.0588
	ROE	NA	0.1541	0.1722	NA	NA	NA	NA	0.0567	0.1395	0.1169	0.0588	0.0970
BEE	ROA	-0.0127	-0.0647	-0.0110	-0.0059	0.0298	-0.0384	0.0219	0.0210	-0.0016	0.0678	-0.1493	0.0088
	ROE	0.0412	0.8690	0.0717	0.0350	0.3318	1.0535	0.5430	NA	-7.1873	1.0197	0.6197	0.1206
IBE	ROA	-0.0395	NA	-0.0185	-0.0060	-0.0945	-0.0007	0.0483	0.0249	0.0147	0.0407	0.0311	0.0513
	ROE	-1.9580	NA	-0.0433	0.0400	-0.4832	0.0279	0.3743	NA	NA	NA	0.1296	0.1771
IRA	ROA	NA	NA	NA	NA	-0.0912	-0.0589	-0.0421	-0.0538	-0.0572	-0.0079	NA	-0.0903
	ROE	NA	NA	NA	NA	-0.1608	-0.0680	-0.0302	-0.0631	-0.1056	0.0052	NA	-0.1042
EXS	ROA	0.0465	0.0000	0.0327	0.0556	0.0285	0.1165	-0.1214	-0.0001	0.0269	0.0807	0.0418	0.0226
	ROE	0.2076	0.2727	0.1706	0.2699	0.1442	0.6760	-2.6808	0.0020	0.2415	0.4707	0.1428	0.0664
KQA	ROA	NA	NA	NA	NA	0.0251	NA	0.0857	0.0988	0.1112	0.1470	0.0910	0.0346
	ROE	NA	NA	NA	NA	0.1018	NA	0.1715	0.2102	NA	0.3303	0.1613	0.0509

Table 6: continued

KAL	ROA	NA	NA	NA	0.0623	0.0079	-0.0063	0.0420	0.0366	NA	0.0278	0.0221	NA
	ROE	NA	NA	NA	0.1320	-0.0419	-0.5782	NA	NA	NA	NA	-0.0718	NA
LAN	ROA	NA	0.0161	0.0706	0.0918	NA	NA	NA	NA	0.0660	0.0941	0.0686	0.0391
	ROE	NA	0.0102	0.2212	0.3228	NA	NA	NA	NA	0.2916	0.3764	0.2370	0.0997
LOT	ROA	NA	-0.0364	-0.0575	-0.0601	NA	NA	0.0224	-0.0133	0.0288	-0.0080	0.0027	-0.0223
	ROE	NA	NA	-0.4490	-0.0992	NA	NA	0.0378	-0.0018	0.0458	0.0128	-0.0879	0.0854
DLH	ROA	0.0041	-0.0139	-0.0057	0.0044	-0.0140	0.0102	0.0272	0.0210	0.0027	0.0073	-0.0015	0.0221
	ROE	0.0517	0.1201	-0.0016	0.1372	-0.0184	0.0873	0.2418	0.1737	0.1047	0.1017	-0.3708	0.1737
MAS	ROA	-0.0322	NA	-0.1792	0.0091	-0.0569	0.0266	0.0600	-0.0573	-0.2254	0.0335	0.0194	-0.0117
	ROE	-0.3170	NA	-2.1445	0.0316	0.8121	0.0559	0.2289	-0.1074	-0.6680	0.0917	0.2273	0.1860
MON	ROA	0.0138	-0.1057	-0.1607	-0.0037	-0.0435	0.0104	0.0182	0.0347	0.0167	0.0121	0.0675	NA
	ROE	0.1750	-1.2294	-0.2965	-0.0603	-0.2198	0.0012	0.0583	0.0839	0.1016	0.0453	0.2438	NA
OMA	ROA	-0.1649	-0.1478	-0.1867	-0.1386	NA	NA	0.0216	0.0419	0.0027	0.0033	-0.0134	-0.0222
	ROE	-2.4980	-1.1642	-1.1422	-0.5299	NA	NA	0.0506	0.1453	-0.0875	-0.0514	-0.1172	-0.1199
PAL	ROA	NA	-0.0289	-0.0567	0.0477	-0.0341	NA	0.0415	NA	0.0494	0.0686	0.0450	0.0501
	ROE	NA	-0.2656	-5.6915	0.5587	0.1263	NA	-0.0144	NA	0.1426	0.2899	-0.1858	0.1039
PIA	ROA	NA	NA	NA	NA	0.0178	-0.0542	-0.0459	-0.0802	-0.0412	0.0244	0.0951	0.1305
	ROE	NA	NA	NA	NA	NA	NA	NA	NA	-0.7138	0.2523	0.5421	3.2866
RJA	ROA	-0.0825	0.0261	-0.1689	0.0413	0.0894	0.0241	0.0588	-0.0075	0.1089	NA	NA	NA
	ROE	-2.0400	0.0314	-0.8944	0.1284	0.2684	0.2719	0.1866	0.0736	0.2600	NA	NA	NA
SAS	ROA	NA	NA	0.0232	-0.0287	-0.0802	-0.0128	0.0723	0.0658	0.0054	-0.0191	-0.0347	-0.0099
	ROE	NA	NA	0.0233	-0.1119	-0.2059	-0.0315	0.1319	0.1150	0.0019	-0.1377	-0.0614	-0.0578
SIA	ROA	NA	0.0090	0.0083	0.0352	-0.0018	0.0366	0.0691	0.0431	0.0313	0.0373	0.0088	0.0124
	ROE	NA	-0.0586	0.0306	0.0718	0.0209	0.0919	0.1329	0.1576	0.0614	0.1115	0.4622	0.5914
JKK	ROA	NA	NA	NA	NA	-0.6849	-0.3013	-0.0508	0.0640	-0.0110	NA	NA	-0.1493
	ROE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-9.3504
ALK	ROA	NA	NA	-0.2796	-0.1246	-0.1516	-0.3165	-0.0707	-0.0457	0.0153	-0.0256	0.0885	0.0511
	ROE	NA	NA	NA	-0.1186	-0.7500	-1.4937	NA	0.0511	NA	0.0012	0.6024	0.1696
TAP	ROA	0.0278	0.0287	NA	0.0550	0.0374	-0.0833	0.0458	0.0211	NA	-0.0260	0.0180	0.0363
	ROE	0.2983	0.2809	NA	1.1835	NA	NA	0.6430	0.0621	NA	-3.7542	0.0209	-0.5782
THA	ROA	NA	NA	NA	0.0360	0.0342	NA	0.0474	0.0337	0.0460	0.1046	0.1048	0.1043
	ROE	NA	NA	NA	0.1882	0.1424	NA	0.0957	0.1369	0.1149	0.1862	0.3202	0.3607
THY	ROA	NA	NA	0.0062	0.0453	0.0845	NA	NA	NA	-0.0200	0.0463	NA	0.1240
	ROE	NA	NA	0.0041	0.0764	0.1623	NA	NA	NA	-0.0062	0.0489	NA	0.1842
VIR	ROA	-0.0099	-0.0934	NA	0.0184	-0.1225	0.0068	0.0125	0.0119	0.0426	0.0122	0.0041	0.0459
	ROE	-0.6382	-3.5140	NA	0.1488	0.9420	0.1244	0.1771	0.0872	0.2875	-0.0645	0.0173	0.2800
AMX	ROA	-0.0737	0.0704	0.0763	0.0656	0.1343	0.0799	0.0355	-0.0223	-0.0117	-0.0321	-0.0016	-0.0063
	ROE	-0.2091	0.0283	0.1847	0.1805	0.3476	0.8048	-0.1502	NA	-0.8318	-0.3579	0.0060	0.0056
ACA	ROA	-0.0864	0.0057	0.0705	0.0170	0.0637	0.0386	0.0434	0.0341	-0.0169	-0.0524	-0.0536	-0.0099
	ROE	NA	-0.2597	0.2940	-0.0107	0.2977	0.1513	0.0576	0.3534	-0.2806	-1.4345	-0.2825	-0.0745

Table 6: continued

AEA	ROA	0.0111	0.0066	0.0464	0.0458	0.0454	0.0780	NA	NA	NA	NA	NA	NA
	ROE	-0.2985	0.0441	0.0566	0.0931	0.0587	0.2807	NA	NA	NA	NA	NA	NA
AFR	ROA	0.0199	0.0436	0.0330	0.0257	0.0518	0.0204	0.0178	-0.0236	NA	-0.0244	-0.0150	-0.0528
	ROE	0.0580	0.1823	0.1003	0.1230	0.1128	0.0257	-0.3555	-0.1987	NA	-7.6564	-0.1552	-0.3387
AIC	ROA	-0.0100	0.0005	-0.0036	0.0066	-0.0023	-0.0538	-0.0404	0.0125	0.0242	0.0679	0.0479	0.0294
	ROE	0.0399	NA	-0.2446	-1.1346	-1.1766	NA	-1.7670	0.2652	2.4425	2.1656	0.9498	0.5288
ANE	ROA	0.0436	0.0659	0.0748	0.1784	0.0827	-0.3672	NA	NA	NA	NA	NA	NA
	ROE	0.2112	0.2007	0.3747	0.8721	0.7083	-11.7141	NA	NA	NA	NA	NA	NA
ANA	ROA	0.0153	0.0589	0.0171	-0.0116	0.0006	0.0168	0.0234	0.0132	0.0044	0.0138	0.0321	0.0229
	ROE	-0.0826	-0.1722	-0.0926	-0.0372	-0.0146	0.0205	0.0162	0.0219	-0.0151	0.0120	0.0369	0.0521
AVA	ROA	-0.2891	-0.2761	-0.0679	-0.0471	0.0074	0.0603	0.0809	0.0028	-0.0698	-0.1115	-0.1067	-0.0792
	ROE	-11.0135	NA	-4.0232	-0.1135	0.0422	0.2936	0.5155	0.0855	0.3482	0.3665	-1.3928	-0.3155
BAW	ROA	-0.0089	0.0272	0.0070	0.0355	0.0447	0.0704	0.0777	0.0729	0.0654	0.0488	0.0655	0.0384
	ROE	-0.0571	0.0828	0.0809	0.0278	0.1537	0.2136	NA	0.1444	0.1590	0.1481	0.2065	0.1069
CPA	ROA	0.0009	0.0473	0.0200	0.0088	0.0239	0.0493	0.0670	0.0438	0.0368	0.0613	0.0677	0.0675
	ROE	0.0210	0.1598	0.0811	-0.0219	0.0662	0.1504	0.1745	0.1753	0.1836	0.2616	0.3045	0.3778
CSA	ROA	0.0422	0.0802	0.0565	0.0990	0.0557	0.0313	0.0309	0.0068	-0.0319	NA	NA	NA
	ROE	0.0542	0.1893	0.0222	0.4592	0.1247	-0.2174	0.1715	0.0962	-0.6827	NA	NA	NA
EZY	ROA	0.0750	0.0849	-0.1667	0.0569	NA	NA	NA	NA	NA	NA	NA	NA
	ROE	0.1198	0.4738	-30.9128	0.3232	NA	NA	NA	NA	NA	NA	NA	NA
ELY	ROA	-0.0204	-0.0433	0.0109	0.0375	0.0133	-0.0555	NA	NA	NA	NA	NA	NA
	ROE	NA	0.1414	NA	NA	NA	0.5328	NA	NA	NA	NA	NA	NA
ETH	ROA	0.0287	-0.0611	-0.0136	0.0322	0.0136	0.0521	NA	0.0370	0.0253	0.0386	0.0488	NA
	ROE	0.0455	-0.0420	0.0222	0.0553	0.0201	0.0570	NA	0.0996	0.8242	0.0704	0.0714	NA
BEE	ROA	-0.1482	-0.1345	0.0308	0.0969	0.0624	0.0431	-0.1482	NA	-0.0496	NA	NA	NA
	ROE	-10.1571	-8.7047	0.0947	0.5046	0.3964	0.7513	-0.5315	NA	-41.9429	NA	NA	NA
IBE	ROA	-0.0056	0.0085	0.0081	0.0902	0.0775	0.0734	0.0529	0.0123	-0.0295	-0.0228	-0.0408	-0.0288
	ROE	0.0412	0.2519	0.1422	0.5185	0.1321	0.0376	NA	-1.5030	-1.0917	-0.2605	-0.7398	-0.1652
IRA	ROA	NA	NA	0.1433	0.1196	0.1349	0.0246	0.0460	-0.0313	0.1227	0.0642	0.0647	0.0181
	ROE	NA	NA	0.4545	NA	NA	NA	0.1967	NA	-0.0295	0.2286	0.3127	0.0388
EXS	ROA	0.1166	0.1346	0.2032	0.2819	0.1430	0.2063	0.3398	NA	0.0960	0.1631	NA	NA
	ROE	0.1678	0.2313	0.3057	0.4566	0.3049	0.4203	6.8977	NA	0.2807	0.7131	NA	NA
KQA	ROA	0.0552	NA	NA	0.0517	NA	NA	NA	0.2872	NA	NA	NA	NA
	ROE	0.1211	NA	NA	0.2019	NA	NA	NA	NA	NA	NA	NA	NA
KAL	ROA	NA	0.0021	0.0170	0.0385	0.0398	0.0031	0.0501	0.0407	0.0457	0.0261	NA	0.0356
	ROE	-0.1737	-0.1211	0.0664	0.2682	-0.5394	-0.2260	0.1464	0.0594	0.0243	0.0025	NA	-0.0201
LAN	ROA	0.0335	0.0521	NA	0.0457	0.1295	NA	0.1056	0.0453	0.0514	0.0402	0.0605	-0.0735
	ROE	0.0376	0.1693	NA	0.1382	0.3023	NA	0.2513	0.0829	0.0055	0.0201	0.0695	-0.2022
LOT	ROA	-0.2699	NA	-0.0427	0.1166	0.0400	0.0897	0.0839	-0.1237	-0.0713	-0.0256	-0.0522	0.0303
	ROE	-0.9108	NA	0.0088	-0.0049	-0.3426	-0.0864	0.0093	0.0084	0.0171	-0.0352	0.0091	0.0197

Table 6: continued

DLH	ROA	-0.0097	0.0428	0.0106	0.0755	0.0502	0.0218	0.0192	0.0383	-0.0008	-0.0445	-0.0251	-0.0165
	ROE	-0.1810	0.1675	0.1708	0.2214	0.2330	0.1627	0.0556	0.0831	-0.0581	-0.1849	-0.4104	0.0056
MAS	ROA	-0.0467	-0.1037	-0.0310	-0.0303	-0.0235	0.0112	0.0133	0.0336	0.0173	NA	0.0243	-0.0080
	ROE	-1.4967	-1.3126	-0.0138	-0.2114	-0.0853	0.0986	0.0819	0.0544	0.0031	NA	0.2450	0.5947
MON	ROA	0.0055	0.0130	0.0542	0.0533	0.0700	0.0451	NA	0.0521	0.0650	0.0594	0.0310	0.0718
	ROE	0.0007	50.8904	0.1900	0.1763	0.1806	0.1318	NA	0.1687	0.2006	0.1872	0.0052	0.1293
OMA	ROA	-0.0573	-0.0553	0.0390	0.0455	0.1051	0.1158	NA	0.1450	NA	NA	NA	NA
	ROE	-0.1860	-0.1936	0.1196	0.1237	0.2250	0.1926	NA	0.1974	NA	NA	NA	NA
PAL	ROA	0.0369	NA	NA	-0.0144	-0.0213	-0.0077	-0.0458	-0.0139	0.0211	0.0962	0.1411	0.0802
	ROE	-0.7318	NA	NA	1.5945	-0.6439	-0.2393	-0.5448	-0.2016	-0.0059	0.1226	-0.0026	0.1708
PIA	ROA	0.0093	-0.0731	-0.0218	0.0821	-0.0021	0.0432	0.0423	0.0306	0.0253	0.0746	-0.0067	0.0426
	ROE	NA	-33.3947	-0.3861	0.2164	-0.6133	0.0143	0.0654	0.0360	0.1847	0.2753	-0.0780	-0.0430
RJA	ROA	NA	NA	NA	NA	NA	0.0058	0.0315	0.0170	0.0573	0.0531	NA	NA
	ROE	NA	NA	NA	NA	NA	-0.3894	NA	-0.6190	NA	-0.5325	NA	NA
SAS	ROA	-0.0377	0.0181	0.0066	0.0391	0.0532	0.0458	0.0827	0.0285	-0.0067	0.0269	0.0522	0.0404
	ROE	-0.0800	0.1552	0.0998	0.1674	0.1638	0.1308	NA	0.2359	-0.0886	-0.0995	0.1070	-0.0709
SIA	ROA	0.0284	0.0577	0.0490	0.0261	0.0433	0.0445	0.0596	0.0652	0.0432	0.0532	0.0713	0.0742
	ROE	0.5882	0.5984	0.5702	0.4385	0.7169	0.7031	NA	0.7321	0.5634	0.5774	1.4346	1.3903
JKK	ROA	-0.0998	-0.0620	0.0390	0.0546	0.0722	0.0399	0.0517	NA	NA	NA	NA	NA
	ROE	-0.6192	0.0226	0.0744	0.1819	0.0432	0.0306	0.0086	NA	NA	NA	NA	NA
ALK	ROA	-0.1229	-0.1875	0.0049	NA	0.0980	0.0470	0.0440	0.0500	0.0390	0.0368	0.0383	0.0549
	ROE	0.4921	-4.4558	-0.0942	0.4842	-0.1826	0.4921	0.0078	0.1151	0.0707	0.0398	0.1300	0.0920
TAP	ROA	NA	NA	-0.0824	0.0015	-0.0001	0.0429	-0.0608	-0.1466	-0.2749	-0.2406	-0.0269	-0.0451
	ROE	NA	NA	-0.5485	0.0293	0.0239	NA	NA	NA	NA	NA	NA	NA
THA	ROA	0.0698	0.0882	0.1186	0.0876	0.0661	0.0715	0.0734	0.0690	0.0409	0.0414	0.0441	0.1062
	ROE	0.1539	0.4941	0.5334	0.8382	1.7572	0.1123	0.1219	0.1277	0.0355	0.1055	0.1638	0.2208
THY	ROA	-0.2841	NA	NA	-0.0322	NA	0.0685	0.0305	-0.0335	-0.0904	-0.0400	-0.0648	0.0685
	ROE	0.1065	NA	NA	0.0546	NA	0.1265	0.0189	-0.9622	-0.3348	-0.1763	-0.3012	-0.1667
VIR	ROA	-0.0045	0.0501	0.0462	0.1286	0.1095	0.0892	0.1144	-0.0592	-0.0639	-0.0832	0.0268	0.0664
	ROE	0.2263	0.1770	0.1840	0.5600	0.5420	0.4149	1.1417	NA	-0.7720	-1.9730	0.0601	0.2764

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
Marketing and Pricing	Government Policy
Financial Controls and Analysis	Equipment Supply
Labor and Employee Relations	Regulation
Carrier Management	Safety
Organization and Planning	Environment and Energy
Technology and Engineering	Intermodal Transportation
Transportation and Supply Chain Management	

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.

Annual Meetings

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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