

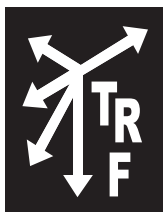
# JOURNAL of the TRANSPORTATION RESEARCH FORUM

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# Table of Contents

<b>A Message from the JTRF Co-General Editors</b>	<b>3</b>
<i>Kofi Obeng and Michael W. Babcock</i>	

## ARTICLES

<b>A Bi-Objective Approach to Evaluate Highway Routing and Regulatory Strategies for Hazardous Materials Transportation</b>	<b>7</b>
<i>Ashrafur Rahman, Lance Fiondella, and Nicholas E. Lownes</i>	

<b>TRANSIMS Implementation for a Small Network and Comparison with Enhanced Four-Step Model</b>	<b>23</b>
<i>Mansoureh Jeihani and Anam Ardeshiri</i>	

<b>Specifying and Estimating a Regional Agricultural Railroad Demand Model</b>	<b>35</b>
<i>Michael W. Babcock and Philip G. Gayle</i>	

<b>Road Supply in Central London: Addition of an Ignored Social Cost</b>	<b>49</b>
<i>Omid M. Rouhani, Christopher R. Knittel, and Debbie Niemeier</i>	

<b>Dynamics of Transport Infrastructure, Exports, and Economic Growth in the United States</b>	<b>65</b>
<i>Tingting Tong, T. Edward Yu, and Roland K. Roberts</i>	

<b>Identifying Traffic Safety Practices and Needs of Local Transportation and Law Enforcement Agencies</b>	<b>83</b>
<i>Kirolos Haleem, Albert Gan, Priyanka Alluri, and Dibaker Saha</i>	

<b>An Optimization Approach Applied to Fair Division Transportation Funding Allocation Models</b>	<b>101</b>
<i>Carlos M. Chang and Edith Montes</i>	

**On the cover:** Good railroad service is essential to a prosperous agriculture industry. Railroads transport grain long distances to consumption centers. Yet there have been few railroad demand studies in recent years. Michael W. Babcock and Philip G. Gayle estimate railroad demand functions for various grains in “Specifying and Estimating a Regional Agricultural Railroad Demand Model.”

## BOOK REVIEWS

### **Dry Ports – A Global Perspective: Challenge and Developments in Serving Hinterlands**

**119**

*Isaac Shafran*

### **The Last Great Stock Market Corner**

**123**

*William Huneke*

### **Transportation Research Forum**

**125**

*Statement of Purpose*

*125*

*History and Organization*

*125*

*Annual Meetings*

*126*

*TRF Council*

*127*

*TRF Foundation Officers*

*127*

*Past Presidents*

*128*

*Recipients of the TRF Distinguished Transportation Researcher Award*

*128*

*Recipients of the Herbert O. Whitten TRF Service Award*

*128*

*Past Editors of JTRF*

*129*

*Recipients of the TRF Best Paper Award*

*129*

*Guidelines for Manuscript Submission*

*131*

# A Message from the JTRF Co-General Editors

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Seven papers appear in this issue of JTRF. They are:

- A Bi-objective Approach to Evaluate Highway Routing and Regulatory Strategies for Hazardous Materials Transportation
- TRANSIMS Implementation for a Small Network and Comparison with Enhanced Four-Step Model
- Specifying and Estimating a Regional Agricultural Railroad Demand Model
- Road Supply in Central London: Addition of an Ignored Social Cost
- Dynamics of Transport Infrastructure, Exports, and Economic Growth in the United States
- Identifying Traffic Safety Practices and Needs of Local Transportation and Law Enforcement Agencies
- An Optimization Approach Applied to Fair Division Transportation Funding Allocation Models

Ashrafur et al. write on “A Bi-Objective Approach to Evaluate Highway Routing and Regulatory Strategies for Hazardous Materials Transportation” with the purpose to enhance network security by identifying critical links that shippers and carriers are likely to choose when transporting hazmat. In their methodology, they define the cost of hazardous materials transportation in terms of the shortest path from an origin to destination and minimize this cost. Additionally, they define risk as the probability of an incident occurring and minimize it also. The authors then develop a bi-objective shortest path model that incorporates these two objectives and apply it to a Sioux Falls network that has been widely used in other researches. Based on their results they surmise that their model can provide “insights into a high risk threshold value for regulators and help determine how route choice may be affected by limiting choice of high risk routes.” For shippers and carriers they note their method could help them assess the suitability of the routes they choose when transporting hazardous materials.

Jeihani and Ardeshtiri’s paper is titled “TRANSIMS Implementation for a Small Network and Comparison with Enhance Four-Step Model.” This paper proposes and applies an activity-based modeling approach called Sub-TAZ with the purpose of addressing some of the shortcomings of the traditional four-step approach in travel demand modeling such as inconsistencies in traffic flows. The proposed approach involves three steps. In step one a Sub-TAZ model is proposed to provide smoother traffic flow than the four-step approach provides. In step two the authors use TRANSIMS Track-1 to perform trip assignment based on the network developed in the first step; and in step 3 they use an activity based model called TRANSIMS Track-2. The proposed approach is applied to a small study area in Maryland and the results show a smoother traffic volume than the traditional four-step modeling approach provides, and a better forecasting of traffic flows even without full calibration. The authors note that although the second and third approaches in their modelling can be done using other software packages, small MPOs can reduce their costs by using TRANSIMS.

Babcock and Gayle write on “Specifying and Estimating a Regional Agricultural Railroad Demand Model.” Their paper fills voids in the railroad demand modelling literature by accounting for regional differences and product effects (wheat, corn, sorghum and soybeans) on railroad demand. In their model (with regional and commodity fixed effects) grain tonnage by rail is the dependent variable, and the independent variables are rail rates, grain production, barge rates and time, and they account for endogeneity by using instrumental variables for price and use data from the *Freight Commodity Statistics of the American Association of Railroads* and the *Agricultural*

*Marketing Services (AMS) of the US Department of Agriculture.* Their results from estimating a GMM model gives own-price elasticity of grain as -1.23, a barge rate elasticity of 0.48, a negative coefficient of sorghum, and positive coefficients for corn and wheat. These results and the product coefficients led Babcock and Gayle to conclude that wheat has the highest rail demand that is not explained by regressors included in the demand model followed by corn, sorghum, and soybeans respectively.

The paper by Rouhani, Knittel and Niemeier is titled “Road Supply in Central London: Addition of an Ignored Social Cost.” These authors argue that the opportunity cost of land (rent) should be included in the social cost of road usage. They calculate this opportunity cost as declining with traffic volume and add it to the social cost of road usage to obtain a U-shaped social cost curve. In their theoretical section they show that with the addition of land rent optimal road usage declines, a higher optimal charge and a higher social cost result, and it may imply closing some roads because the costs of providing them are higher than the benefits drivers obtain. Their findings in applying the methodology to the congestion pricing scheme in London confirmed the theoretical results by showing social cost increase of 204%, a decrease in optimal road usage by 40% and an increase in optimal road charge by 88%. Another result is that adding the opportunity cost of land makes the optimal benefit large.

In the “Dynamics of Transport Infrastructure, Exports and Economic Growth in the United States” Tong, Yu and Roberts address the long term effects of transport infrastructure on economic growth by including trade in the analysis to overcome the omitted variable problem common in other studies. Their hypothesis is that “enhancing transport infrastructure can increase economic output in the United States. They test this hypothesis using vector autoregression (VAR) models and data from 1950 to 2006 and find: 1) a direct impact of transport infrastructure on economic growth, no direct impact of transport on aggregate output using Granger causality, but causality from economic output to transport infrastructure and 2) positive effects of aggregate non-transport capital on economic growth and exports. They also find that transport and non-transport capital Granger cause exports; “economic output and exports react to each other immediately”; and “... non-transport infrastructure capital creates multi-year impacts on private capital formation.”

Haleem, Gan, Alluri and Saha’s article is titled “Identifying Traffic Safety Practices and Needs of Local Transportation and Law Enforcement Agencies.” They use two online surveys which ask respondents to provide information on a variety of topics including “standardization of crash analysis, training needs, and working with the Florida Department of Transportation.” A total of 37 local agencies and 46 law enforcement agencies in the state responded. Among its results, 70% of local agencies agree that standardization of crash analysis and procedures would be beneficial; 46% agree that the Highway Safety Manual should be used as the standard for crash analysis; 62.1% agree or strongly agreed that using the analytical tool *SafetyAnalyst* which incorporates the advanced Bayes approach would also be beneficial; and 90% agree or strongly agree that the Florida Department of Transportation should provide training in the use of the *SafetyAnalyst* program. The responses from law enforcement agencies show that speeding, failing to use seat belts and child safety restraints, and driving under the influence of alcohol or drugs are the most prevalent safety violations they record.

The last paper is by Chang et al. and it is titled “An Optimization Approach to Fair Division Transportation Funding Allocation Models.” The paper applies an optimization technique to allocate transportation funding fairly in order to reduce envy defined as funding recipients perceiving that they received less money compared to others. More specifically the authors define envy as “the expression of an unbalanced distribution of funds affecting the overall economic growth in a region with the addition of discomfort” and operationalize it as the ratio of allocated to requested funds. According to the authors the larger this ratio exceeds one the higher the level of envy of those whose ratios are less than one. After this definition the authors review several proportional and envy free methods of funding allocation and develop a Fair Division Transportation Funding Allocation



Model (FDTAM) which “aims to minimize total envy and maximize participants’ desirability subject to budget constraints.” Then, they apply this method to a case study of 10 participants and find that their methodology results in smaller differences in allocated/requested funding ratios and a lower level of total envy. Furthermore, they found that it is not possible for one funding recipient to manipulate the fairness of the funding allocation process they propose. They conclude that using this methodology results in “more proportional, equitable, efficient, and envy free allocations as perceived by the participants requesting funding.”

Michael W. Babcock  
Co-General Editor

Kofi Obeng  
Co-General Editor





# A Bi-Objective Approach to Evaluate Highway Routing and Regulatory Strategies for Hazardous Materials Transportation

by Ashrafur Rahman, Lance Fiondella, and Nicholas E. Lownes

*Hazardous materials (hazmat) transportation is of concern to policymakers because of the serious safety, health, and environmental risks associated with the release of hazmat. One effective approach to minimize risks associated with hazmat transport is the prohibition of hazmat transportation on higher risk links that either pose safety hazards or increased exposure by traversing densely populated areas. Because of high risk, there are multiple stakeholders involved in hazmat transportation. While shippers and carriers are directly involved in making routing decisions, regulatory agencies influence this decision by imposing routing restrictions. In this paper, we apply a bi-objective shortest path problem to evaluate routing and regulation plans for hazmat transportation. We characterize the cost objective as the shortest path between an origin and a destination. The risk objective is to minimize the risk of exposure by restricting the link with the highest risk on the best available path from an origin to a destination. We formulate the bi-objective model and apply it to a test network. Solutions consider multiple origin-destination pairs and present a non-dominated frontier to establish routing and regulatory strategies for hazmat transportation.*

## INTRODUCTION

Transportation of hazardous materials (hazmat) poses risks because of the danger associated with the accidental release of hazardous materials. An incident involving a vehicle carrying hazardous materials can produce undesirable short- and long-term consequences to human health and the environment, including severe illness, death, and irreversible pollution, and in the worst case may require evacuation. A recent United States Department of Transportation commodity survey reports that hazmat transportation on highways has increased by approximately 4% from 2002 to 2007 (U.S. Department of Transportation July 2010). Due to this increase in hazmat transportation and the negative consequences associated with these incidents, various risk mitigation strategies have been proposed to lower the probability and consequence of hazmat release into the environment. Effective methods in hazmat transport risk minimization identify minimum risk paths and eliminate hazmat transport on links where the risk of population or environmental exposure is unacceptably high.

Hazardous materials transportation is different from the conventional vehicle routing because of the risk associated with hazmat transportation. Hazmat routing is usually controlled by multiple criteria, making the routing suitable for multi-objective optimization (Chang et al. 2005). These criteria may be pursued by a single or a group of stakeholders. For example, shippers and carriers may want to find a route that minimizes transportation costs but at the same time minimizes risk to reduce liability. Regulatory agencies may restrict links where risk is excessively high, which may affect shippers' and carriers' route choice. Regulators may also want to make sure that the restriction is not imposing an overly burdensome transportation cost. Hence, there are two aspects in both routing and link restriction decisions: risk and cost. Bi-objective optimization can be effective for problems with two dissimilar objectives and in cases when the competing objectives have different units (e.g., risk and cost).

This paper proposes a bi-objective optimization model satisfying both risk and cost aspects of hazmat routing. In this model, one objective is to enhance network security by identifying critical links that shippers and carriers are likely to choose, in which risk exposure is unacceptably high. Risk is defined as the product of hazmat vehicle incident probability and the consequence of an incident. Consequence is defined as a link's neighboring population exposure. Routing risk is usually minimized by identifying minimum risk paths; however, because of the serious consequences associated with hazmat release, an incident on a single link can produce severe impacts even though that link is on the minimum risk path. Thus, avoiding the link with the highest risk may constitute a better risk aversion strategy than approaches that minimize aggregate path risk. The second objective is to determine a least cost path for hazmat transport. The combination of these two objectives requires a tradeoff between maximum link risk and minimum transportation cost. We employ a test network with synthetic data to illustrate the model. Multiple origin-destination pairs are considered. The effect of link restriction or avoidance of a particular link on the path choice is examined. The model output can be used to support decisions involving roadway and route restrictions in hazmat transport.

## LITERATURE REVIEW

A widely accepted definition of hazmat transportation risk is the product of the probability of an incident and the consequence of this incident (Erkut and Ingolfsson 2000). Consequences of an incident can range from fatalities to infrastructure and environmental damage. Due to the complexity of enumerating all possible forms of loss and the fact that consequences are proportional to the population in the neighborhood of the incident, population exposure is often taken as the surrogate measure of risk. In the Federal Highway Administration guidelines for hazardous materials (Shaver and Kaiser 1998), population exposure has been viewed as the most important criterion in routing. Numerous hazmat routing problems have studied risk aversion using this definition. We also consider this definition in this paper.

List et al. (1991) provided a broad overview of hazmat transportation models, including risk analysis, routing and scheduling, and facility location prior to 1991 and observed a shift from single- to multi-objective optimization. Erkut and Verter (1998) discussed several risk models, all of which involve minimization of aggregate link risk at their core. They showed that optimal paths under one model could perform poorly under another model. Erkut and Ingolfsson (2000) introduced three somewhat different risk aversion objectives in a hazmat transportation model: minimizing the maximum population exposure, minimizing the variance of losses along a route, and minimizing the expected disutility of the losses. All three of these models can be characterized as shortest path problems. The authors concluded that the first of these three models may be the most intuitive and tractable.

Bi-level models have also gained popularity because they accommodate the two decision makers (government regulators and hazmat shippers/carriers) most directly involved in route planning. For example, Kara and Verter (2004) and Erkut and Gzara (2008) formulated bi-level models where the government selects a subset of available roads to minimize total risk and then allows carriers to choose routes that offer the shortest distance within the reduced network. The bi-level program of Bianco, Caramia, and Giordani (2009) considers multiple layers of government authority, responsible at different geographical levels, including regional and local authorities. In this approach, regional authorities seek to minimize the total risk in the area under their jurisdiction, while local authorities prefer to minimize the risk to the local population.

There exists a substantial literature related to transportation security and terrorism, and many of these studies apply game theory. A comprehensive review of game theoretic techniques in transportation can be found in Hollander and Prashker (2006). Network vulnerability assessment has also received significant attention. Bell (2006; 2007) formulated a two-person, non-cooperative,

zero-sum game in which the hazmat router seeks a shortest path assignment and the tester seeks to maximize network disruption. In this game, a shipper wishes to minimize the average population affected; while the demon desires to maximize the average population affected by creating an incident on one edge. This study demonstrated that a shipment possessing multiple routes between a single origin-destination pair reduces the risk of exposure more than shipments with only one available route. Nune and Murray-Tuite (2007) identify the possible routes taken by a demon hijacking a hazmat truck to maximize the consequences. They found that travel time rather than travel distance is a more appropriate criterion to identify the paths in urban areas during peak hours. Dadkar, Nozick, and Jones (2010) used a non-zero sum game structure between a shipper and a terrorist and maximize carrier utilities to optimize link use restrictions. The terrorist's link attack preference is influenced by the routes chosen by the carrier and the regulations implemented by the government. Given the carriers' choice of path and the terrorist attack strategy, the government then decides which links to prohibit. An extension of this study by Reilly et al. (2012) included a Stackelberg game in which the government acts as a leader to maximize the carrier's payoff and limit the terrorist's payoff. Rahman et al. (2012) showed that reducing the size of hazmat network may increase the attacker's expected payoff.

Similar to the bi-level modeling approach, the multi-objective path finding approach has gained attention as a method to model scenarios where there are several stakeholders. List and Mirchandani (1991) presented a multi-objective model for routing and facility location of hazardous materials considering travel time as a link attribute and risk as a zonal attribute. Nozick, List, and Turnquist (1997) introduced time varying patterns of accident rates and exposure into multi-objective routing and scheduling of hazmat transportation based on three minimization criteria: the accident rate, link population exposure, and route length. The authors examined the tradeoff between two criteria considering time varying and static patterns of accident and exposure. A time varying pattern was also explored by Miller-Hooks and Mahmassani (1998) and Chang, Nozick, and Turnquist (2005).

In this paper, we use a bi-objective model addressing both the cost and risk aspects of hazmat routing. A shortest path from origin to destination captures the minimum transportation cost objective. This objective is consistent with the Department of Transportation's routing guideline (U.S. Department of Transportation 1994) that endeavors to avoid imposing an excessive burden on commerce. The risk objective is to restrict or avoid links exhibiting high risk to exposure. That is, we seek to minimize the maximum risk within a path. This is different from the prevailing literature where routing is usually obtained by minimizing the total path cost. This paper proposes a method that can be used by regulators to obtain link regulation strategies and also by shippers and carriers to determine what routes should be avoided to reduce risk, yet strike a balance between cost and risk.

## FORMULATION

Consider a directed transportation network,  $G = (N, A)$ , where  $N$  is a set of nodes and  $A$  is a set of  $m$  links. Each link is indexed by  $(i, j) \in A : i, j \in N$ . Hazardous materials are transported through from origins, to their destinations. The following notations and data are used in the model:

### Data

- $P_{ij}$  = Population on a link  $(i, j)$  within a threshold distance
- $\rho_{ij}$  = Incident probability on a link  $(i, j)$
- $c_{ij}$  = Hazmat transportation cost on a link  $(i, j)$
- $\Omega_{ij} = \rho_{ij} P_{ij}$  = Hazmat risk of link  $(i, j)$
- $z_{ij} = \begin{cases} 0, & \text{link } (i, j) \text{ is restricted to hazmat transport} \\ 1, & \text{link } (i, j) \text{ is open} \end{cases}$

The at-risk population  $P_{ij}$  is the population living within a specified threshold distance from the link. The impact radius varies for different types of hazmat ranging from 0.5 to 5.0 miles (US Department of Transportation 1994). Therefore,  $P_{ij}$  is defined as the population within 0.5 to 5.0 miles of a link  $(i, j)$  in all directions depending on the type of hazmat. It is assumed that on-link population is negligible. The restricted links where risk is excessively high are represented by  $z_{ij}$ . Some links may be closed *a priori* to prevent exposure to particularly sensitive populations (e.g., schools, government offices, hospitals). These links may require a well-coordinated evacuation plan in the event of an accident. Therefore, the regulator may decide to close them in advance to minimize the possibility of such scenarios. Also, even though the impact area is not circular, the analyst can consider the population within the impact area obtained from any diffusion pattern and use this model.

### Decision Variable

$$x_{ij} = \begin{cases} 0, & \text{link } (i, j) \text{ is not used for hazmat transport} \\ 1, & \text{link } (i, j) \text{ is used} \end{cases}$$

The decision variable  $x_{ij}$  identifies the links included in the hazmat routes.

### Bi-Objective Shortest Path Model

$$(1) \quad P1 \quad \min \max_{(i, j) \in A} \Omega_{ij} x_{ij}$$

$$(2) \quad P2 \quad \min \sum_{(i, j) \in A} c_{ij} x_{ij}$$

Subject to

$$(3) \quad \sum_{j: (i, j) \in A} x_{ij} - \sum_{j: (i, j) \in A} x_{ij} = \begin{cases} 1, & i \text{ is origin} \\ -1, & i \text{ is destination} \\ 0, & \text{otherwise} \end{cases}$$

$$(4) \quad x_{ij} \leq z_{ij}$$

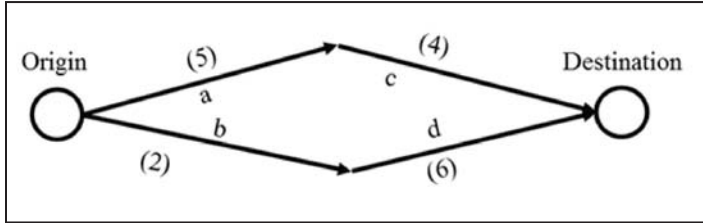
$$(5) \quad x_{ij}, z_{ij} \in \{0, 1\}$$

Here, the two dissimilar objectives, referred to as P1 and P2, are given by equation (1) and equation (2). The first objective is a minimum maximum (minmax) formulation, whereas the second one is a minimum sum (minsum) formulation. The bi-objective formulation creates a minmax-minsum shortest path problem (Berman, Einav, and Handler 1990; de Lima Pinto, Bornstein, and Maculan 2009). Equation (3) is the flow balance constraint employed to find the shortest path between an origin and a destination. Equation (4) ensures that only links available to hazmat transport are selected by the carriers. Equation (5) is the binary requirements of the decision variable and initial link closure.

To illustrate the suitability of the model, consider a carrier wishing to transport a hazmat shipment from the origin to the destination in the network shown in Figure 1. The network consists of four links:  $a$ ,  $b$ ,  $c$ , and  $d$ , with two paths  $(a, c)$  and  $(b, d)$ . All links possess equal travel time. The risk of an incident on each link is shown in parentheses and the incident probability is independent of the carrier's path choice. Although path risk is lower on path  $(b, d)$ , the minmax-minsum model prefers path  $(a, c)$  because it avoids the maximum risk link  $d$  on the two paths available. Hazmat transportation is defined as a "low probability high consequence" event, where even a single incident in one million shipments can produce severe consequences. Thus, avoiding the link with the highest

risk may constitute a better risk aversion strategy than approaches that sum the risk of each link in a path.

**Figure 1: Example Illustrating the Minmax-Minsum Model**



### SOLUTION PROCEDURE

In this paper, the algorithm proposed by Berman et al. (1990) is adapted to solve the program given by Eqs. (1) to (5). They considered network problems that are characterized by two performance measures. One performance measure is a cost function and the other is a maximum cost. In this algorithm, one or more links with cost above a certain value in the first problem are deleted from the network to obtain a reduced network. The second problem is solved on the reduced network. The algorithm continues until the origin and destination become disconnected from each other. The algorithm produces all solutions that satisfy both objectives and identifies all non-dominated (Pareto optimal) solutions. A solution is called a non-dominated solution when there is no alternative solution that is better than that solution with respect to any of the objectives. More detailed explanation of non-dominated solutions can be found in de Lima Pinto et al. (2009), Huang et al. (2005), and Erkut and Gzara (2008). The algorithm from Berman et al. (1990) is described below:

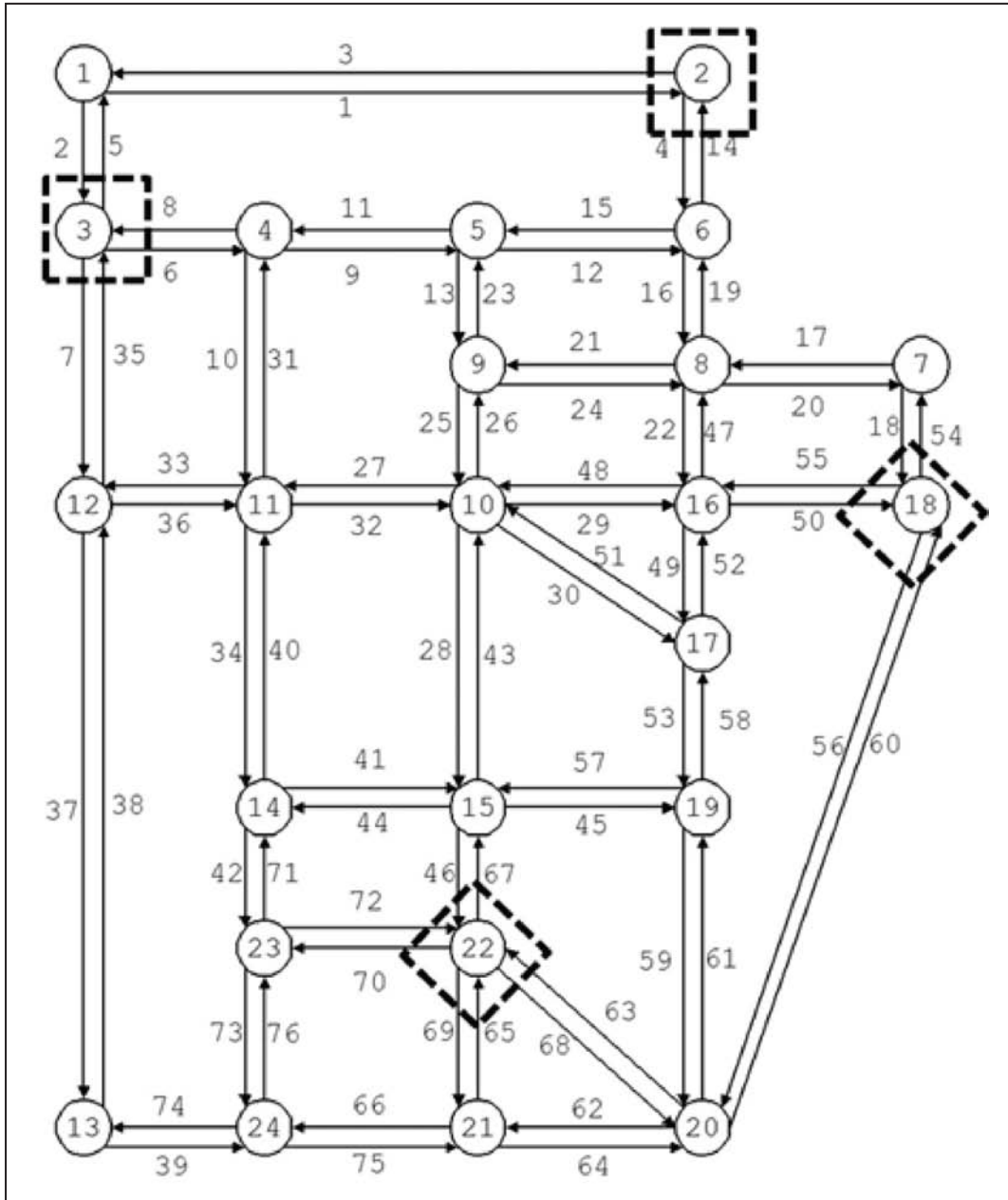
- Step 0.* Initialize the network by setting initial restrictions,  $z_{ij}$  if any. Set  $F = \emptyset$ . Here  $F$  is a set of all Pareto solutions  $(\alpha^0, \beta^0)$ .  $\alpha^0$  and  $\beta^0$  correspond to the Pareto or non-dominated solutions of P1 and P2 respectively. Set  $\beta^0 = \infty$ .
- Step 1.* Rank all available links in the network in non-decreasing order of the link risk,  $\Omega_{ij}$ . To do this, define a link with rank  $r, l^r, r = 1, \dots, m$ , so that  $\Omega_{ij}(l^1) \leq \Omega_{ij}(l^2) \leq \dots \leq \Omega_{ij}(l^m)$ . Here  $l^r$  represents ranked link and  $m$  is the number of links in the network. Set  $r = m$ .
- Step 2.* Set  $\alpha_r = \Omega_{ij}(l^r)$ . If there are other links  $l^k, k < r$ , with the same risk as  $\Omega_{ij}(l^r)$  update  $r$  to be equal to the smallest such  $k$ . Delete from the network all links where  $\Omega_{ij} \geq \alpha_r$ . Solve P2 on the reduced network. Let the solution be  $\beta_r$ . If  $\beta_r > \beta^0$  then  $F = F \cup \{(\alpha^0, \beta^0)\}$ . If no solution exists, stop.
- Step 3.* Set,  $\beta^0 = \beta_r, \alpha^0 = \alpha_r$  and  $r = r - 1$ , if  $r = 0$ , then set  $F = F \cup \{(\alpha^0, \beta^0)\}$  and stop, otherwise go to step 2.

The algorithm produces all feasible solutions  $(\alpha_r, \beta_r)$  and identifies all the non-dominated solutions  $(\alpha^0, \beta^0)$ .

### APPLICATION

We apply the MinMax-MinSum shortest path model to the Sioux Falls network (available at <http://www.bgu.ac.il/~bargera/tnp/>), a widely used case study employed in recent research, including Ukkusuri and Yushimito (2009) and Lownes et al. (2011) for network vulnerability analysis. Figure 2 shows the network, which consists of 24 nodes and 76 links. The analysis considers two origin nodes (nodes 2 and 3) and two destination nodes (nodes 18 and 22), resulting in four origin-destination pairs. The randomly generated synthetic link data used in this analysis are reported in Table 1. While generating the data, relatively higher populations were placed in the middle of the network, imitating a dense core with a lower density fringe.

**Figure 2: Sioux Falls Network** (Dashed Squares = Origins, Dashed Diamonds = Destinations)





**Table 1: Sioux Falls Network Data**

Link ID	Travel Time (hr), $c_{ij}$	Population, $P_{ij}$	Incident Probability ( $\times 10^{-8}$ ), $\rho_{ij}$	Risk ( $\times 10^{-4}$ ), $\Omega_{ij}$	Link ID	Travel Time (hr), $c_{ij}$	Population, $P_{ij}$	Incident Probability ( $\times 10^{-8}$ ), $\rho_{ij}$	Risk ( $\times 10^{-4}$ ), $\Omega_{ij}$
1	0.40	10800	3.0	3.24	39	0.90	18400	9.0	16.56
2	0.30	9000	8.0	7.2	40	0.30	15100	6.0	9.06
3	1.00	10800	1.0	1.08	41	0.90	11800	8.0	9.44
4	0.20	9300	3.0	2.79	42	2.90	10500	1.0	1.05
5	3.20	9000	8.0	7.2	43	0.60	16000	3.0	4.8
6	0.20	13300	9.0	11.97	44	0.50	11800	8.0	9.44
7	0.10	7600	3.0	2.28	45	1.20	11300	7.0	7.91
8	0.40	13300	6.0	7.98	46	1.30	9200	8.0	7.36
9	0.20	14000	2.0	2.8	47	1.20	5200	5.0	2.6
10	1.70	11700	2.0	2.34	48	1.60	4800	7.0	3.36
11	1.70	14000	6.0	8.4	49	0.20	8700	9.0	7.83
12	3.20	11100	9.0	9.99	50	0.60	9100	7.0	6.37
13	1.70	9500	7.0	6.65	51	0.60	7800	6.0	4.68
14	3.20	9300	3.0	2.79	52	0.20	8700	9.0	7.83
15	0.30	11100	9.0	9.99	53	1.50	12300	8.0	9.84
16	1.10	5100	8.0	4.08	54	2.90	3400	5.0	1.7
17	0.30	12300	8.0	9.84	55	0.60	9100	7.0	6.37
18	0.90	3400	3.0	1.02	56	0.30	10400	4.0	4.16
19	0.50	5100	5.0	2.55	57	1.00	11300	7.0	7.91
20	0.20	12300	8.0	9.84	58	0.70	12300	8.0	9.84
21	1.70	6000	7.0	4.2	59	0.90	12200	4.0	4.88
22	3.20	5200	1.0	0.52	60	0.50	9600	9.0	8.64
23	0.30	9500	6.0	5.7	61	2.90	12200	4.0	4.88
24	0.20	6000	8.0	4.8	62	0.90	2600	1.0	0.26
25	0.50	8900	9.0	8.01	63	1.00	7400	8.0	5.92
26	0.50	8900	9.0	8.01	64	1.60	2600	2.0	0.52
27	0.20	14400	7.0	10.08	65	0.50	10400	4.0	4.16
28	3.20	13900	8.0	11.12	66	1.60	6900	3.0	2.07
29	1.30	4800	5.0	2.4	67	0.40	9200	8.0	7.36
30	0.50	7800	6.0	4.68	68	0.70	7400	6.0	4.44
31	0.20	11700	7.0	8.19	69	0.50	6900	1.0	0.69
32	0.60	14400	7.0	10.08	70	0.30	8700	7.0	6.09
33	0.60	12400	4.0	4.96	71	0.70	10500	3.0	3.15
34	0.60	15100	6.0	9.06	72	0.30	8700	7.0	6.09
35	0.30	7600	8.0	6.08	73	1.20	12000	3.0	3.6
36	1.10	12400	4.0	4.96	74	0.30	8400	4.0	3.36
37	0.60	11000	7.0	7.7	75	0.40	6900	8.0	5.52
38	1.90	11000	7.0	7.7	76	0.40	12000	7.0	8.4



Fortunately, hazmat transportation possesses a very low accident probability. Kokkinos et al. (2012) reported that the hazmat accident rate is about  $10^{-6} \sim 10^{-8}$  per km traveled ( $6.21 \times 10^{-7} \sim 6.21 \times 10^{-9}$  per mile). A small incident probability between  $1 \times 10^{-8}$  to  $9 \times 10^{-8}$  per mile was generated for all links assuming a uniform distribution within that range. The unit of risk, the product of population and accident rate, is person exposure per mile traveled.

The shortest paths for each origin-destination pair are calculated at the beginning of the algorithm without imposing any link restrictions on the network ( $z_{ij} = 0$ ). These paths represent the second objective, without considering the first objective. The path cost in these paths are the lower bound of the cost in this bi-objective problem. These paths are the desirable hazmat routes when no restrictions are imposed to any link for safety purpose. The paths are reported as A1, B1, C1, and D1 for O-D pairs (2, 18), (2, 22), (3, 18), and (3, 22), respectively, in Table 2. Link 39 (node 13–node 24) possesses the greatest risk and is restricted at the first iteration. The risk value of link 39 is the upper bound of the risk in the bi-objective problem. The restriction on link 39 does not impact the travel decision for O-D pairs (2, 18) and (3, 18) because A1 and C1 do not utilize link 39. However, the desirable paths for O-D pairs (2, 22) and (3, 22) change because of this restriction. The new paths are shown as B2 and D2 with path costs 222 minutes and 240 minutes in Table 2. After closing 32 links, O-D pairs (3, 18) and (3, 22) become inaccessible, while O-D pairs (2, 18) and (2, 22) become inaccessible after closing 35 links, as shown in Table 2. We stop the algorithm after this since there are no routes available for any O-D pair. Figure 3 illustrates the reduction in link risk until no paths are available. The corresponding path costs due to closure of links are shown in Figure 4.

Figure 5 shows link risk vs. path cost for each O-D pair for all iterations. The figure shows the influence of the link closure on the desirable routing (shortest path) strategy. Each point in the plot represents a link risk that has been restricted and the shortest path due to this restriction. These points correspond to the solution  $(\alpha_r, \beta_r)$  described in the algorithm. Paths on the same vertical line on the plots are not non-dominant, because the route selection strategy did not change even though the riskier links are being closed. For example, with O-D pair (2, 18), restricting the first eight links on the network does not change the shortest path. The path costs are therefore not dependent on the link restriction; furthermore, the risk and path cost combination during these iterations are not non-dominant.

The non-dominant solutions  $(\alpha^0, \beta^0)$  can be identified from Figure 5 in addition to the algorithm. To identify a non-dominant (Pareto optimal) frontier, it is necessary to identify the risk level where the route selection strategy changes. If a new path is found for a particular link closure, the associated link risk and the cost of the previous path constitute a point of the Pareto frontier. There are only three paths (A1, B1, and C1) that are generated for O-D pair (2, 18). Newer (A1 to A2, A2 to A3) or inaccessible paths (infinite cost) are generated when closing links with risk 9.84, 8.01, and 6.37, respectively. The non-dominant points for O-D pair (2, 18) are the risk and cost combination of (link 20, path A1), (link 25, path A2), and (link 30, path A3). Figure 6 shows the Pareto solutions for the four O-D pairs. The paths represented by each point are shown in Table 2.

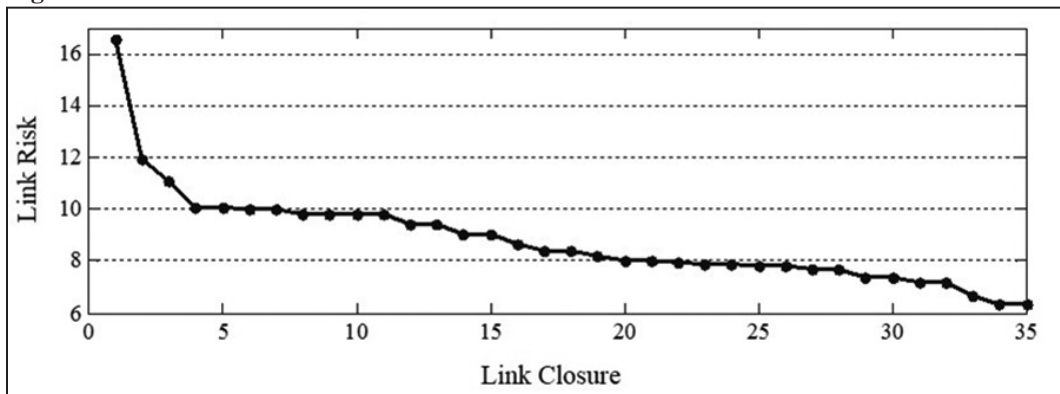
The non-dominant solutions have important implications for decision making, both from regulators' and shipper/carriers' perspectives. Figure 6 summarizes the travel cost imposed on shipper/carriers when a particular hazmat link prohibition strategy is implemented. Furthermore, for a particular risk value, the paths below that risk value are those available for hazmat transport. For example, if the regulator's target is to restrict all links with risk greater than or equal to 10, all paths are available to shipper/carriers for O-D pair (2, 18) because the risk on all relevant paths lies below this threshold. The shipper/carriers will most likely choose path A1 because it gives the lowest cost among all paths. If they are more concerned about risk, they may choose either A2 or A3 if cost is not a major issue. For all other O-D pairs, they lose their first choices B1, C1, and D1 and may choose second lowest cost paths B2, C2, and D2. Observing the non-dominated front for O-D pair (2, 22) explains that some cases may occur when risk may be reduced even without visibly increasing cost. If the first routing strategy (route B1) is eliminated and the second option (route

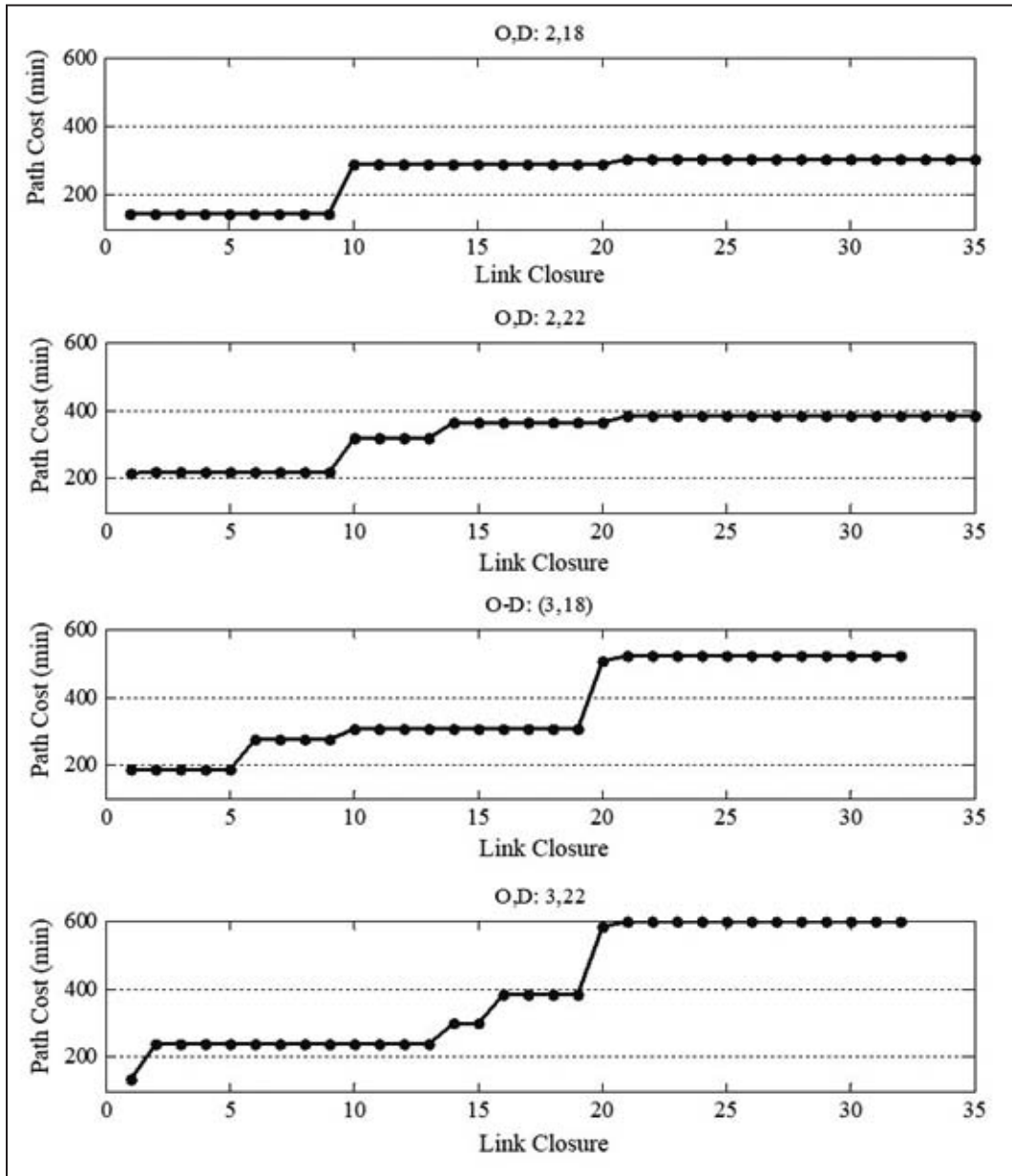
**Table 2: Path Selections at Each Link Closure**

Number of Link Closure	Link ID	Link Risk <sup>§</sup> ( $\times 10^{-4}$ )	OD Pair (2,18)		OD Pair (2,22)		OD Pair (3,18)		OD Pair (3,22)	
			Shortest Path*	Path Cost (min)	Shortest Path*	Path Cost (min)	Shortest Path*	Path Cost (min)	Shortest Path*	Path Cost (min)
0	N/A	N/A	2-6-8-7-18 (A1)	144	2-2-3-12-13-24-23-22 (B1)	216	3-12-11-10-17-16-18 (C1)	186	3-12-13-24-23-22 (D1)	138
1	39	16.56	2-6-8-7-18 (A1)	144	2-6-8-7-18-20-22 (B2)	222	3-12-11-10-17-16-18 (C1)	186	3-12-11-14-15-22 (D2)	240
2-5	6,28,27,32	11.97-10.08	2-6-8-7-18 (A1)	144	2-6-8-7-18-20-22 (B2)	222	3-12-11-4-5-9-8-7-18 (C2)	276	3-12-11-14-15-22 (D2)	240
6-11	12,15,17,20,53,58	9.99-9.84	2-6-8-9-10-17-16-18 (A2)	288	2-2-3-12-11-14-15-22 (B3)	318	3-12-11-4-5-9-10-17-16-18-20 (C3)	306	3-12-11-14-15-22 (D2)	240
12-13	41,44	9.44	2-6-8-9-10-17-16-18 (A2)	288	2-6-8-9-10-17-16-18-20-22 (B4)	366	3-12-11-4-5-9-10-17-16-18-20 (C3)	306	3-12-11-14-23-22 (C4)	300
14-15	40,34	9.06	2-6-8-9-10-17-16-18 (A2)--	288	2-6-8-9-10-17-16-18-20-22 (B4)	366	3-12-11-4-5-9-10-17-16-18-20 (C3)	306	3-12-11-4-5-9-10-17-16-18-20-22 (D4)	384
16-19	60,11,76,31	8.64 -8.19	2-6-8-9-10-17-16-18 (A2)	288	2-6-8-9-10-17-16-18-20-22 (B4)	366	3-3-2-6-8-9-10-17-16-18 (C4)	504	3-1-2-6-8-9-10-17-16-18-20-22 (D5)	582
20	25	8.01	2-6-8-16-18 (A3)	306	2-6-8-16-18-20-22 (B5)	384	3-3-2-6-8-16-18 (E5)	522	3-1-2-6-8-16-18-20-22 (D6)	600
21-32	26,8,45,57,49,52,37,38,46,67,2,5	8.01-7.2	2-6-8-16-18 (A3)	306	2-6-8-16-18-20-22 (B5)	384	Inaccessible	Inf	Inaccessible	Inf
33-35	13,55,50	6.65-6.37	Inaccessible	Inf	Inaccessible	Inf				

<sup>§</sup> Link risk are reported in decreasing order

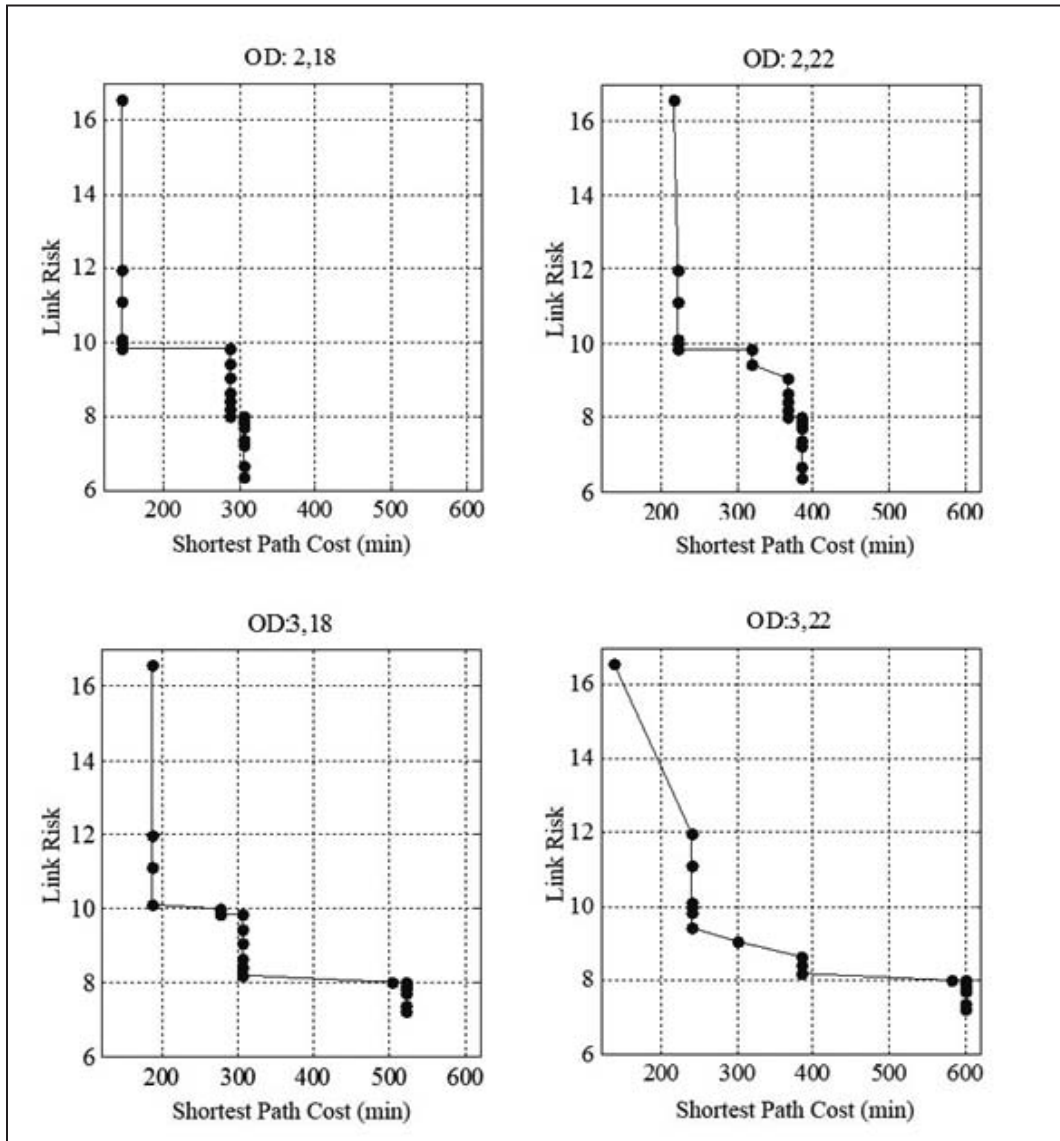
\* Shortest paths are reported as node-to-node

**Figure 3: Link Risk at Each Link Closure**

**Figure 4: Cost vs. Link Closure for Each O-D Pair**

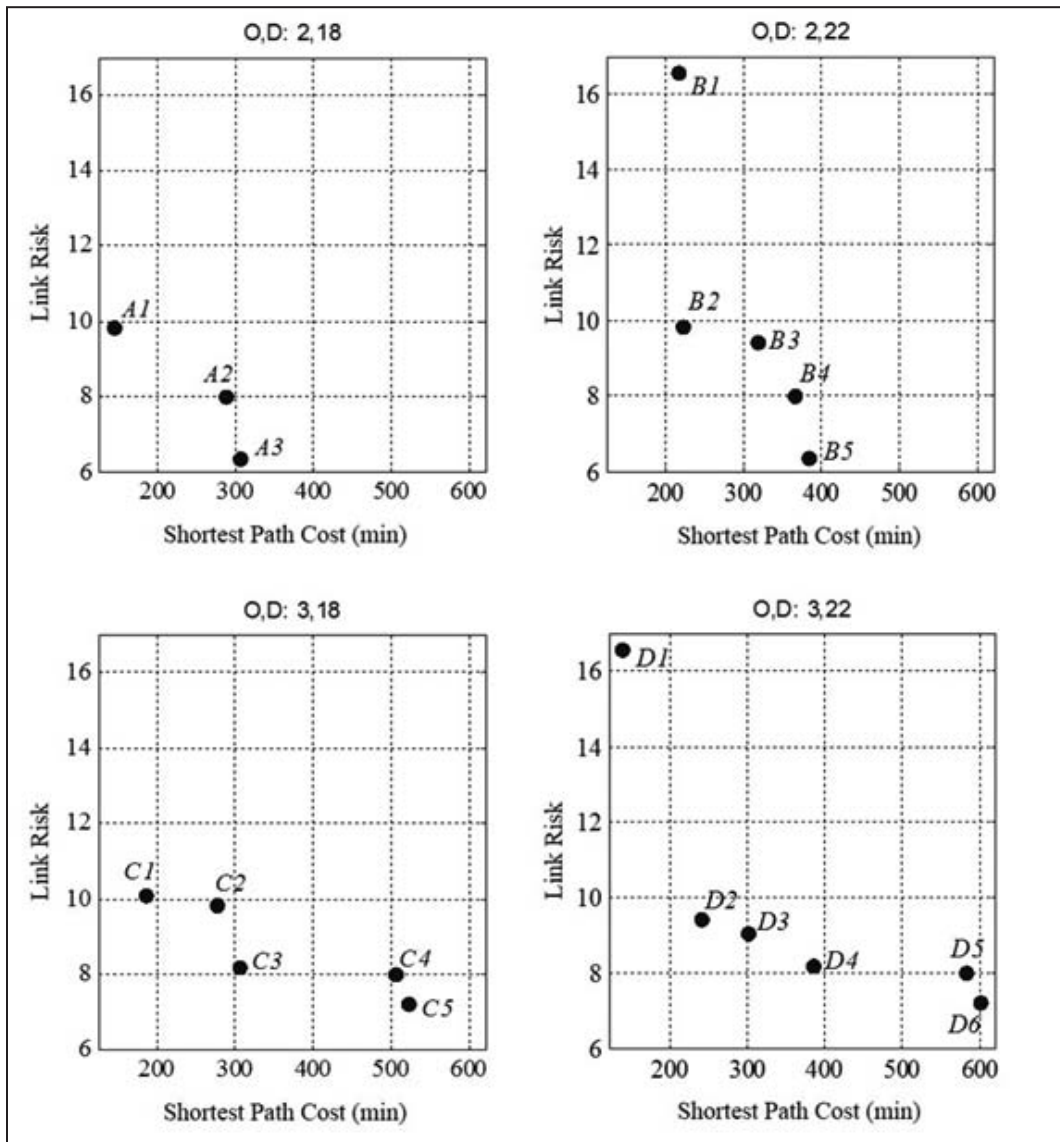
B2) is taken, we can reduce risk 40% (16.56 to 9.84) with only about a 3% (216 min to 222 min) increase in travel cost. It is seen that a substantial increase is observed for O-D pair (3, 18) and (3, 22) if first routing options are eliminated. The costs for O-D pair (3, 18), and (3, 22) increase to 48.39% (186 min, path C1 to 276 min, route C2), and 73.91% (138 min, path D1 to 240 min, route D2), respectively. The risk reduction for O-D pair (3, 18) is only 2.5%, however, for O-D pair (3, 22), it is about 42%.

In addition to a Pareto optimal front for each of the O-D pairs, a system level Pareto frontier can serve regulators in evaluating the trade-off between link closure and system level cost. The

**Figure 5: Link Risk vs. Path Cost**

system-level Pareto points are constructed by summing the path costs of all shortest paths at a given restricted network and the associated maximum link risk as shown in Figure 7. It is seen that if the allowable maximum risk is set to 10, the system cost increases from 684 min, when there is no restriction, to 882 min. Also, the allowable maximum risk cannot be lowered below 7.2 because no paths will be available for any shipments.

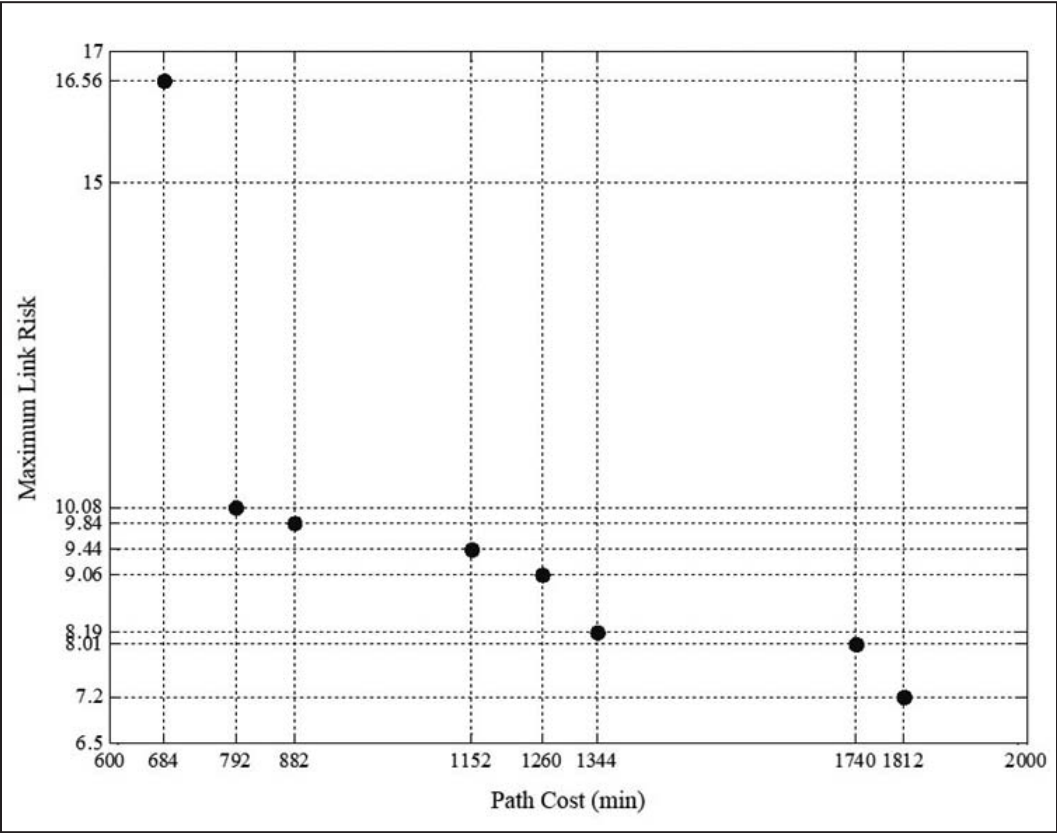
The bi-objective model discussed in this paper can offer insights to identify a risk threshold value for regulators and to determine how route choice may be affected by such restrictions. For shippers and carriers, this will provide a strategy to verify the suitability of routing, how to decrease transportation costs, and if risk is being shifted from one subpopulation to another. Although the analysis was demonstrated with a hypothetical network, the model can be used for any network with real data.

**Figure 6: Pareto Optimal Frontiers for Each O-D Pair**

## CONCLUDING REMARKS

A bi-objective shortest path problem was formulated for hazardous materials routing. Although the method was applied to a test network, the methods can be applied to any network as a decision-support tool for hazmat link prohibition policies. The method described in this paper constructs non-dominated frontiers for each origin-destination pair and the complete hazmat transportation network, which can aid a regulatory agency to establish and evaluate a tolerable threshold risk; the links exceeding the risk tolerance may then be restricted, and routing plans minimizing the impact on the carriers can be identified. Shippers and carriers can also establish their routing strategies by eliminating paths that utilize high risk links to determine an appropriate cost estimate of transportation. The method described in this paper can therefore be used to compare alternative regulation and routing strategies to achieve a desired balance between risk and routing convenience.

Figure 7: System Level Pareto Optimal Frontier



In future research, these metrics will be illustrated on medium- and large-scale real transportation networks considering multi-commodity hazmat flow.

The model is static, not dynamic, so it doesn't include travel time variability by day of the week or by season of the year. The model also doesn't identify the effect that weather has on dispersal areas of hazardous materials. These matters are outside the scope of the paper, which is focused on hazmat routing. Thus, the paper doesn't consider accident risk during loading and unloading.

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**Disclaimer**

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Department of Homeland Security.



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**Ashrafur Rahman** is a Ph.D. student in the department of civil and environmental engineering at the University of Connecticut. His primary research interests include transportation network modeling, transportation security, public transportation, and traffic flow. Ashrafur is currently working on hazardous materials routing for his doctoral research.

**Lance Fiondella** is an assistant professor in the department of electrical and computer engineering at the University of Massachusetts, Dartmouth. His research interests include reliability, performance, and transportation engineering. He received his Ph.D. in computer science and engineering from the University of Connecticut.

**Nicholas Lownes, P.E.**, is an associate professor in the department of civil and environmental engineering at the University of Connecticut. His primary research interests include public

*transportation systems, transportation network modeling and transportation security. His current research focuses on a collaborative database initiative building analytical tools for evaluating equity in public transportation systems and optimizing public transportation service configuration and operation. He earned his Ph.D. from The University of Texas at Austin.*

# TRANSIMS Implementation for a Small Network and Comparison with Enhanced Four-Step Model

by Mansoureh Jeihani and Anam Ardeshiri

*Travel demand forecasting is a major tool to assist decision makers in transportation planning. While the conventional four-step trip-based approach is the dominant method to perform travel demand analysis, behavioral advances have been made in the past decade. This paper proposes and applies an enhancement to the four-step travel demand analysis model called Sub-TAZ. Furthermore, as an initial step toward activity-based models, a TRANSIMS Track-1 approach is implemented utilizing a detailed network developed in Sub-TAZ approach. The conventional four-step, Sub-TAZ, and TRANSIMS models were estimated in a small case study for Fort Meade, Maryland, with zonal trip tables. The models were calibrated and validated for the base year (2005), and the forecasted results for the year (2010) were compared to actual ground counts of traffic volume and speed. The study evaluated the forecasting ability of TRANSIMS versus the conventional and enhanced four-step models and provided critical observations concerning strategies for the further implementation of TRANSIMS.*

## BACKGROUND

Traffic pattern prediction is necessary for infrastructure improvement, and travel demand modeling provides tools to forecast travel patterns under various conditions. This modeling involves a series of mathematical equations that represent how people make travel choices. Traditional travel demand models use the four-step method, which was introduced in the 1950s and has been used widely in transportation planning. Although the four-step method has been practical in producing aggregate forecasts, it has some shortcomings. For example, in short-range planning networks, existing and newly constructed roads become congested much faster than forecasted (TRB 2007) and the performance of current four-step models is not always satisfactory. Additionally, these models are not behavioral in nature and as a result they are unable to represent the time chosen for travel, travelers' responses to demand policies (e.g., toll roads, road pricing, and transit vouchers), non-motorized travel, time-specific traffic volumes and speeds, and freight and commercial vehicle movement (TRB 2007). Some researchers have modified the four-step model to improve its efficiency while others have proposed new alternatives such as activity-based models.

One modification designed to yield more realistic traffic volumes on roadways adjacent to zone-centroid connectors was developed and used by the Virginia Department of Transportation for its regional, county, corridor, subarea, and intersection studies (Mann 2002). This modified four-step model, designated b-node, used zone-level network trip tables and performed a subzone capacity-restrained traffic assignment. The model allocated the zone trip table into subzones by land activity (when there is information on land use in the subzone) or by equal weights. It was reported that despite lumpiness where the centroid connectors tied into the network, the model produced smoother traffic volumes (Mann 2004).

The fixed-order sequential approach of the traditional four-step models suffers from inconsistency among the flow values in each step. Recent research has made some improvements to the traditional sequential approach. Zhou et al. (2009) developed a combined travel demand model using random utility theory. This model brought consistency to travel choice and incorporated behavioral aspects

in the traditional four-step models. In another study, a model was developed to assess changes in system performance measures due to slight changes in the network (Yang and Chen 2009). Festa et al. (2006) improved travel demand forecasting by employing experimental sequential models that simulate trip chains. They calibrated and validated behavioral random utility models to simulate the traveler's decision process.

Four-step models employ static traffic assignment (STA), which assumes that traffic is steady-state, link volumes are time-invariant, the time to traverse a link depends only on the number of vehicles on that link, and that vehicle queues are stacked vertically and do not traverse to upstream links in the network. STA has very restrictive assumptions, which limit its applicability. To enhance STA, Jaihani et al. (2006a) calculated link delay as a function of link flow and flow on adjacent links using intersection delay calculations. In their proposed method, a combination of the Frank-Wolfe algorithm and the method of successive averages was used to model multi-path vehicle assignment within reasonable computational time for small- and medium-sized transportation networks (Jaihani et al. 2006a).

Dynamic traffic assignment (DTA) models were introduced as an extension of STA. In DTA models, demand is allowed to be time-varying so that the number of vehicles passing through a link and the corresponding link travel times become time-dependent. These complexities are implemented in some traffic simulation software using microscopic models (Cheng and Wang 2013). Demand estimation, supply presentation, methods for computing dynamic traffic assignment, and convergence among several well-known computer packages were compared by Jaihani (2007).

Activity-based modeling is a relatively new method that replicates the activities of individuals in a network for a 24-hour period. The four-step model aggregates the trip generation process and finds the total number of trips produced by each development type (e.g., residential and commercial) in traffic analysis zones. Conversely, the activity-based model is disaggregated and finds trips for each traveler. Four themes characterize the activity-based framework: travel derives from the demand to participate in an activity, and sequences or patterns of behavior are the basic unit of analysis; household and activities influence travel behavior; spatial, temporal, transportation, and interpersonal interdependencies constrain activity or travel behavior; and activity-based approaches reflect the scheduling of activities in time and space (McNally 2000). The Virginia Department of Transportation (VDOT 2009) reports that activity-based models are currently used by the New Hampshire Department of Transportation (since 1998), San Francisco County Transportation Authority (since 2001), Mid-Ohio Regional Planning Commission (since 2005), New York Metro Transportation Commission (since 2005), Tahoe Regional Planning Agency (since 2007), and since 2007 by the Sacramento Area Council of Governments. The Atlanta Regional Commission, Denver Regional Council of Governments, Portland Metro, Ohio Department of Transportation, Metropolitan Transportation Commission, and the Puget Sound Regional Council all have activity-based models in development (VDOT 2009).

Transportation Analysis and Simulation System (TRANSIMS) is an integrated travel demand activity-based modeling system developed by the Los Alamos National Laboratory to eventually replace the four-step travel demand model. It is a microsimulation model that addresses current legislative policy issues facing transportation planners, including sustainability, environmental impact, and the emerging intelligent transportation systems. It consists of a series of modules that produce synthetic households. The modules are the Population Synthesizer, the Activity Generator, the Route Planner, the Microsimulator, the Emission Estimator, and the Feedback.

While TRANSIMS has been available for about two decades, it has not been widely employed because it is data intensive, complex, and difficult to implement. Several researchers and practitioners have attempted to operate it on different networks. A component of TRANSIMS (referred to as Track-1 by practitioners) was implemented and calibrated in Chittenden County, Vermont (Lawe et al. 2009). It was reported that TRANSIMS and the four-step model for three screen lines (imaginary lines to select traffic count locations in an organized manner so that the major travel movements

are measured) produced similar results. TRANSIMS nearly replicated the daily trip distributions; however, there were shifts in both the exact time and value of the morning and afternoon peak periods possibly caused by inaccuracies in the trip table (Lawe et al. 2009). TRANSIMS Track-1 was also employed by Rilett et al. (2003) in a case study of El Paso, TX, by importing the origin-destination (OD) matrix and network from the four-step models. It was found that TRANSIMS needed more input data and more sophisticated troubleshooting than the four-step model (Rilett et al. 2003). Dixon et al. (2007) compared TRANSIMS estimates of intersection delay to field data and concluded that TRANSIMS' delay estimates for signalized intersections were very close to the real-world observations, but overestimated unsignalized intersection delays. Track-1 TRANSIMS was also applied to a small sized MPO in Illinois. In comparison with the four-step model, the TRANSIMS results were better for links, which were collector roads, than those obtained following FHWA guidelines (Ullah et al. 2011).

Jeihani et al. (2006b) developed a new heuristic algorithm to determine dynamic user equilibria (DUE) and incorporated it into TRANSIMS. The developed DUE model was applied to networks in Blacksburg, Virginia, and Portland, Oregon. An improved distribution of travelers was obtained while consuming less than 17%–33% of the computing time required by the original assignment model in TRANSIMS. Zhang and Mohammadian (2008) developed a new methodology to facilitate household travel data transferability for local areas. With their proposed data simulation tool, metropolitan planning organizations (MPOs) can avoid the high costs associated with data collection for micro-simulation models such as TRANSIMS.

This study proposes a three-phase process to transition from the traditional four-step model to an activity-based model. The first step is an improvement to the four-step model, which will be referred to as the Sub-TAZ model. The Sub-TAZ model provides smoother traffic than the four-step model and requires a detailed network that includes minor roads and driveways. It also divides the traffic analysis zones (TAZs) into smaller segments called Sub-TAZ. The second step is TRANSIMS Track-1, which uses the detailed network and origin-destination matrices from the first step and performs a dynamic traffic assignment. The final step is TRANSIMS Track-2, which is an activity-based model. The study then applies the traditional four-step model, the proposed Sub-TAZ model, and TRANSIMS Track-1 on a small network and then validates and compares them for two horizons. The study also compares the ability of TRANSIMS to that of the prior four-step models regarding planning and future demand forecasting.

#### **FOUR-STEP MODEL FOR A SMALL AREA NETWORK**

The selected case study includes Maryland Route 175 (MD-175) and the surrounding roads, in a 100-square kilometers area in central Maryland. This area is growing and has many new developments constructed. A four-step model for this small area was developed based on the Baltimore Metropolitan Council's (BMC) regional model (i.e., a travel forecasting model for Baltimore metropolitan area). The developed model is calibrated and validated for the base year 2005 and it is called the base model. As presented in Figure 1, there are 28 traffic analysis zones (TAZs) and 327 links in the study area. Thirteen of the 28 TAZs are external (i.e., outside the study area) and all trips outside the study area are assumed to traverse one of these TAZs to enter the study area.

Ground counts of traffic were obtained for approximately 13% of the links in the study area. Individual link errors were calculated by subtracting the estimated model's volume from the link's ground count. The model was calibrated and validated according to the Federal Highway Administration's (FHWA) guidelines to reasonably represent reality (Ismart 1990). Equations (1) to (3) were used to measure how well the calibration performed:

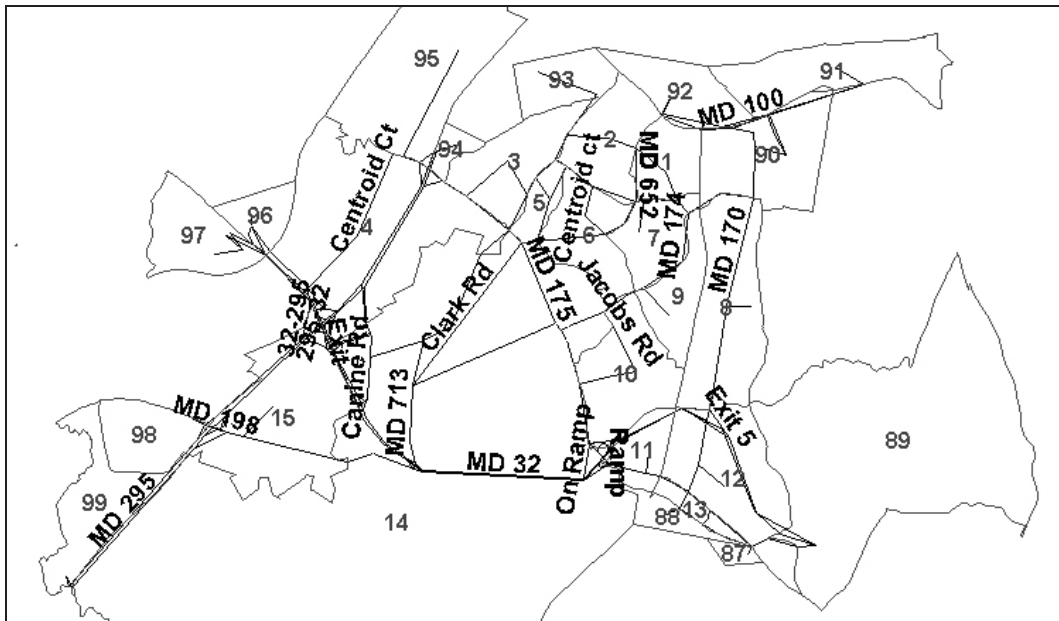
$$(1) \quad r = \frac{\sum (x,y) - n\bar{x}\bar{y}}{\sqrt{(\sum (x^2) - n\bar{x}^2)(\sum (y^2) - n\bar{y}^2)}}$$

$$(2) \quad RMSE = \frac{\sqrt{\frac{\sum [(x - y)^2]}{n}}}{\frac{\sum x}{n}} ee$$

$$(3) \quad AE = \frac{\sum |y - x|}{\sum x} \times 100\%$$

where,  $r$  is the correlation coefficient; RMSE is the root mean square error;  $x$  is ground count of traffic;  $y$  is the calibrated traffic volume;  $n$  is the number of observations; and  $AE$  is the absolute error. The calibration and validation results for the base model are in Table 1.

### Figure 1: TAZs and Links in the Base Model



## ENHANCEMENTS TO THE FOUR-STEP MODEL

Sub-TAZ and TRANSIMS Track-1 models were developed as modifications to the four-step model and calibrated and validated for the small study area for the base year 2005.

### Sub-TAZ Model

One of the reported problems associated with the current four-step models is the lumpiness of loadings around centroid connectors. This is because all trips are generated from a centroid in one zone and destined to other zones via a few imaginary centroid connectors. As a result, the

connection between the imaginary centroid connectors and the major roads becomes very congested with traffic while other segments of the major road are less utilized. The proposed new approach, the Sub-TAZ model, addressed this problem by including minor roads and driveways in the network and allowing each zone to be divided into up to 12 subzones depending on local road and driveway locations. Also, each zone can be divided based on land use instead of roads if it has land available for development.

If land use and socio-economic data for all subzones are available, the input data to the four-step model can be expanded to reflect subzone information and the regular four-step model applied at the subzone level. However, since all the required data are usually unavailable at the subzone level, the proposed method applies the trip generation step in the zonal level. The productions and attractions of each zone—the trip generation output—are then divided between the subzones. This division is performed equally among the zones if there is not much information about sub-zonal land use. For example, if a zone is divided into four subzones, each subzone is allocated one-fourth of the total trip productions and attractions of the original zone if information is unavailable about sub-zonal land uses such as trip generators. If this information is available, then total trip productions and attractions are distributed proportionally and not equally. Due to the absence of data on sub-zonal land uses, the distributions are based on equal weights.

In comparison with the b-node model (Mann 2004), which divides the origin to destination trips and zones into subzones in the last step (traffic assignment) of the four-step model, the Sub-TAZ divides the zones into subzones in the second step (trip distribution). Therefore, the output of the trip generation procedure is divided into the number of subzones in each zone, and the rest of the steps of the four-step model use the extended matrices. The result is a detailed network that includes all local streets and developments' driveways and represent a more realistic road network than the base model.

In Figure 2, the Sub-TAZ model includes 55 zones whose detailed network consists of 1,782 links and 1,461 nodes. As in the four-step model, the Sub-TAZ model assumes that all vehicles originate from and travel to zone centroids and uses imaginary links (centroid connectors) to connect to the highway network. The Sub-TAZ model was developed, calibrated, and validated for the study area. The results are presented in Table 1.

**Table 1: Calibration/Validation Results of the Base, Sub-TAZ, and TRANSIMS Models**

Calibration/Validation	FHWA Guideline	Base	Sub-TAZ	TRANSIMS
Correlation coefficient	0.88	0.94	0.92	0.93
Percent error regional-wide	5%	-5.7%	5.8%	10.9%
Sum of differences by functional class				
Freeway	7%	-5.6%	-1.7%	11.5%
Principal Arterial	10%	-11.5%	0.2%	14.9%
Minor Arterial	15%	1.0%	44.4%	4.7%
Collector	25%	-41.2%	-5.4%	-1.4%

### TRANSIMS Model

TRANSIMS is based on individual behavior and interactions. It traces and simulates the movements of each individual traveler in a fully described network as that traveler accomplishes travel activities in a 24-hour period. TRANSIMS also collects statistics on traffic, congestion, and pollution. The major goal of applying TRANSIMS for such a small study area is to compare its forecasting capability to that of the four-step models.



**Figure 2: The Sub-TAZ Network for MD-175**

TRANSIMS as a travel model improvement program aims to precisely model the interaction between demand and supply. Micro-simulation is typically the supply side of TRANSIMS, while Track-1 and Track-2 are the two approaches to enhance the demand side. In most studies, researchers utilize the standard trip origin-destination matrix for the demand side, which can be simply extracted from the existing four-step models of the desired study area. The Track-1 approach is mainly a trip-based approach to the TRANSIMS model that only employs Route Planner and Microsimulator modules. Track-1's advantage over the four-step models is its dynamic traffic assignment capability.

The Track-2 approach, which is activity-based, utilizes the whole TRANSIMS model package (including the Population Synthesizer, Activity Generator and Router modules) to forecast travel demand. This approach is more complicated and more data intensive, but is microscopic and addresses many of the existing problems in the four-step models. Track-2 was also developed in this study. However, the results were not plausible due to the small size of the network. The Track-2 model underestimated traffic volumes because of trip-to-activity conversion problems for external zones. That is, the current Track-2 model does not convert external trips to activities and, therefore, does not include external trips. This issue does not affect models for large areas since external trips are negligible compared with the areas' trips.

Two major inputs from the four-step model are required to create Track-1 of the TRANSIMS model. The first is network data, which must be converted into TRANSIMS format. TRANSIMS requires considerably more detailed network data than the traditional four-step models. Since this research created a detailed network for the Sub-TAZ model down to the local level of roadway classification, the detailed network is completely compatible with the TRANSIMS' model requirement. Therefore, TRANSIMS network was completed by removing the virtual centroid connectors from the Sub-TAZ model. The second input to Track-1 is demand files, which are represented by the four-step OD trip matrices. The demand files matrices were converted into TRANSIMS format (see the Convert Trip Section).

**Network.** TRANSIMS developers have developed some utility programs to create all required files using four major inputs: node, link, shape, and zone files converted from a four-step model. As a result, other inputs such as parking and activity locations are not required to be entered manually. The four aforementioned files are similar to those from four-step models but are more detailed. For example, turn pockets (pocket lanes to turn right or left) and merge lanes (high-occupancy-vehicle lanes) are determined. Three files of highways (links), endpoints (nodes), and TAZ were exported from TransCAD to shape files (geographical format) and then converted to TRANSIMS format using GISNet and TRANSIMSNet. Some manual adjustments were made to make the files acceptable by GISNet, which is a useful control key that exports shape files to text files. The TRANSIMSNet utility program was then utilized to synthesize the TRANSIMS network and generate other network inputs such as activity locations. The log file was checked for warning messages after TRANSIMSNet was run and corrections were made as required. The following files were generated as TRANSIMS network files: link, node, process link, signal, transit, activity location, parking, shape, and zone.

TRANSIMS conceptually views the network as a set of interconnected single-mode layers. Thus, a separate layer exists for each travel mode (walk, bike, car, bus, rail, and trolley). At designated locations in each layer (activity location, parking location and transit stops), a special link called a process link connects one single mode layer to another. These process links allow intermodal interactions to take place from one layer to another. For example, a person can switch from walk (W) mode to car (C) mode, then transit (T) mode, and then go back to walk mode to go from his home to his work place using process links, and this trip can be presented by WCTW. The parking file includes information about parking such as identity (ID), type, capacity, and location. TRANSIMS assumes vehicle start and end locations are in a parking lot. An activity location represents a place where a household member would travel to and from and includes such information as ID, node, link, and zone.

Activity locations in the external zone required specific attention. This is because external links in the study area were mostly freeways with separate origin and destination activity locations. Also, external trips may not be routed properly when an inbound link is the destination or an outbound link is the origin.

**Convert Trip.** To develop the Track-1 approach in TRANSIMS, the four-step model's zone-to-zone trip tables for different trip purposes and travel modes were converted to trips between activity locations for each second during the day. To do so, the Convert Trip utility program in TRANSIMS was utilized. Daily trip volumes from the TransCAD model were extracted to form a TRANSIMS trip table, and the TRANSIMS smoothing tool was employed to modify the daily distribution of trips from this table. Household and vehicle files were the other two major outputs of the Convert Trip program.

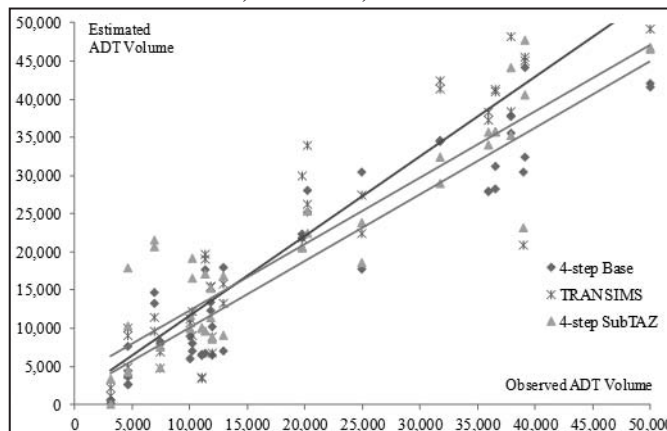
**Feedback Module and Calibration.** The feedback process is the calibration tool in TRANSIMS and can be run between two or more modules. It is used to calibrate the model, stabilize travel times in the network and yield the desired mode choice, and to correct the network, locations, modes and activity times. Connection problems between the links and process links were addressed manually. Because TransCAD is not sensitive to network geometry, some links in the imported network, especially ramps, did not follow the proper curvature. As a result, the Microsimulator could not load vehicles on the links that exceeded the restriction of maximum connection angle (the angle between two links). The authors modified the network by reducing connectivity angles. Several feedbacks were performed to improve the activity and plan files and address trips with problems. Two of the most common problems were path-building (due to network limitations) and zero-node path (due to the aforementioned activity locations for external trips or when the origin and destination are in the same link).

Also, a feedback was created between the Route Planner and the Microsimulator to stabilize travel times. The feedback loop randomly re-routed 10% of travelers until link travel times stabilized. The relative stabilization (when the difference between the travel time of the current iteration and the previous is negligible) happened after 10 iterations in this study. Despite following this approach, it is better always to ensure that user equilibrium occurs. At the first iteration, the Route Planner used free-flow travel times to find the shortest path. However, after all vehicles were loaded onto the network, the link travel times were higher than the free-flow travel time, especially in congested areas. As a result, some routes no longer provided the shortest time path. The random re-routing of travelers stabilized link travel times. The results of the calibrated Track-1 TRANSIMS model in Table 1 were validated with traffic counts in the same way as the base model and the Sub-TAZ model.

### New Approaches Versus the Base Model

Table 1 compares the calibration/validation results of the three models developed for the base year 2005 along with the FHWA guideline. As the table shows, the base model offers a slightly better correlation coefficient but it poorly estimates collector roads. The Sub-TAZ model and TRANSIMS estimate traffic volumes on collector roads generally better. Except minor arterials, the Sub-TAZ estimation outperforms the base model for all classes of roads. TRANSIMS outperforms the other two models for collectors and overestimates traffic on arterials and freeways probably due to a large number of external traffic. The estimated traffic volumes versus actual ground traffic counts for all three models are in Figure 3.

**Figure 3: Estimation-Observation Regression Lines for the 2005 Base, Sub-TAZ, and TRANSIMS Models**



For validation, the three calibrated models were employed to forecast traffic in 2010 and then validated with traffic counts. As indicated in Table 2, the TRANSIMS and Sub-TAZ models had a higher correlation coefficient than the base model. The base model forecasted freeway traffic best with a 6.2% error compared with the Sub-TAZ model's 12.1% and TRANSIMS' 13.2%. However, the TRANSIMS model could be calibrated in just the same way as the four-step model. In Table 1, the freeways' error was 11.5%, which is more than the 7% error following the FHWA guidelines in the base model. If user equilibrium is applied to the TRANSIMS model and a lower error rate is obtained for freeways in 2005, then the 2010 prediction model will give a lower error rate and a better forecast of freeway traffic volumes. Traffic volumes on principal and minor arterials were forecasted better in TRANSIMS (5.3% and 6.9% error, respectively) than in the Sub-TAZ (8.6% and 39.9% error) and the base models (16.6% and 44.3% error). The forecasted volumes and 2010

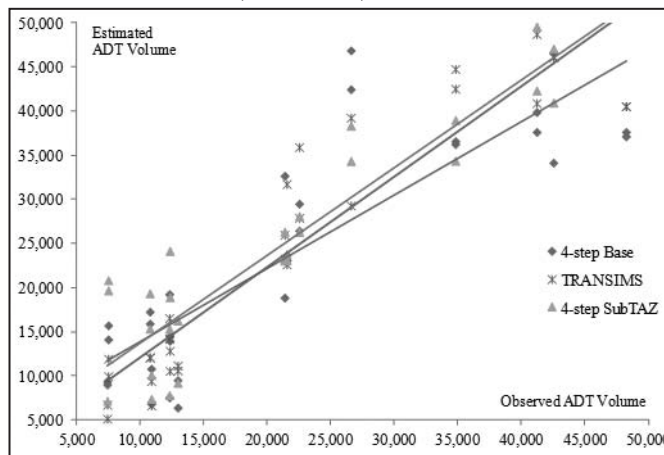
traffic counts in Figure 4 verify that TRANSIMS and Sub-TAZ models produce less discrepancy in short-run forecasting of traffic volumes than the base model.

**Table 2: 2010 Forecast Validation Results of the Base, Sub-TAZ, and TRANSIMS Models**

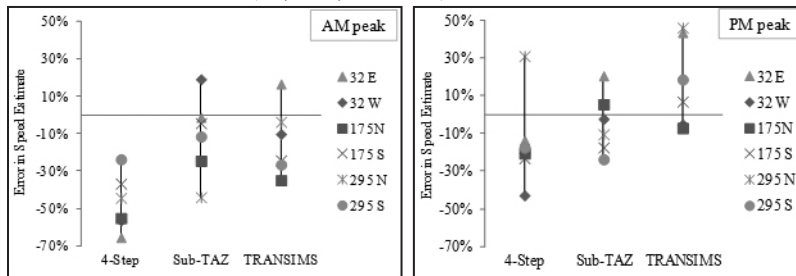
Validation	Base	Sub-TAZ	TRANSIMS
Correlation coefficient	0.86	0.94	0.94
Percent error regional-wide	8.0%	16.4%	10.5%
Sum of differences by functional class			
Freeway	6.2%	12.1%	13.2%
Principal arterial	-16.6%	-8.6%	-5.3%
Minor arterial	44.3%	39.9%	6.9%

Although traffic counts have been widely used to calibrate and validate the traditional four-step models for facilities not affected by signals, speed checks may be a helpful measure to evaluate model performance. Consequently, the study used the observed 2010 speed data for the major roads in the study area obtained from the Regional Integrated Transportation Information System (RITIS) in the CATT Laboratory at the University of Maryland, College Park to evaluate performance. The average speed data for mid-weeks (Tuesday to Thursday) of spring and fall 2010 were calculated. These average speeds were then compared with the modeled speeds of the base, Sub-TAZ and TRANSIMS models. Figure 5 shows the percentage differences between the modeled speeds in each of the three models compared with observed speeds for congested periods (morning and afternoon peak hours separately) for three selected corridors in both directions. Percentage differences in traffic volume for Sub-TAZ and TRANSIMS are less than that for the four-step model; whereas, TRANSIMS is the best predictor for morning peak traffic volume and Sub-TAZ is the best for afternoon peak traffic volume.

**Figure 4: Forecast-Observation Regression Lines for the 2010 Base, Sub-TAZ, and TRANSIMS Models**



**Figure 5: Observed Speeds Compared to 2010 Modeled Speeds of Base, Sub-TAZ, and TRANSIMS Models for Three Bi-Directional Corridors (32, 175, and 295)**



## SUMMARY AND CONCLUSION

This study applied the TRANSIMS model to a small area in Maryland. The objective was to provide critical guidance in transitioning from the traditional four-step modeling to activity-based modeling. Many transportation agencies are considering adopting dynamic traffic assignment and/or activity-based modeling. Since this adoption is a major change, it requires significant effort and human resources. This paper proposes a three-phase process to make the transition easier and less overwhelming. These phases are labeled Sub-TAZ, Track-1 TRANSIMS, and Track-2 TRANSIMS. In the first phase, Sub-TAZ, a transportation agency develops a more detailed transportation network and divides the zones into smaller subzones. The result of this phase is a smoother traffic volume than the traditional four-step model. The second phase, Track-1 TRANSIMS, converts the detailed network provided in the first phase and trip tables into TRANSIMS format and the model is implemented. In the third phase, Track-2 TRANSIMS, a complete activity-based model is achieved. The second and third phases can be achieved using packages other than TRANSIMS. However, small MPOs can reduce costs by using the FHWA-funded TRANSIMS package instead of expensive commercial software (Ullah et al. 2011).

The paper also examines the forecasting capabilities of the models by comparing the results to ground traffic counts. The results show that Sub-TAZ yields better forecasts than the conventional four-step model. The Track-1 TRANSIMS model showed promising results; it performed well in forecasting future travel demand even without full calibration. Applying user equilibrium in TRANSIMS is likely to result in more accurate output data. The TRANSIMS model estimated and forecasted traffic volumes on minor arterials and collectors better than the two four-step models. It also offered better model fit with less error in forecasted data for each facility type. TRANSIMS was not successful in replicating observed traffic volumes for freeways due in part to the selected study area, which is affected by interference from external traffic entering freeways that cannot be properly associated with activity locations. A future direction of this study is to modify Track-2 TRANSIMS to account for external trips and apply it to the study area.

## Endnotes

1. The Frank-Wolf method was suggested by Frank and Wolf in 1956 (Sheffi 1985). It is widely used in determining equilibrium flows in static transportation network problems.

## Acknowledgements

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***Dr. Mansoureh Jeihani** is an associate professor in the Department of Transportation and Urban Infrastructure Studies at Morgan State University. She has a multidisciplinary background: a PhD degree in civil (transportation systems) engineering, a master’s degree in economics, a master’s in socio-economics systems engineering, and a bachelor’s degree in computer engineering. Dr. Jeihani is interested in different research areas such as transportation planning, transportation economics, intelligent transportation systems, and travelers’ behavior. She has published more than 35 papers in journals and conference proceedings. She has also been principal investigator for more than 10 research grants.*

***Anam Ardeshiri** is a doctorate candidate in the Department of Transportation and Urban Infrastructure Studies at Morgan State University, Baltimore. He received his master’s degree in transportation planning and engineering and his bachelor’s degree in civil engineering from Sharif University of Technology, Tehran, in 2007 and 2004, respectively. He has five years of experience in the private sector and has been working as a research assistant in six projects funded by state and federal agencies.*



# Specifying and Estimating a Regional Agricultural Railroad Demand Model

by Michael W. Babcock and Philip G. Gayle

*In recent years there have been few railroad demand studies. Also, no study has investigated the possibility of regional differences in railroad demand. The objective of the paper is to estimate railroad demand functions for wheat, corn, sorghum, and soybeans for the United States as well as the east and west regions. A two-region spatial equilibrium model is employed to specify the empirical model in which railroad tons originated is the dependent variable. The explanatory variables include railroad price per ton, crop production, and barge price per ton. The theoretically expected sign is negative for rail price. Alternatively, the expected sign is positive for crop production and barge rate. Results include estimates of railroad own-price elasticities and cross price elasticities relative to barge transport. The estimates also reveal regional differences in railroad grain demand.*

## INTRODUCTION

The last three decades have witnessed tremendous change in the U.S. rail freight industry. The Staggers Rail Act of 1980 led to major restructuring of the industry. The act gave railroads the ability to set any rate between variable cost and 80% above variable cost, without regulatory review. The act prohibited railroads from discussing local rates in rate bureaus establishing the conditions for intrarailroad price competition. Railroads were given the ability to enter into rail/shipper contracts that contributed to increases in rail market shares. The Staggers Act accelerated the decision process for abandonment and merger decisions to promote railroad cost reductions.

In 1980 there were 40 Class I railroads, which has declined to seven in 2011. Thus there have been numerous consolidations and mergers that have restructured the industry. Both shippers and railroads benefit from end-to-end mergers (mergers of railroads that previously served different territories). Shippers experience reduced inventory and stockout costs due to reduced transit times as the merged railroad is able to ship commodities over longer distances without having to interchange freight with other railroads. Shippers also benefit from direct access to more markets and fewer record-keeping costs. Railroads benefit from end-to-end mergers by gaining access to a larger territory, fostering more differential pricing opportunities. Railroads also reduce costs as a result of the economies of scale resulting from a merger.

Miles of track owned by Class I railroads fell from 270,623 miles in 1980 to 161,926 miles in 2010, a 40.2% decline (AAR 2011). Some of the 108,697 miles of track were abandoned, but a large share of these lines were sold to Class II (regional railroads) and Class III (local railroads). The Association of American Railroads (2011) defines regional railroads as line-haul railroads below the Class I revenue threshold (\$398.7 million in 2011) operating at least 350 miles of road and/or earning annual revenue between \$40 million and the Class I revenue threshold. Local railroads are line-haul railroads below the regional criteria, and switching and terminal railroads. The number of regional railroads fell from 27 in 1987 to 21 in 2010 (a 22% decrease) while the number of local railroads rose from 457 (1987) to 537 (2010), a 17.5% increase (ASLRRA 2012). Thus the total number of Class II and III railroads increased from 484 (1987) to 558 (2010) a gain of 15.3%. In 2010, regional and local railroads accounted for 31% of U.S. track miles and 10.3% of U.S. rail industry employment (AAR 2011).

The U.S. freight railroad industry has achieved tremendous advances in labor productivity. Freight revenue ton miles per employee rose from 2.1 million in 1980 to 11.2 million in 2010, a

433% gain (AAR 2011). Freight revenue ton-miles per employee hour increased from 863 in 1980 to 4505 in 2010, a 422% increase (AAR 2011).<sup>1</sup>

The productivity gains have contributed to improved financial condition of the Class I railroad industry. Net railway operating income rose from \$1,338.6 million in 1980 to \$9,959.2 million in 2010, a 644% increase (AAR 2011). The rate of return on net investment rose from 4.22% in 1980 to 10.36% in 2010, while the rate of return on shareholders' equity increased from 6.01% (1980) to 11.23% (2010) (AAR 2011).

The objective of the paper is to examine the demand for railroad grain transportation over this period of change to obtain own price and cross price elasticities, and to determine if rail demand differs between east and west regions, which has rarely been investigated. Major grain crops (wheat, corn, sorghum, and soybeans) are a good case study commodity for railroad demand because of the large gains in railroad tonnage. Collectively, farm products accounted for 8.6% of total Class I railroad tons originated in 2010, which was only exceeded by chemicals and coal (AAR 2011).<sup>2</sup> Between 1970 and 2011, total railroad tons originated of the four above named crops collectively increased by 48.3%, with most of the gains occurring in corn and soybeans (AAR 2012).

The measurement of railroad grain transportation demand is important to railroads, grain exporters, grain marketing companies, and barge operators. Railroads need grain demand model forecasts as an input to equipment planning and staffing decisions. Price elasticities obtained from the demand models can indicate which markets offer the best opportunities for increased revenue as a result of specific price changes. Cross price elasticities with respect to barge prices reveal the impact on railroad demand of competitive price changes instituted by water carriers. Grain exporters and grain marketing companies could use information from railroad grain demand models as an input to their logistics system planning. Barge operators need to know railroad grain demand to formulate competitive strategy.

## LITERATURE REVIEW

Miklius, Casavant, and Garrod (1976) apply a logit model to estimate the price elasticities and cross elasticities for freight transport service. The model is applied to a sample of cherry and apple shipments. The cherry shipments are from Washington, Oregon, and Montana, and the apple shipments originated in Washington. The authors selected cherries because of their high perishability. Thus, quality of service would be expected to be a major factor in mode selection. Apples are storable for longer time periods; thus, modal selection would be expected to be responsive to modal rate differences.

The authors specify a binary choice model where the shipper choice is a function of rail and truck rates, transit times, and transit time dependabilities. Elasticities for own-price and cross price elasticities are calculated for both rail and truck. Most of the coefficients of both the cherry and apple models have the theoretically expected sign and are statistically significant.

The authors found that in the cherry model the demand for both rail and truck service was relatively elastic, not only for its own price and transit time but also with respect to those of the competing mode. For cherries, the choice of transport mode was much more sensitive to transit time than rates.

The authors concluded the results for the apple model were less satisfactory than the cherry model. The apple model had an unexpected sign for rail transit time, and the coefficient for truck transit time was statistically insignificant.

Oum (1979) formulated a demand model for intercity freight transport as an intermediate input to the production and distribution sectors of the economy, and to estimate the price elasticities and the elasticities of substitution between the major freight modes (rail, truck, and water).

The author used a twice continuously differentiable production function relating the gross output to capital, labor, and freight transport. The data are from the Canadian economy 1945-1974 and were transformed using a price index for each mode to calculate the revenue per ton mile.

The author found that the demand for railway freight services is only slightly responsive to the change in railway freight rates; but the own-price elasticity has been increasing in absolute value over time. Also, railway and motor carriers exhibited a complementary relationship until 1955 when they started competing heavily with one another. There is also a highly competitive relationship between rail and water carriers that can be seen throughout all years of data, but it has been decreasing slightly over time.

Friedlaender and Spady (1980) analyzed the demand for freight transportation with freight being a productive input in the firm that should be treated like any other input, and the full costs of transportation should include inventory costs as well as shipping and storage. The authors derive an explicit freight demand equation from a general cost function recognizing the interrelationship between rates and inventory cost through shipment characteristics. The demand equation was generated from a cost function that uses labor, capital, materials and energy, rail transportation, and truck transportation to produce an aggregate output.

The authors find that commodities such as iron and steel products, electrical machinery, and food appear to have an elastic demand. By region, the demand for rail service in the southern region appeared to be elastic. The cross price elasticities between rail and truck service were low in absolute value across all goods in all areas, suggesting a large amount of independence between the two modes. The authors note that this was reasonable since most of the data for trucks they used were for LTL shipments, which are not a strong competitor for rail service.

Winston (1981) noted that previous work in freight transportation has focused on the aggregate approach without considering the underlying behavior of the firms responsible for actually making the mode-choice decision. The author examined these choices as they apply to intermodal competition. This was done by developing a random expected utility model that was suitable for econometric analysis comparing both regulated and unregulated motor freight and rail.

The author made expected utility a function of modal attributes, and commodity and firm characteristics that were divided into two different elements: observed and unobserved parts. This was further disaggregated into the observed part and a stochastic term representative of a random parameter, modal attributes, and an independent identically distributed disturbance.

It was found that the commodity groups most sensitive to service quality are perishable products or inputs to perishable products. Conversely, the commodity groups that are least sensitive to service quality are neither perishable nor likely to have storage problems such as high storage costs or unstable demand. Generally, freight charges and location had the most explanatory power, with tangible shipping costs tending to play a dominant role in mode choice decisions.

Babcock and German (1982) forecast national and regional rail demand for selected agricultural commodities including wheat, corn, sorghum, and soybeans. The forecasting models are single equation regression employing annual data from the 1958-1980 period. Each model is estimated for the United States and for the east, south, and west regions.

The dependent variable for each of the crop models was rail tons originated of the commodity. Independent variables for each model included crop production, crop exports, and a time trend. The corn model also had cattle on feed in addition to the above mentioned variables. The soybean model also contained the barge share of combined rail and barge tonnage.

The empirical results of the model were good with high  $R^2$ s and no autocorrelation. The exception was the soybean equations, which had significant autocorrelation and was corrected using the Cochrane-Orcutt method. The explanatory variables generally had the theoretically expected sign and are highly significant.

The authors obtained 1985 forecast values for each of the explanatory variables to forecast 1985 railroad crop demand.

Babcock and German (1983) forecasted 1985 railroad market shares for 12 intercity manufactured goods freight markets. The authors noted that the railroad share of these markets declined in the 1955-1980 period while the truck share rose. One of the principal objectives of the Staggers Rail Act of 1980 was to arrest the decline of rail market shares. Whether this would occur was the primary question addressed by this paper.

The authors employed a model in which railroad market share (measured by ratio of a rail tonnage index to an index of industrial production) is made a function of the ratio of the rail rate to the truck rate, the prime interest rate, and the ratio of truck service to rail service. Truck service was measured by interstate highway miles as a percent of total highway miles. Rail service was measured by an index of average daily freight car miles. The authors found the potential forecast performance of the estimated rail share equations to be excellent.

The authors also found that rail market shares would continue to decline in about half of the 12 markets if truck service improved relative to rail service. If the decline in rail service relative to truck service was arrested, railroad market shares increased in all 12 markets. The principal conclusion of the paper was that the secular decline of railroads was ending in most transport markets by the middle 1980s.

The purpose of the Wilson, Wilson, and Koo (1988) paper is to analyze the market for transport services and the behavior of modal rates, and to identify critical parameters affecting rail market power they estimate modal demand and supply functions from time series data.

The theoretical model is a dominant firm (the railroad) price leadership model with differentiated services. Price-taking motor carriers form the competitive fringe. Thus, the transport market consists of two highly interdependent submarkets, one for rail and the other for trucks. They form demand functions in which truck and rail demand are functions of truck and rail price. The rail decision process includes some conjecture on the market response of trucks. Thus, the rail demand includes the rail price and the competitive price response of trucks.

In the empirical model, a recursive system is specified with two blocks. One describes rail pricing and the other a system of structural equations and equilibrium conditions. The second block includes structural equations for intermodal competition and simultaneously determines equilibrium values of modal outputs and truck rates. The rail demand function is  $QRD_t = f(PR_t, PT_t, C_t, U_t)$  where  $QRD$  is rail shipments,  $PT$  is truck rates,  $PR$  is rail rates,  $C$  is an index of railcar availability (reflects service quality), and  $U$  is a dummy variable equal to 1.0 after multi-car shipments were introduced. Truck demand is a function of the same variables.

The equation was estimated for wheat from North Dakota to Minneapolis and Duluth from 1973 to 1983 in monthly frequency. All the explanatory variables had the theoretically expected sign and were statistically significant. The equation had a good fit and there was no autocorrelation.

The authors found that in the pre-Staggers period, the rail own-price elasticity of demand was -1.18 and the cross price elasticity was 2.30. In the post-Staggers period, the corresponding elasticities were -1.46 and 2.54. Own-price elasticities for truck were -0.73 in the pre-Staggers period and the cross price elasticity was 0.70. In the post-Staggers period, the corresponding figures were -13.4 and 8.29.

Yu and Fuller (2005) estimated the structural demand for grain barge transportation on the upper Mississippi River. They specified a model in which the dependent variable is the quantity of barge grain service. The independent variables included grain barge rate, grain exports, the domestic grain demand and supply, a rate proxy for the price of other modes, weather and seasonal dummy variables, and the quantity of barge grain service, lagged one period.

The authors estimated the equation in OLS and 2SLS. In the OLS estimates, the barge rate had the expected negative sign and was statistically significant. Grain exports had the expected positive sign and were significant. Neither the domestic grain demand nor supply was significant. The same was true for rail rates to the PNW from Minnesota and ocean freight rates. However, the rail rate from Minnesota to upper Mississippi River elevators had the expected negative sign and

was statistically significant. The weather and seasonal dummies had the expected sign and were significant.

The 2SLS estimates of the coefficients were worse than OLS. The barge rate elasticity increased but was more non-significant. Grain exports continued to be significant, but the regional grain stock variable as well as total domestic corn consumption were not significant. The rates for other transport modes were also non-significant. Thus grain exports, winter season, and the flood dummy are the only unlagged statistically significant variables influencing barge demand.

The authors concluded that the short-run own-price elasticity is -0.479 while the long-run elasticity is -1.015. In summary, the authors found that barge demand on the upper Mississippi is influenced by barge rates, grain exports, the rail rate for Minnesota-originated grain shipped on the Mississippi River, winter season, and floods.

Train and Wilson (2007) focus on the access that shippers have to transportation markets. They estimate a discrete choice model framed around the access shippers have to transport markets, and they use the model to aggregate shipment decisions to provide spatially generated transport demands. The choice model results are combined with models of access cost (truck rates) over distance and aggregated to form demand functions.

In applying the model, two alternatives (barge or rail) for each shipper are used. The connection to barge and/or rail facilities is treated as an access cost. The shipper selects the alternative that maximizes profits, which are a function of barge and rail rates, access costs (measured by truck costs), and railcar loading capacity (number of railcars that can be placed on the shippers' siding). The model is estimated with a logit specification and the method of maximum likelihood.

The estimated model has a good fit, and the variables have the theoretically expected sign and are statistically significant. The results are that as the rate for barge or rail rises, profits of using the higher cost mode decline. Also, as the cost of trucking to a barge or rail terminal rise, profits fall, and the probability of using barge or rail falls. Profits for shippers that have greater car loading capacities have higher profits from rail relative to barge.

For an excellent discussion of the types of freight demand models as well as empirical findings and public policy applications see Small and Winston (1999).

## **THEORETICAL MODEL**

As indicated by Train and Wilson (2007), the demand for freight transportation has historically taken two alternative approaches. Early studies modeled aggregate demands using aggregate data across locations and commodities. More recently, emphasis has shifted to modeling transport demands at a disaggregate level where transport demands are modeled at a shipment level using choice methods. We use an alternative approach developed by Yu and Fuller (2005).

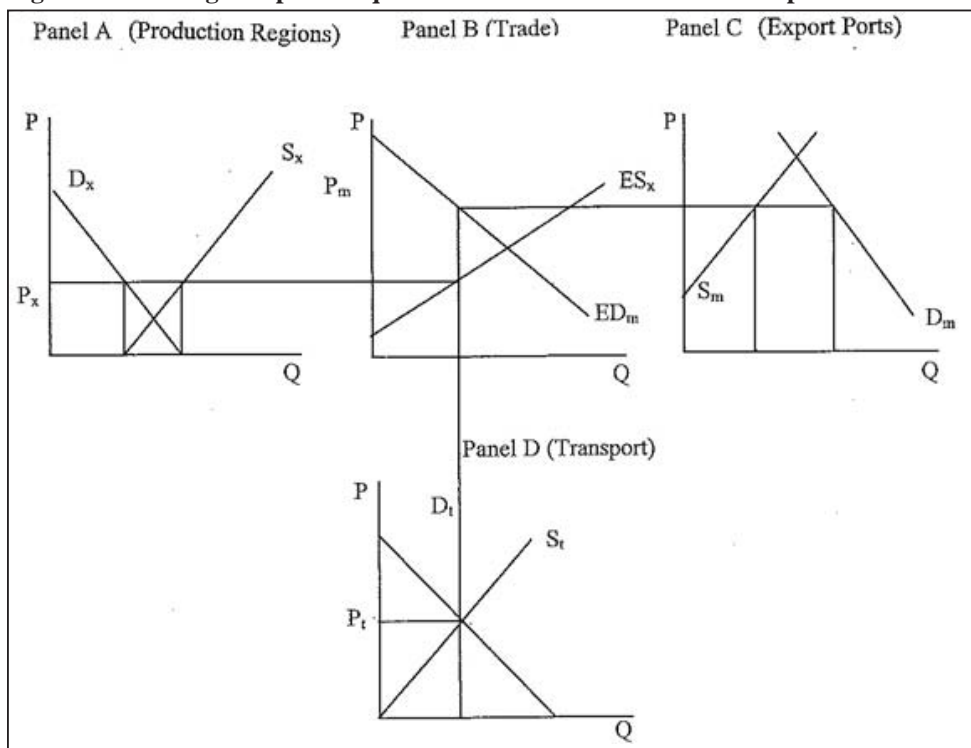
### **Theory of Transport Demand**

The demand for agricultural grain rail service is a derived demand. Therefore, factors that shift grain supply and demand in production regions and export demand will shift the demand for rail transportation (Boyer 1997). A two-region spatial equilibrium model is used to illustrate the theoretical foundation of grain railroad demand.

Panel A depicts the supply ( $S_x$ ) and demand ( $D_x$ ) of grain in production regions, while Panel C represents the rest of the world's (ROW) demand ( $D_m$ ) and supply ( $S_m$ ) for grain as reflected at U.S. export ports. Panel B is the trade panel, which includes the excess grain supply of grain production regions ( $ES_x = S_x - D_x$ ) and the excess demand of the ROW that buy grain at U.S. export ports ( $ED_m = D_m - S_m$ ). The intersection of excess supply ( $ES_x$ ) and excess demand ( $ED_m$ ) determines the equilibrium price and quantity of grain traded between production regions and export ports if no transportation costs were required to link the production regions to the ports.

Of course, transportation costs are very important in the marketing of grain. The derived demand for grain transportation and the supply of grain transportation service are depicted in Panel D. The derived transportation demand is equal to the vertical distance between the excess supply ( $ES_x$ ) and the excess demand ( $ED_m$ ) in Panel B. Also in Panel D is the supply of transportation service linking grain production regions with export ports. In 2010, railroads transported 68% of the combined railroad and barge tonnage of corn, wheat, and soybeans (AAR 2010). Thus, it is reasonable to assume that the supply is an approximation of the railcar fleet operating on the U.S. railroad system and the barge fleet operating on the inland waterways. The intersection of derived transport demand and supply determines the transportation rate ( $P_t$ ) linking grain production regions to export ports. The corresponding grain prices are  $P_x$  in Panel A for the grain production regions, and  $P_m$  in Panel B for ports, where grain prices in the two regions ( $P_x$  and  $P_m$ ) differ by the transport rate ( $P_t$ ) that links the two areas.

**Figure 1: Two-Region Spatial Equilibrium Model and Derived Transportation Market**



Any variable that shifts the regional supply ( $S_x$ ) and demand ( $D_x$ ) of grain in the production regions will also shift the excess supply ( $ES_x$ ) and the derived transport demand. Similarly, any variable that shifts the ROW excess grain demand and supply will alter the derived demand for rail transport. We use actual grain production, which embodies the demand (both domestic and foreign) and supply shifting factors in grain markets as a regressor in the grain rail demand specification to capture the derived demand nature of rail transport.

In addition to the economic factors identified in the partial equilibrium case in Figure 1, other transport modes may compete with, as well as complement, grain railroad transportation. For example, much of the grain is delivered by truck to rail transloading locations, resulting in a complementary relationship. Railroads compete with barge transport in the coal, grain, ores and chemical markets.



## Model Specification

*Grain Tonnage Transported by Rail*<sub>ijt</sub> =  $f(\text{Rail Price}_{ijt}, \text{Grain Production}_{ijt}, \text{Barge Rates}_t, \eta_i, \lambda_j, \tau_t)$

$i$  – commodity which includes wheat, corn, sorghum, and soybeans

$j$  – region which includes East and West

$t$  – year

$\eta_i$  – commodity fixed effect

$\lambda_j$  – region fixed effect

$\tau_t$  – time trend

Railroad prices (rates) should be included as an explanatory variable. According to the law of demand, an inverse relationship exists between rail demand and rate. That is, an increase in grain rail rate will reduce grain rail demand.

As mentioned previously, *Grain Production*, which embodies the demand (both domestic and foreign) and supply shifting factors in grain markets, is used as a regressor in the grain rail demand specification to capture the derived demand nature of rail transport. Grain production is expected to affect the derived rail transport demand in a positive manner.

The prices of alternative modes would also impact rail grain demand. The principal substitute mode for railroads in the grain markets is barge transport. An increase in barge rates would increase rail grain demand as shippers switch to relatively lower priced rail service.

Last,  $\eta_i$  controls for determinants of rail demand that are commodity-specific and unobserved to the researchers;  $\lambda_j$  controls for determinants of rail demand that are region-specific and unobserved to the researchers; and  $\tau_t$  controls for determinants of rail demand that are time-specific and unobserved to the researchers.

## DATA

Data for railroad tonnage of corn, wheat, sorghum, and soybeans for east and west regions, as well as data to compute rail price (revenue per originated ton), were obtained from various issues of *Freight Commodity Statistics* published by the Association of American Railroads. Data for grain production of corn, wheat, sorghum, and soybeans were obtained from various issues of *Agricultural Statistics* published by the U.S. Department of Agriculture. Barge rates were obtained from personnel at the Agriculture Marketing Service (AMS) of the U.S. Department of Agriculture. Data for the variables in the equation were collected for the 1965-2011 period. The AMS surveys barge companies on a weekly basis to obtain grain barge rates.

The barge industry uses percent of tariff as rate units for buying and selling barge services. These rate units are from the Bulk Grain and Grain Products Freight Tariff No. 7, which was used by the Waterways Freight Bureau of the Interstate Commerce Commission (ICC). In 1976, the U.S. Department of Justice entered into an agreement with the ICC that made Tariff No. 7 no longer applicable, but the barge industry continues to use it as a benchmark. For example, Tariff No. 7 (1976) has a grain barge rate of \$4.04 per ton for the lower Ohio River. If the current rate is 200% of tariff, then the rate is \$8.08 per ton ( $2.0 \times \$4.04 = \$8.08$ ).

Figure 2 plots the volumes (measured in thousands of tons) of agriculture grains transported by rail over the time span of the data set. The figure shows that for much of the time period, corn is transported by rail in greater volumes compared with the other three commodities. In contrast, for almost all the time period, sorghum is transported by rail in smaller volumes compared with the other three commodities. In addition, 28,446.20 thousand tons of corn, 9,782.20 thousand tons of soybeans, and 39,686 thousand tons of wheat were transported by rail in 1965, compared with 73,322.70 thousand tons of corn, 22,243.10 thousand tons of soybeans, and 44,460.50 thousand tons of wheat in 2011, respectively. Therefore, over the sample period, the volumes of corn, soybeans,

and wheat that are transported by rail grew by 157.75%, 127.38%, and 12.03%, respectively. In contrast, 9,498.80 thousand tons of sorghum was transported by rail in 1965, compared with only 1,918.70 thousand tons in 2011, resulting in a 79.80% decline. In summary, over the sample period, corn was transported by rail in greater volumes and showed the largest growth compared with the other three commodities, while sorghum was transported by rail in the smallest volumes and these volumes actually declined.

**Figure 2: Grain Tonnage Transported by Rail from 1965 to 2011**

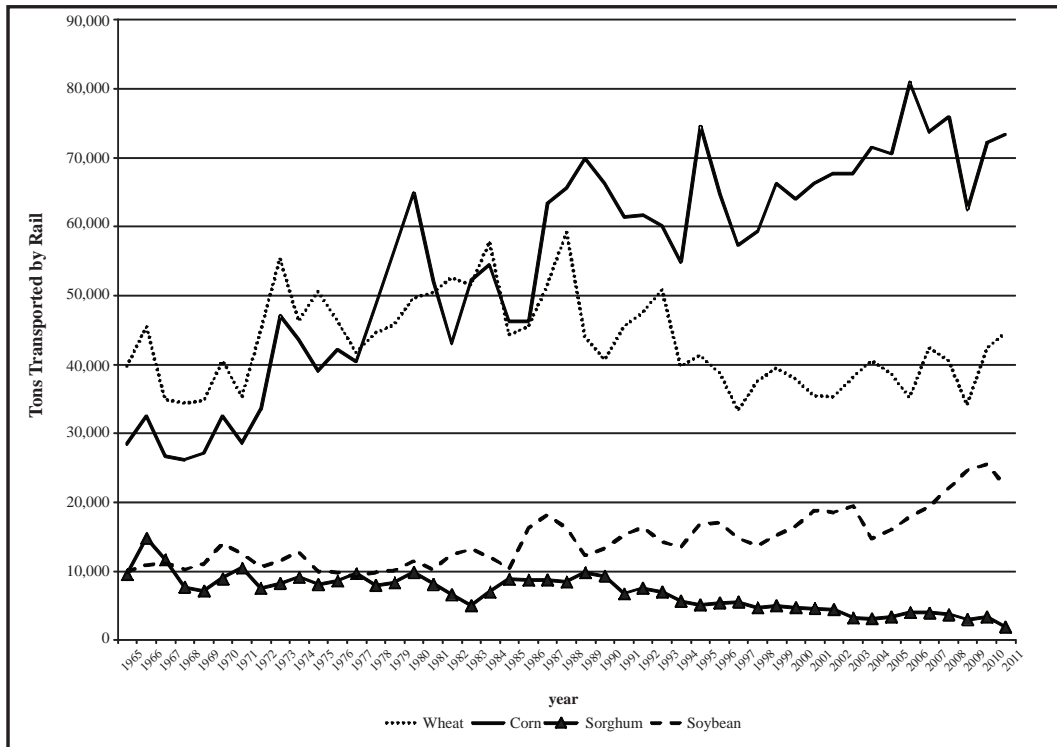


Table 1 reports descriptive statistics for the dependent, independent, and instrument variables used in estimating the agricultural grain railroad demand model. The table reports each variable's mean, standard error, number of observations, minimum value, and maximum value. The sample means for all variables are statistically different from zero at the 1% level of statistical significance. In terms of mean tons of each commodity transported by rail over the sample period, we see that corn has the largest mean tonnage of rail transport followed by wheat, soybeans, and sorghum, respectively.

Rail revenue per ton is the measure we use for rail price. The mean rail price to transport wheat is highest (\$17.14 per ton) followed by the mean rail price for corn (\$14.87 per ton), sorghum (\$14.66 per ton), and soybeans (\$13.29 per ton), respectively. As previously discussed, the demand for rail transport coming from producers of grain is derived from the volume of grain produced that needs to be transported. Mean grain production is largest for corn (7,970,880 thousand bushels) followed by mean production of soybeans (2,079,755 thousand bushels), wheat (2,076,975 thousand bushels), and sorghum (636,632.40 thousand bushels), respectively.

Grain is also transported by barge. As such, changes in the relative price to transport by barge, measured by the Barge Rates variable, should influence the demand for rail transport. Barge rates are measured by the grain spot barge price as a percent of tariff. Mean barge rate is 214.38%, and it ranges from a low of 117% to a high of 494%.

Three variables that were used as instruments for rail price when estimating demand: Railroad Labor Cost, Railroad Diesel Fuel Price, and Number of Covered Hopper Railcars. These variables are all expected to influence the unit cost of providing rail transport and therefore capture rail supply-shifting shocks to rail price. Railroad labor cost is measured by earnings per employee per year in dollars. Mean annual earnings per employee is \$37,734.20. Railroad diesel fuel price has a mean 73.79 cents per gallon, and the mean number of covered hopper railcars is 293,824.2.

**Table 1: Descriptive Statistics for Variables Used in the Agricultural Grain Railroad Demand Model**

<b>Variables</b>	<b>Wheat</b>	<b>Corn</b>	<b>Sorghum</b>	<b>Soybean</b>
	Mean (Std. error; N) [Min] {Max}	Mean (Std. error; N) [Min] {Max}	Mean (Std. error; N) [Min] {Max}	Mean (Std. error; N) [Min] {Max}
Grain Tonnage Transported by Rail (measured in thousands of tons)	43,062.16*** (952.84; 47) [33,200.30] {59,048.10}	54,914.40*** (2,257.38; 47) [26,199.70] {80,974.30}	6,897.84*** (387.77; 47) [1,918.70] {14,784.80}	14,480.03*** (593.79; 47) [9,189.60] {25,543.70}
Rail Price (measured by Rail Revenue Per Ton in dollars)	17.14*** (1.18; 47) [5.88] {37.15}	14.87*** (1.09; 47) [4.27] {32.08}	14.66*** (0.84; 47) [5.35] {27.31}	13.29*** (1.25; 47) [3.50] {34.00}
Grain Production (measured in thousands of bushels)	2,076,975*** (56,965.03; 47) [1,304,889] {2,785,357}	7,970,880*** (378,999.30; 47) [4,102,867] {13,091,862}	636,632.40*** (28,103.79; 47) [214,443] {1,120,271}	2,079,755*** (102,983.40; 47) [845,608] {3,359,011}
Barge Rates <sup>a</sup> (measured as grain spot barge price as a percent of tariff)	214.38*** (19.20; 32) [117] {494}			
Railroad Labor Cost (measured by earnings per employee per year in dollars)	37,734.2*** (3,129.28; 46) [7,490] {73,843}			
Railroad Diesel Fuel Prices (measured by average cost per gallon in cents)	73.79*** (9.38; 46) [9.16] {312.05}			
Number of Covered Hopper Railcars	293,824.30*** (12,760.86; 46) [100,608] {414,418}			
Years (total of 47)	1965 to 2011			

Notes: \*\*\* indicates statistical significance at the 1% level. <sup>a</sup> We only have data on Barge Rates from 1980 to 2011. Whenever the number of observations for a variable, denoted by N in the table, is 46 or 45, it means that observations for the variable were missing in year 2011 or years 2010 and 2011 respectively.

## RESULTS

The demand model estimates are reported in Table 2. We begin by estimating the demand model without using instruments for railroad price, i.e., we first use ordinary least squares (OLS) to estimate the demand equation parameters.<sup>3</sup> These model estimates are reported in the columns labeled OLS. We then re-estimate the demand equation parameters using instruments for price via Generalized Methods of Moments (GMM) estimation. The substantial difference in the size of the OLS and GMM coefficient estimates on rail price suggests that rail price is endogenous. The endogeneity of rail price is confirmed using a formal statistical test of endogeneity, which is reported in the third-to-last row of Table 2. The statistical test is distributed Chi-square under the null hypothesis ( $H_0$ ) that rail price is exogenous. Given that the probability value for the Chi-square statistic is 0.0035, which is less than 0.05, then we reject that rail price is exogenous at the 5% level of statistical significance.

An overidentification test, reported in the second-to-last row of Table 2, is used to help evaluate the validity of instruments used in the GMM estimation. A criterion for validity of instruments is that they are uncorrelated with the residuals of the model. The overidentification test is distributed Chi-square under the null hypothesis that instruments are uncorrelated with residuals of the model. Given that the probability value of the Chi-square statistic is 0.837, which is greater than 0.05, then we cannot reject the null hypothesis that the instruments are uncorrelated with the residuals at the 5% level of statistical significance. In other words, the instruments are orthogonal to the residuals of the demand model.

Another criterion for validity of instruments is that they are correlated with the endogenous regressor, i.e., valid instruments should be correlated with rail price. The weak instruments test, reported in the last column of Table 2, is used to evaluate the validity of instruments based on this criterion. The weak instrument test is distributed  $F$  under the null hypothesis that instruments jointly cannot explain variations in rail price. Given that the probability value for the  $F$ -statistic is 0.000, which is less than 0.05, we then reject this null hypothesis at the 5% level of statistical significance. Therefore, the instruments pass the weak instruments test, revealing that the instruments have a joint statistically significant effect on rail price.

In summary, both standard demand-supply equilibrium theory and diagnostic statistical tests suggest that rail price is endogenous in the regression model. Furthermore, the diagnostic statistical tests discussed above suggest that the instruments we use to deal with the endogeneity problem are valid and effective. Therefore, the remainder of the discussion focuses on the GMM estimates.

Since both dependent and independent variables are in their logarithm form when estimating the model, coefficient estimates are interpreted as elasticities. The own-price elasticity estimate of grain demand for rail transport has the theoretically correct sign and is estimated to be -1.228. This own-price elasticity estimate is statistically significant at the 1% level of statistical significance.

The coefficient on Grain Production is 0.956, suggesting that a 1% increase in grain production increases rail demand by 0.956%. This rail derived demand effect is statistically significant at the 1% level of statistical significance. The positive relationship between grain production and rail demand agrees with theoretical expectations.

The coefficient estimate on Barge Rates is positive and statistically significant, suggesting that barge transport of grain is predominantly a substitute for rail transport. The 0.484 coefficient estimate suggests that a 1% increase in barge rates will increase railroad grain demand by 0.484%.

**Table 2: Agricultural Grain Railroad Demand Model Estimates**

	Dependent Variable: Grain Tonnage Transported by Rail			
	Ordinary Least Squares (OLS)		Generalizes Methods of Moments (GMM)	
Variables	Coefficients	Standard Errors	Coefficients	Robust Standard Errors
Rail Price	-0.333***	0.118	-1.228***	0.282
Grain Production	1.022***	0.035	0.956***	0.055
Barge Rates	0.197**	0.095	0.484***	0.111
Sorghum	0.030	0.141	-0.254	0.208
Soybean	-0.098	0.083	-0.319***	0.112
Wheat	0.944***	0.082	1.039***	0.100
Western Region	0.420***	0.072	0.676***	0.104
Time Trend (year)	0.005	0.004	0.019***	0.007
Constant	-15.293*	7.984	-41.945***	13.454
R-squared	0.964		0.955	
Sample Size	248		248	
Test of Endogeneity <i>Ho</i> : Rail Price is exogenous	$\chi^2(1) = 8.523$ Probability Value = 0.0035			
Test of overidentifying restrictions	<i>Hansen's J</i> $\chi^2(8)=4.216$ Probability Value = 0.837			
Weak instruments test	$F(9, 231) = 7.27$ Probability Value for $F = 0.000$ First Stage Regression R-squared = 0.809			

Notes: \*\*\* indicates statistical significance at the 1% level, \*\* indicates statistical significance at the 5% level, while \* indicates statistical significance at the 10% level. Regressions are estimated using the logarithm of dependent and all continuous right-hand-side variables. Therefore, reported coefficient estimates are interpreted as elasticities.

We include commodity fixed effects (captured by commodity zero-one dummy variables) to control for unobserved differences in the level of rail demand across different commodities. The excluded commodity dummy variable is corn. Therefore, the coefficients on dummy variables sorghum, soybeans, and wheat measure these commodities' rail demand relative to corn rail demand. The coefficient on the sorghum dummy is not statistically significant at conventional levels of statistical significance; suggesting that level of rail demand from sorghum producers that is not captured by the other control variables in the demand model is not statistically different from the level of rail demand from corn producers, *ceteris paribus*. At first glance this result might seem surprising given the line plots of grain volumes transported by rail in Figure 2. Figure 2 revealed that substantially smaller tonnage of sorghum is transported by rail compared with tonnage of corn transported by rail. However, the regression results in Table 2 are simply suggesting that much of the rail transport volume difference across these two commodities displayed in Figure 2 can be explained by the control variables included in the demand model.

The coefficient estimate on the soybean dummy is -0.319 and statistically significant, suggesting that soybeans have a lower rail demand compared with corn, *ceteris paribus*. In contrast,

the coefficient estimate on the wheat dummy is 1.039 and statistically significant, suggesting that wheat has a higher rail demand compared with corn, *ceteris paribus*. So the coefficient estimates on the commodity dummies suggest that wheat has the highest rail demand that is not explained by regressors included in the demand model followed by corn, sorghum and soybeans, respectively.

The 0.676 coefficient estimate on the western region dummy variable suggests that grain rail demand is higher in the western region of the United States compared with the eastern region. This regional rail demand difference is statistically significant at conventional levels of statistical significance.

Last, the coefficient estimate of 0.019 on the time trend variable suggests that grain rail demand, on average, grew annually by 1.9%, *ceteris paribus*. This annual growth in grain rail demand is statistically significant at 1% level of statistical significance.

## CONCLUSION

The Staggers Rail Act of 1980 promoted a major restructuring of the U.S. Class I railroad industry. The number of Class I railroads fell from 40 in 1980 to seven today due to numerous mergers and consolidations. The Class I railroads reduced their costs as they abandoned branch lines or sold these lines to regional or local railroads. The Class I industry achieved tremendous increases in labor productivity, which contributed to improved financial condition. Despite the enormous changes in the Class I railroad industry, recent studies of railroad demand have been relatively few. This paper partially addressed this research gap by estimating the railroad demand for wheat, corn, sorghum, and soybeans for the United States as well as the east and west region. Railroads, grain exporters, grain marketing companies, and barge operators need estimates of railroad demand as an aid to strategic planning.

As opposed to utilizing an aggregate or disaggregate approach, this study used a two region spatial equilibrium model developed by Yu and Fuller (2005). The empirical model made grain tonnage transported by rail a function of rail price, grain production, barge rates, commodity and region fixed effects, and a time trend. The model was initially estimated with OLS. However, rail price was found to be endogenous. The demand equation was re-estimated using instrumental variables for price via the Generalized Method of Moments (GMM) estimation.

All the variables had the theoretically expected signs and were statistically significant at the 1% level (except sorghum). The equation had a good fit with an  $R^2$  of 0.96. The own-price elasticity of grain demand for rail transport was -1.23. The barge rate elasticity was 0.48, confirming that barge transport of grain is a substitute for rail transport.

The coefficient of the soybean dummy was negative, suggesting that soybeans have a lower rail demand compared with corn. In contrast, the coefficient of the wheat dummy was positive, suggesting that wheat had a higher rail demand compared with corn. In summary, the coefficients of the commodity dummies suggest that wheat has the highest rail demand not explained by other variables in the model, followed by corn, sorghum, and soybeans, respectively. Another contribution of the paper was the result that region has a differential effect on railroad grain demand, which is higher in the west region compared with the east.

## Endnotes

1. For a comprehensive discussion of Class I railroad productivity trends between 1980 and 2010 see Martland (2012).
2. In 2010, field crops accounted for 98% of total railroad originated tonnage of farm products.



3. Recall that rail price instruments include: (1) Railroad Labor Cost, (2) Railroad Diesel Fuel Price, and (3) Number of Covered Hopper Railcars. We also include as instruments, interactions and the square of these three instrumental variables.

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**Philip G. Gayle** is a professor of economics at Kansas State University. He received his Ph.D. in economics from the University of Colorado, Boulder, in 2002. Gayle earned his bachelor and master of science degrees in economics from the University of the West Indies, Mona. His main area of research is empirical industrial organization. He has published several research articles on the airline industry. His research has appeared in such journals as *Journal of Law and Economics*, *International Journal of Industrial Organization*, *Journal of Regulatory Economics*, *Southern Economic Journal*, *Economic Letters*, among others.

**Michael W. Babcock** is a professor of economics at Kansas State University (KSU). In his 40-year career at KSU, he has published 75 articles in professional journals, along with numerous monographs and technical reports, and his research has been cited in more than 70 books, the transportation press, and professional journals. He has presented 70 papers at professional meetings, and he was principal investigator or co-investigator on 33 federal and state government research grants worth more than \$2.3 million. Babcock is recognized as a leading national and international authority in three research areas, including short line railroad transportation, agricultural transportation, and impact of public policy on transportation market shares.

He has received numerous national awards for his transportation research. He has been recognized five times by the Transportation Research Forum for outstanding research in transportation economics. In addition, Babcock has received the Edgar S. Bagley Award four times from the KSU Department of Economics for outstanding achievements in transportation economics research. In 1999 he was awarded the ISBR Senior Faculty Award for Research Excellence in the Social and Behavioral Sciences from KSU. Babcock has served as an advisor to former Governor Bill Graves on transportation policy, and contributed testimony to congressional hearings on transportation issues.

# Road Supply in Central London: Addition of an Ignored Social Cost

by Omid M. Rouhani, Christopher R. Knittel, and Debbie Niemeier

*Studies examining the social cost of driving usually ignore the opportunity cost of having roads in place: the associated land rents. Especially for geographic regions where land is valuable, including the rent costs may even lead governments to close some roads. By using the London congestion charging zone case, a more general long-run social cost curve is calculated with the addition of the rents. Based on the optimal road usage concept, this study found that including the rents in the cost/benefit analysis significantly affects the results and can increase the social cost by up to 200% and decrease the optimal road usage by 40%.*

## INTRODUCTION

Providing a partially charged service, as is the case with public roads, leads to more travel demand, which can result in wasteful consumption: the free-rider problem (Cornes 1986). The associated cost burden is enormous; Nash et al. (2008) estimated the costs of traffic congestion in the UK to be £15 billion per year, about 1.5% of GDP. Congestion pricing has been developed based on the notion that the users of roads, as public goods, should pay for the negative externalities they produce. Each additional user imposes a time cost burden on other users. The main idea involves charging users for this social cost (the difference between marginal social cost and marginal private cost) to reach a more efficient road usage (Pigou 1920; Vickrey 1963; Walters 1961; Yang and Huang 1998; Rouhani and Niemeier 2011).

Several cases of congestion pricing exist in Singapore (Olszewski and Xie 2005), London (Leape 2006), and Stockholm (Eliasson 2008). Various studies have analyzed different aspects of congestion pricing. Olszewski and Xie (2005) modeled the effects of the pricing on traffic flows in Singapore and found that time-variable road pricing or “shoulder pricing” method, increasing the charges before the peak and lowering them after, tends to transfer congestion to other periods and other routes and is an effective method of controlling congestion. Xie and Olszewski (2011) proposed a methodology for using the traffic data from the Singapore’s Electronic Road Pricing (ERP) system to forecast the short-term impacts of trip rate adjustments on peak period traffic volumes.

Eliasson and Mattsson (2006) developed a method for quantitative assessment of equity effects of the Stockholm congestion pricing system. In another study, Eliasson (2009) set up a cost-benefit analysis for the case of the Stockholm congestion pricing and estimated that the Stockholm system yields a large social surplus, well enough to cover both investment and operating costs. Santos and Bhaka (2006) revised the standard approach to value travel time savings for the London congestion pricing system and showed that by switching to the bus, low-income users can gain from the system, when users account for the generalized costs of trips. Safirova et al. (2004) studied the welfare effects of various road pricing schemes for the Washington, D.C., metropolitan area. The study found that the aggregate social welfare gain from comprehensive pricing could reach \$220 million, and most of this gain could also be achieved by using only HOT lanes (77%) and limited freeway pricing (82%).

In a controversial study, Prud’homme and Bocarejo (2005) constructed the demand and supply functions for the London congestion pricing scheme and determined the optimal road usage and

optimal congestion toll for the system. They showed that the London congestion pricing is an economic failure despite its political success. Hamilton (2011) also indicated the unpredicted and excessive costs of congestion pricing in the case of Stockholm, Sweden. Nevertheless, Hamilton (2011) showed that by modifying insurance cost, recognizing the election's role, and informing the public it would be possible to establish a system, such as the Stockholm congestion charging system, for a considerably lower cost. For a review on methods and technologies available for congestion pricing, refer to de Palma and Lindsey (2011).

Studies on optimal road usage usually ignore some of the social costs that are associated with public roads (Rouhani et al. 2013a). Construction and maintenance costs are good examples (Verhoef and Mohring 2009). Although one can argue that users are paying for these costs through fuel taxes, the payments are not directly related to the usage. The users' cost burden should be based on the true total road costs and how much they use the road system. Users should not pay comparable amounts for a very expensive superhighway and a low-cost collector. And the payments should not be the same for roads with comparable construction and maintenance costs, but different levels of demand. One limitation in applying this concept is that part of the funding for roads comes from sources other than fuel taxes (revenue sources that are not related to road usage), for example, sales tax (Schweitzer and Taylor 2008).

Because it is difficult to find a defensible means of including construction and maintenance costs in optimal road usage analysis since they are partially paid by fuel taxes, one can replace these costs with the opportunity cost of having roads in place, which are the forgone rents of the land used for roads. If officials could close the roads, they could immediately lease the available land. But unlike other markets where supply and demand dynamics can drive products out of market, closing roads very rarely happens because not all the costs are considered (Rouhani 2009; Rouhani 2013; Rouhani et al. 2013b). As a result, once a road is constructed, the present calculation suggests that decision makers should use the land for roads, no matter if the future usage (benefits) is (are) really low. Nevertheless, studies show that decreasing capacity through blocking roads can even improve transportation network performance (Youn et al. 2008).

In old and well-developed cities, few new roads are being financed using current fuel taxes<sup>1</sup>. Most of the fuel taxes are used for road maintenance, alternative modes to cars, and purposes other than directly financing or paying for the rents. Even though existing old roads were financed through previously paid fuel taxes, one can argue that the forgone rents, at least partially, are not considered in individual users' current cost calculations, and so do not affect their current road usage. There exists a social (opportunity) cost associated with these rents. For geographic regions where land is valuable, like London (Cheshire and Hilber 2008), these ignored social costs may have significant impacts on the externalities associated with driving.

Previous research studies have examined the consideration of the opportunity cost of land in the context of curbside pricing (Shoup 2004 and 2005). For the road pricing concept, Roth (1967, page 67) makes the distinction between the cost of providing roads and the cost of using roads and concludes that the fixed costs of providing roads should not enter directly into congestion charges. Based on this distinction, one can argue that the fixed opportunity cost is not part of the marginal social cost of driving. However, the counter-argument is that 1) in the case of London, the rent costs are not paid by the individual costs of travel; the rent costs are even higher than all other social costs at some road usage levels, and 2) the rent costs are not fixed, but they depend on the amount of usage and vary from one time period to another (the change in the value of land). The total rent cost should be divided by the road usage. Therefore, a thorough calculation should consider (a portion of) the rents in addition to individual cost and congestion cost. Otherwise, these costs would be ignored.

In this study, these costs are added to the social costs typically considered and calculate a modified social cost curve. The model developed in this study is an extension of a previously calibrated model (Prud'homme and Bocarejo 2005) on the London congestion pricing zone.

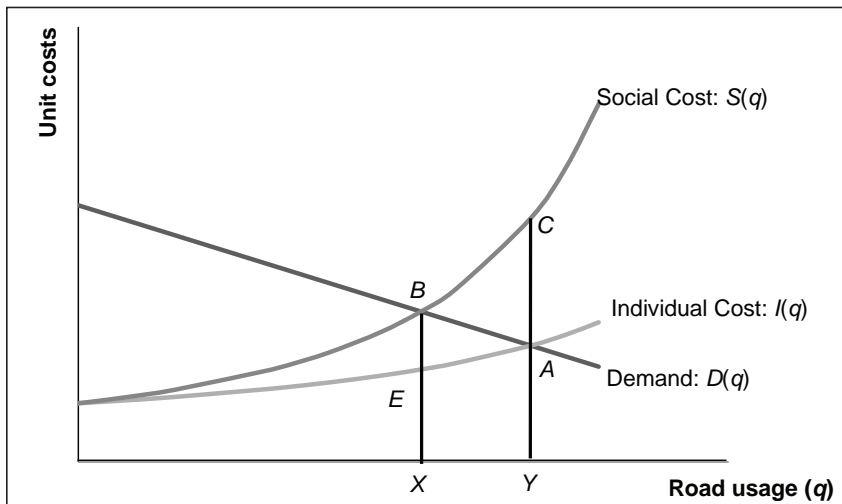
The next section begins by describing the basic model for the optimal road usage analysis. An extension to the model will be introduced by adding forgone rents to the social cost. The case study, the London congestion charge zone, will be described. A model developed in a previous study will be presented and then be modified taking the rents into account. Finally, the paper concludes with the results of modifying the social cost for the case study.

## BACKGROUND

Figure 1 represents a simple model of road usage where  $D(q)$  is the demand for road usage as a function of the unit cost of using roads (costs per km);  $I(q)$  represents the unit individual cost (or marginal private cost), which is the per km cost borne by a motorist. As road usage ( $q$ ) increases, the travel time as a part of the general cost of travel increases, and the cost born by motorists,  $I(q)$ , increases. An equilibrium is reached at point A, where  $I(q)$  and  $D(q)$  intersect, in which the cost of driving is equal to the benefit of driving, and the original road usage is  $Y$ .

But the unit social cost,  $S(q)$ , is different than  $I(q)$ . The social cost equals the individual cost plus the cost of additional time spent by all other vehicles because one extra vehicle is on the road (congestion externality). So the social optimal point (the optimal road usage) is at B, where  $D(q)$  and  $S(q)$  intersect, and the social optimal road usage will be  $X$ . To reach the optimal road usage, decision makers should impose a tax or congestion charge of  $BE$  as the optimal congestion charge. Without any charges, the deadweight loss (DWL) or congestion cost of the triangle  $BCA$  will be imposed on society.

**Figure 1: The Optimal Road Usage and Congestion Concept**



The original equilibrium, A, is sub-optimal because of the difference between the unit individual cost and the unit social cost. The original equilibrium of road usage is always greater than the social optimal usage because the social cost is greater than the individual cost. However, the optimal level of congestion is not zero. Therefore, policies should be aimed at ensuring the optimal level of congestion, not the elimination of congestion.

The optimal level of congestion charge ( $BE$ ) is the congestion externality (the difference between the social and private costs) at the social optimal equilibrium, not the original equilibrium. In fact, charging the congestion externality at the original equilibrium is suboptimal and higher than the social optimal charge. Finally, a thorough cost/benefit analysis of a congestion pricing scheme should compare the benefits of a congestion charge ( $BCA$  or a lower amount of social welfare gain

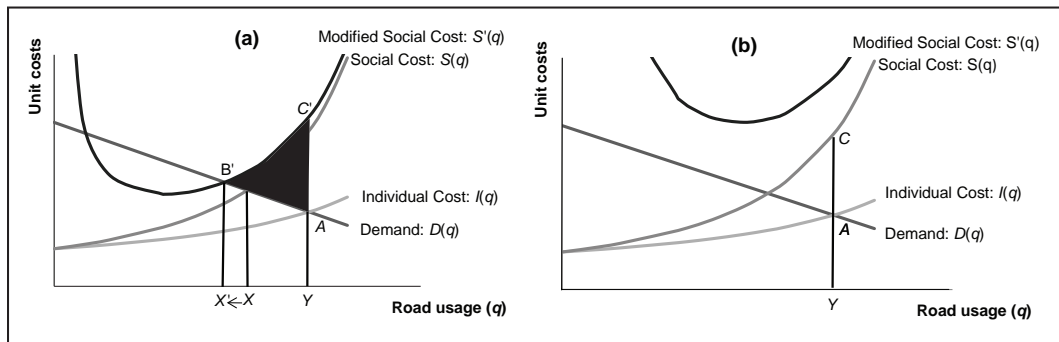
from a charge) to its transaction costs or the collection costs of the charging scheme (McDonald et al. 1999; Prud'homme and Bocarejo 2005).

## AN EXTENSION OF THE MODEL

An important part is missing in the social cost calculation of the simple model: the opportunity cost of having roads in place or the rent that can be gained by leasing the lands occupied by roads.

The social cost associated with rent depends on road usage. So the higher the road usage, the lower the social cost of the rents. In fact, the associated social cost is equal to the total fixed rent that can be gained from leasing the lands divided by the quantity of road usage. One could add this cost to the common social cost curve. Figure 2 shows the results of adding the rents to the common social cost. Instead of an increasing curve, the modified social cost curve will have a U shape. For the modified social cost, the social optimum will be  $X'$  instead of  $X$ , and a higher congestion cost of  $B'C'A$  will result if the modified social and demand curves intersect (Figure 2-a). In the cases of very high levels of rents, the modified social cost may no longer intersect with the demand curve (Figure 2-b). For this case, because of over-supply, some low-demand roads or some lanes of the roads should be closed so that the social benefits of driving (associated with travel demand) match social costs. It should be noted that the alternative decision to adding the rent costs to the analysis is leasing the land for purposes other than driving and decrease capacity. In this case, the individual cost curve (supply curve) would be different. However, the assumption of this study is that charging for the rent is preferred.

**Figure 2: Modifying the Social Cost by Adding the Rents (a) With an Intersection (b) No Intersection**



The addition of the rents and/or decreasing capacity are long-run decisions by nature. In the standard analysis of road pricing (Small and Verhoef 2007), short-run calculations are based on short-run marginal social costs for which capacity, and consequently rent, should be held constant. The rents enter long-run marginal social cost along with congestion, where every factor (capacity, rent, and congestion) can vary.

In fact, the analysis in this study is focused on a long process where the higher value of road space is realized by land owners or tax payers. The public funding, used long ago to build roads, may now have much more value than before, especially for a city like London with its very high present value for land. When the land owned by the citizens of the relevant jurisdiction has drastically increased in value (going from short-run to long-run), the citizens as the rightful owners might decide to use the land for purposes other than roads or charge the rents from users. The goal of this study is the appropriate inclusion of the rents in the long-run optimal road usage analysis.

In summary, adding the rents to the unit social cost leads to lower optimal road usage, a higher optimal charge, and a higher social cost. And in some cases, this addition may imply closing roads



because the costs of providing roads are higher than the benefits of driving (based on the area under a demand function above the equilibrium price). The new social cost includes the unit opportunity cost associated with the rent (not paid by users) as well as private costs (time, fuel costs including taxes, insurance, etc.) and congestion costs, both of which have been typically considered in the previous optimal road usage studies.

## BACKGROUND ON THE LONDON CONGESTION PRICING

The application of the London congestion pricing scheme<sup>2</sup> results from a long history of studies over the congestion costs of driving, and an interesting political process. In 1995, the London Congestion Charging Research Program (MVA Consultancy 1995) proposed a £4.00 toll on vehicles entering the central London area. The proposal led to another report in 2000: Review of Charging Options for London (ROCOL 2000). The latter report focused on the central London area and recommended two alternatives for charging: an area licensing scheme based on video camera enforcement and a workplace parking levy. With the election of Ken Livingstone as the Mayor of London in 2000 and after an 18-month period of extensive public consultation (as the main factor for the public acceptance of the scheme), an area licensing congestion pricing scheme was chosen for central London (Leape 2006).

As a result of the decision, since 2003, a daily charge has been imposed for driving or parking a vehicle on roads within central London. A constant charge of £5 (later increased to £8 and then to £10) must be paid for driving or parking within the congestion charging zone between 7:00 am and 6:30 pm on weekdays, with some exemptions for motorcycles, licensed taxis, and some alternative fuel vehicles (Litman 2006). Also, a 90% discount to residents and a 12.5% discount to fleets, and various discounts for monthly and annual payments are offered (de Palma and Lindsey 2011). Users can pay the charges at selected retail outlets or payment machines located in the area, by Internet and cellular telephone messaging, any time during the day of usage. Automatic number plate recognition is used to ensure the charges are applied, assigning penalties for the offenders.

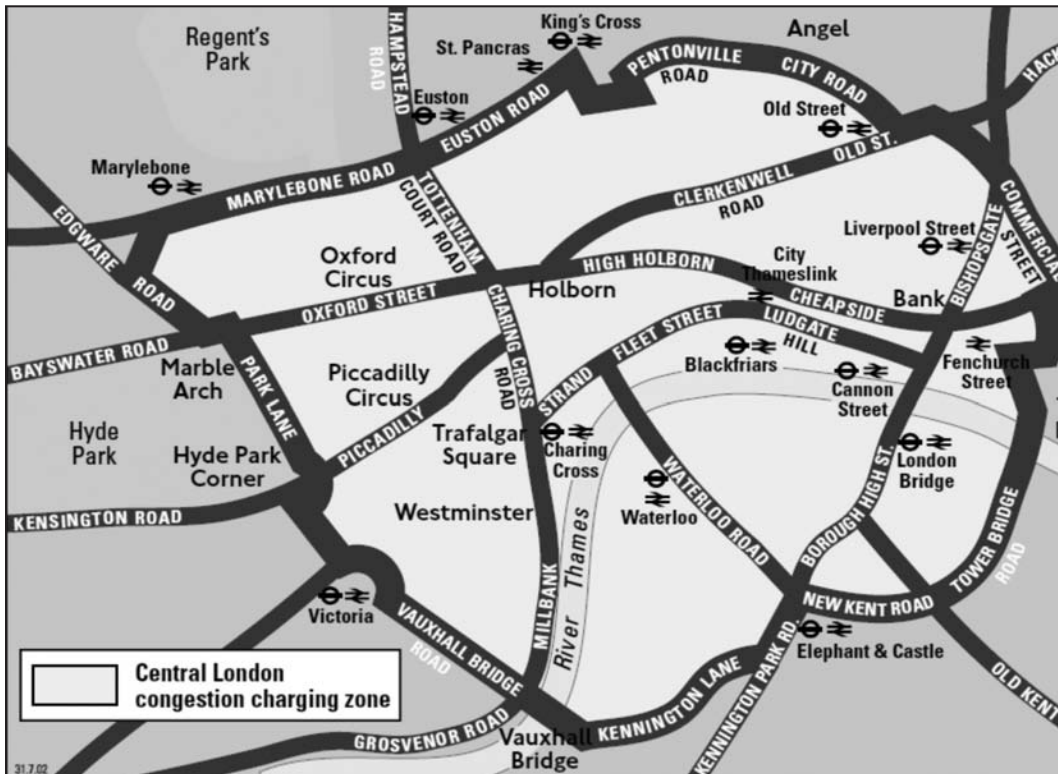
The congestion charge zone covers an area of about 22 km<sup>2</sup> (8 square miles) in downtown London (more than 1% of the total area of Greater London). The zone includes the financial centre, Parliament and the principal government offices, and the major tourist and entertainment centers (Leape 2006). Although the area is small compared with Greater London, it includes the main areas for the worst congestion. Figure 3 illustrates the London congestion zone.

Transport for London (TFL Sixth annual report 2008) cites four contributions of the pricing scheme as follows: 1) to reduce congestion; 2) to improve the bus system; 3) to reduce travel time for car users; and 4) to increase the efficiency of goods and services' distribution.

The early estimations showed that the charging scheme reduces vehicle miles traveled in the zone by around 15% and increase average speeds by around 20% (Banister 2003). Litman (2006) reported a higher increase of traffic speed (30% higher than prior to charging). Also, he reported that after imposing charges, peak period congestion delays declined about 30%, bus congestion delays declined 50%, bus ridership increased 14%, subway ridership increased about 1%, and taxi travel costs declined significantly (by 20%–40 %) due to reduced delays.

The effects on externalities other than congestion are also significant. By introducing congestion charging in London, total NO<sub>x</sub> emissions and PM10 emissions have been reduced by about 12% in the charging zone. In addition to the travel pattern impacts, the charging scheme has important effects on the generalized cost of various users of the London transportation system, which is not limited to car users (Santos and Bhakar 2006).

**Figure 3: A Map of the London Congestion Zone with Extended Areas**



Source: Transport for London, 2004.

Transport for London (TFL Fifth annual report 2007) has estimated a gross benefit of £ 200 million and a total cost of £ 88 million, resulting in a net annual benefit of £ 112 million. Opposite to what was found by Transport for London, and in a controversial study, Prud'homme and Bocarejo (2005) estimated a negative net benefit for the London congestion pricing scheme (−€393 thousand per day or − £ 75 million per year). There are various factors that led to the different results from the two studies. In the benchmark model section, some of the critiques of the Prud'homme and Bocarejo (2005) study will be discussed.

## MODEL FRAMEWORK

### Benchmark Model

Prud'homme and Bocarejo (2005) have studied the conventional model of optimal road usage for the London congestion zone. They estimated the unit individual cost, the demand, and the unit social cost functions. Their estimated unit individual cost ( $I(q)$ ) and unit social cost ( $S(q)$ ), both in terms of euros per vehicle-km, are functions of road usage  $q$ , in terms of thousand vehicle-km per day, as follows:<sup>3</sup>

$$(1) \quad I(q) = 0.15 + \frac{20.9}{(31.6 - 0.0124 \cdot q)}$$

$$(2) \quad S(q) = I(q) + I'(q) \cdot q = 0.15 + \frac{20.9}{(31.6 - 0.0124 \cdot q)} + \frac{0.26 \cdot q}{(31.6 - 0.0124 \cdot q)^2}$$

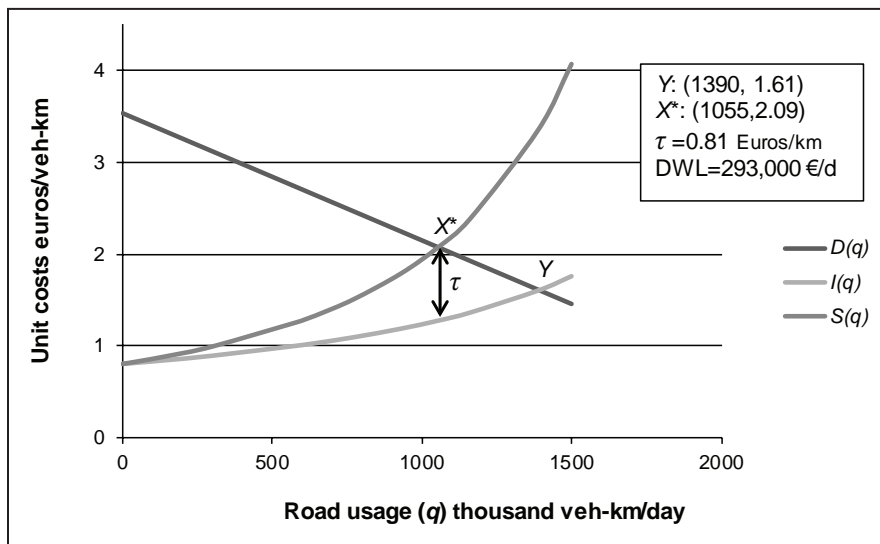
The estimated individual cost function consists of two parts; a fixed part representing amortization and fuel cost (0.15 euros/veh-km), and a variable part representing the value of time spent driving one km for each vehicle ( $20.9/(31.6-0.0124.q)$ ). To estimate the second part, they used 20.9 euros/veh-hour for the value of time, and estimated travel time function (speed function) using the free flow speed, and a point based on average speed and road usage in 2002. There are several important questionable assumptions made: 1) the value of time of 20.9, which has been reported low by some studies (Raux 2005; Mackie 2005); 2) the linear speed (travel time) function, which is estimated by using only two points; and 3) fixed fuel costs and some other costs, which should be affected by road usage.

To determine the demand equation ( $D(q)$ ), they used two points on the curve based on the data before (2002) and after imposition of the charges (2003). Their estimated demand function is as follows:

$$(3) \quad D(q) = 3.54 - 0.00139.q$$

Figure 4 shows their estimated demand, individual cost, and social cost. The original equilibrium (without imposing any charge), where  $D(q)$  and  $I(q)$  intersect, is at 1,390 thousand vehicle-km per day, with the unit individual cost of 1.61 euros per vehicle-km. The social optimal point, where  $S(q)$  and  $D(q)$  intersect, is at 1,055 thousand vehicle-km per day, with an optimal congestion charge of 0.81 euros per vehicle-km (equivalent to a charge of £7.2 per day [Prud'homme and Bocarejo 2005]) required to move from the original equilibrium to the social optimal point. Based on the estimation, the charges initially imposed on the congestion zone (£5) capture 90% of the potential benefit of a charge.

**Figure 4: The Optimal Road Usage and Congestion Charge from the Prud'homme and Bocarejo Study**



Using this framework, Prud'homme and Bocarejo (2005) showed that the economic costs associated with the London charging system are larger than the economic gains. The main assumed benefit of the charging system is the reduction in congestion costs while the costs are calculated using the operating and investment costs of the system. Their conclusion was that the London congestion charge, although politically and technically successful, seems to be an economic failure.

However, other studies (Raux 2005 and 2006; Mackie 2005) argued that with different parameters (higher value of time, more environmental benefits, more detailed public transportation system), the results could dramatically change. Taking these factors into account, the Prud'homme and Bocarejo model is used in this study as the benchmark model.<sup>4</sup>

### Modified Model

The calculations show that around 10% of the total area of the existing London congestion zone consists of road proper (an area of 2.16 km<sup>2</sup>), excluding sidewalk space, which allows continued access to the area. The annual rent of the lands in the area is assumed to be 300 euros/m<sup>2</sup> (£21.6/ft<sup>2</sup>). This figure is calculated by converting the present value of different properties to the annual rent, considering the area of each property, and averaging the rents over different properties. Note that the assumed annual rent is relatively low. But, as can be observed in Figure 5, the cost associated with this rent is high relative to the demand curve, and assuming higher levels of rent will result in no intersection of demand and supply curves.

The annual rent of 300 euros/m<sup>2</sup> results in a total rent of 648 million euros per year or 2,541 thousand euros per working day.<sup>5</sup> But one could reasonably argue that not all roads should be considered in the calculation. Some roads are critical, for example, offering lifeline routes for emergencies; eliminating these roads may interfere with vital activities in the area. Although a counter argument is that people can travel using public transit or even by walking, especially in a city like London with a ubiquitous and largely efficient public transportation system, it is still reasonable that some roads would be necessary. In addition to the private costs, the social costs of closing the critical roads could be much more than other roads. However, calculating these costs is beyond the scope of this study.

Using a proxy, this study considers a new concept called “substitutable roads.” In order to disregard the social costs of closing critical roads, the assumption is that only the roads which can be substituted by other roads are considered. It is difficult to estimate the percentage of roads that are practically substitutable. Therefore, different values for this parameter are assumed and applied to the model.

The modified model incorporates the percentage of substitutable roads as a new parameter. Another argument in favor of including a proportion of, not all, the rents in the analysis is that the current fuel taxes cover part of the rents. In addition, the figures for fuel taxes paid are small relative to the rents in central London, given the value of land. So considering a proportion of the rents seems reasonable.

Note that the unit individual cost remains the same as before because the rent is not paid by the users. However, the rent costs are present, and should the rent costs be paid, it would be shared by all users. So the total rent cost should be divided by the road usage ( $q$ ), and multiplied by the percentage of substitutable roads. The new unit social cost function is as follows:

$$(4) S(q) = I(q) + I'(q) \cdot q + \text{rent cost} = 0.15 + \frac{20.9}{(31.6 - 0.0124 \cdot q)} + \frac{0.26 \cdot q}{(31.6 - 0.0124 \cdot q)^2} + \frac{2541 \cdot P_{SR}}{q}$$

where  $P_{SR}$  is the percentage of substitutable roads.

An important consideration is that the relationship between land rents and road supply is reciprocal; the land rents also depend on accessibility and, consequently, road usage. In fact, the last term in equation (4) should include another term for road usage ( $q$ ) in its numerator, reflecting accessibility. This reciprocal relationship should be considered in the optimal road usage analysis. Reducing road supply can reduce land values (rents) because of less accessibility (Clonts 1970; Paulsen 2013), which in turn reduces the optimal charge and increases the optimal road usage. On the other hand, reducing road supply can increase land values by pedestrianization and traffic calming, which further increases the optimal charge and reduce the optimal road usage. However,

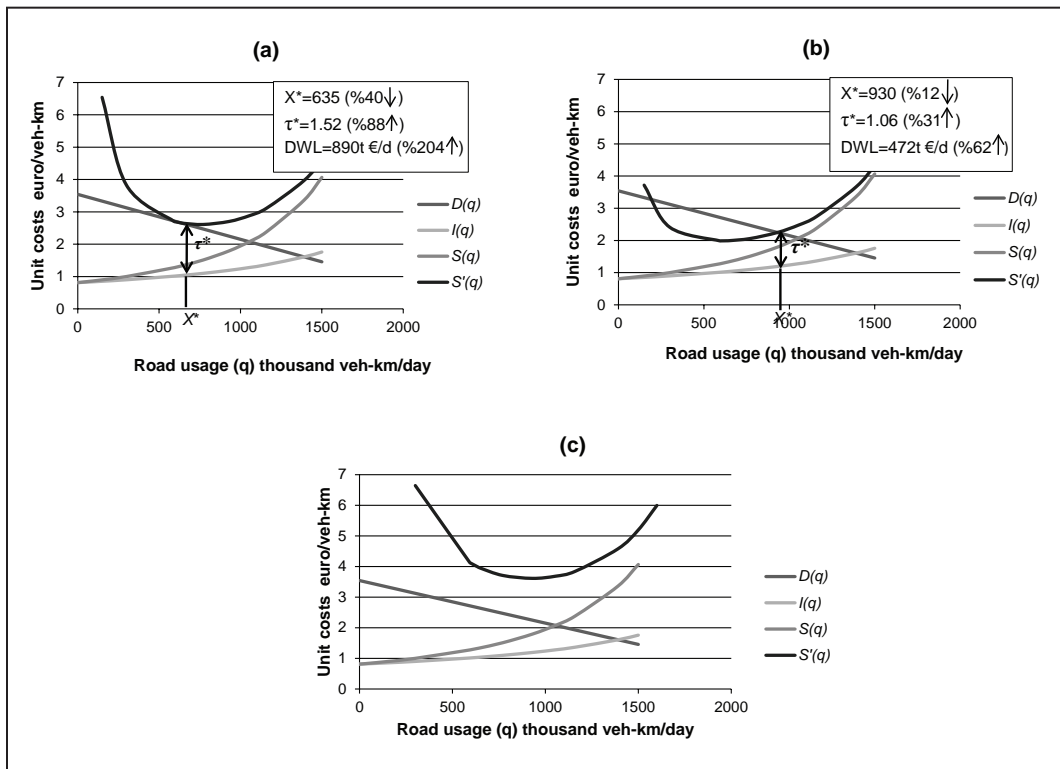
the relationship can be very complex to determine. Therefore, this more detailed complex analysis has not been considered in this study.

## RESULTS

Assume first that the annual rent is 300 euros/m<sup>2</sup>, (£21.6/ft<sup>2</sup>) and 33% of the roads (or road areas) are substitutes, or  $P_{SR} = 0.33$  (Figure 5-a). This level is equivalent to the rent of 100 euros/m<sup>2</sup> for the whole road area. Before going over the results, it should be noted that the assumed values for  $P_{SR}$  are based on round equivalent rents per squared meters; for example, 33% is equivalent to 100 euros/m<sup>2</sup> for all the roadway area. However, the selected values are used to run a sensitivity analysis, represent the limits of the parameter for the analysis, and lack a theoretical background.

For this level of  $P_{SR}$ , the modified social cost translates into a 40% decrease in the optimal road usage (see background section), and an 88% increase in the optimal charge, compared with the raw model (developed by Prud'homme and Bocarejo 2005). Now, the formerly applied charge (£5/day) only captures 69% of the social costs (DWL) vs. 90% from the raw model, and the existing charge (£10/day) captures about 97% of the social costs (DWL) even though the optimal charge (£13.5/day) is significantly more than the existing charge.

**Figure 5: Optimal Congestion Using the Modified Social Cost for Rent of**  
**(a) 100 euros/m<sup>2</sup>-33% Substitute (b) 50 euros/m<sup>2</sup>-16% Substitute**  
**(c) 200 euros/m<sup>2</sup>- 67% Substitute**



An important observation is that the rent cost, the difference between  $S'(q)$  and  $S(q)$ , comprises a substantial part of the total social cost and is even higher than the congestion cost, the difference between  $S(q)$  and  $I(q)$  for this case, at the optimal road usage point. This fact can further support the hypothesis that the rent cost should be involved in the calculation of social optimal road usage

because of its significant impacts. Another important reason for involving the rent cost is that the rent cost is definitely more than the fuel tax paid by each driver (in Figure 5-a,  $I(q)$  is lower than  $S'(q) - S(q)$ ; fuel tax is only part of the  $I(q)$ ). This evidence shows that drivers are not fully paying for the rent cost through taxes. Even a large proportion of fuel taxes are used for purposes other than renting or buying the land for driving such as maintenance, and alternative modes.

Assuming only 16% of the roads are substitutable (equivalent to 50 euros/m<sup>2</sup> for all area), a significant impact can still be seen: a 12% decrease in the optimal road usage and a 30% increase in the optimal charge, compared with the original model. The initially existing charge captures 80% of the potential benefits of a charge, and the existing charge (£10/day) is higher than the optimal level of charges (Figure 5-b). With the assumption that 35% or more of the roads are substitutes (equivalent to 105 euros/m<sup>2</sup> for all the road area), the modified social cost curve no longer intersects with the demand curve (Figure 5-c). With this assumption, low demand roads in the zone should be closed and for which land rents could be made available for other purposes.

Table 1 reports a number of significant observations for various scenarios. First, the optimal road usage decreases dramatically as a result of the added land rents (down from 1,055 to as much as 635 thousand veh-km) while the change in the individual cost at the optimal point is relatively smaller (from 1.28 to 1.03 euros/veh-km). In fact, the decrease in the optimal road usage has only a small effect on the congestion costs, but significantly affects the social costs associated with the rents. This means that for the optimal level of road usage, most of the social costs are from the rent costs rather than congestion costs; the rent costs can be more significant than congestion costs in an expensive city like London, especially if road usage is being set at its optimal level, not at its actual level.

**Table 1: Results of Various Scenarios**

	Non-modified Social cost	Modified 16% substitute (50 €/m <sup>2</sup> )	Modified 33% substitute (100 €/m <sup>2</sup> )
Optimal road usage (1000 veh km)	1055	930	635
Individual cost at optimal (€/veh-km)	1.28	1.19	1.03
Social cost at optimal (€/veh-km)	2.09	2.25	2.65
Pre-charge social cost (€/veh-km)	3.38	3.67	3.98
Optimal Charge (€/veh-km)	0.81	1.06	1.52
Optimal benefits (1000 €/day)	296	474	895
Collection costs (1000 €/day)	689	689	689
Net benefits (1000 €/day)	-393	-215	206

Note: Pre-charge road usage and individual cost are 1390 and 1.16, respectively.



Second, modifying the social cost curve increases the optimal charges, as expected. The optimal charge increases from 0.81 to 1.52 euros/veh-km (equivalent to £7.2/day to £13.5/day). So, the inclusion of the rents in the analysis results in higher optimal charges. Prud'homme and Bocarejo model's optimal charges are lower than what was found by TFL (2008). So the existing charge (£10/day) should be further increased if the rent is taken into account.

Third, the increase in optimal charge is substantial, but the increase in optimal benefits from charging (DWL) is even more (from 296 to 895 thousand €/day or from 57 to 172 million £/year).<sup>6</sup> One of the main findings of the Prud'homme and Bocarejo (2005) study was that the net benefits of any charges to alleviate congestion are negative, which means that, even for the optimal benefits, the economic costs of collecting charges is higher than the benefits. But if the land rents are added to the social cost, this finding can be reversed.

Table 1 shows that for a high share of substitutable roads (33% or 100 euros/m<sup>2</sup> for the whole area), the net benefits become positive. So, instead of being an economic failure, as found by Prud'homme and Bocarejo (2005), the London congestion charge system would be considered an economic success, especially if higher charges are imposed. This outcome demonstrates the importance of taking the rents into account. The net benefits can range from -393 to +206 thousand €/day (-75 to 39 million £/year) based on the levels of  $P_{SR}$ . Also, this shows the importance of the share of substitutable roads in the analysis. One important note in Table 1 is that toll collection costs are assumed to be fixed while these costs could be affected by the number of trips (Rouhani et al. 2014a). Since the main London scheme's toll collection costs are sunk capital costs, we ignore the change in toll collection costs.

## CONCLUSION

The opportunity cost of having roads in place is the rents that may be acquired by leasing the road space itself. Society may gain more from leasing the lands for other purposes than from using it for roads, assuming that the charges for rents will be returned to the users or will be used for public finance. For geographic regions where land is valuable, these ignored social costs may have significant consequences on the externalities associated with driving.

Based on the results of the London congestion zone case study, modifying the social cost by adding the rent of the lands dedicated to roads can have significant impacts on the analysis of optimal road usage. To summarize the results, the addition of the rent can increase the total social costs by as much as 204%, decrease the optimal road usage by as much as 40%, and increase the optimal charge by as much as 88%. And with the assumption of high values for rent or a high share of substitutable roads, the results suggest that some roads could be closed.

Also, the inclusion of the rents can substantially increase the benefits from charging. The net benefits from charges in the London congestion zone can change from -393 (found by Prud'homme and Bocarejo (2005)) to +206 thousand euros per day (-75 to 39 million £/year) using a relatively moderate value for the rents. The impact on the cost/benefit analysis demonstrates the importance of taking the rents into account. For high rent values, the rent costs can be even more significant than congestion costs, especially in an expensive city like London.

The applied model in this study suffers from several limitations. The share of substitutable roads could be extremely important in the optimal road usage analysis. This study employs only a sensitivity analysis for the related parameter, and the selected values lack a theoretical background. Some interesting further research would be developing a method to estimate this parameter.

The other limitation is that the details about who will get the benefits of selling or leasing the roads are missing in the analysis. A public fund, the residents of the relevant jurisdiction, or the federal government could potentially receive the benefits. The choice of the potential beneficiary could have important ramifications for social welfare analysis (Levinson 2005; Geddes and Nentchev 2012; Rouhani et al. 2014b).

Finally, the applied model in this study cannot estimate the costs (and benefits) to the property owners and is unable to capture the benefits (and costs) of the congestion pricing scheme beyond the congestion charge zone. Another interesting future study would estimate the effects of the changes in road capacity and road supply, which can affect the access to different land use functions, on the value of the neighboring land, using a method like Hedonic pricing (Earnhart 2006). The rental value of roads is a function of road supply; the value of land and consequently the rents could fall once the roads are removed. In fact, the relationship between road supply and land rent is reciprocal, and this fact should also be considered in the analysis.

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### Endnotes

1. In some European countries, new roads can be completely financed through high fuel taxes paid. So, one can argue that roads are completely financed because fuel taxes are high enough. However, very few new roads are built in old cities with already developed urban environments. As a result, the fuel taxes are not used for developing these cities' road networks.
2. The London's congestion charging scheme is different from conceptual congestion charging systems in its structure. The London scheme is a zonal scheme that is unable to price the social costs of congestion efficiently. In fact, the scheme can incentivize more traveling once the charge is paid (opposite to what a congestion pricing system should follow). In spite of the difference, the scheme is called the London congestion pricing.
3. Considering  $I(q)$  as the generalized cost of a trip, the total cost is  $TC=I(q).q$ , the marginal social cost of a trip is  $MSC=dTC/dq=I(q)+I'(q).q$ , and the external social cost is  $MSC-I(q)=I'(q).q$ . Therefore, the Pigouvian tax is  $\tau = I'(q).q$ .
4. The Prud'homme and Bocarejo model (our model) is a partial equilibrium model. A general equilibrium model is valuable for a comprehensive analysis of the benefits and costs of congestion pricing schemes, which should include changes outside the limited scope of the partial equilibrium model (such as employment, land values, activities). The changes in these parameters are not considered in this analysis.
5. To calculate the total annual rent, the annual rate (300 euros/m<sup>2</sup>) is multiplied by the area of the congestion zone (2.16 km<sup>2</sup>). The result will be 648 million euros per year. And dividing the result by 255 working days, the total rent per working day will become 2,541 thousand euros (648 million/255).
6. To estimate the optimal benefits, we used the (approximately) triangle  $B'C'A$ , as shown in Figure 2. For example,  $P_{SR} = 0.16$ ,  $C'A = 3.67$  (pre-charge social cost) – 1.61 (pre-charge individual cost) = 2.06; and  $X'Y = 1,390$  (pre-charge road usage) – 930 (optimal road usage) = 460. So, the optimal benefits equal  $0.5 * C'A * X'Y = 473.8$ .

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**Omid M. Rouhani** is a postdoctoral research associate at Cornell University, where he works on policy options to improve New York City's transportation system. Omid's research focuses on the application of systems analysis, economics, optimization, simulation, and modeling methods to transportation problems at different scales. His academic articles have appeared in the Journal of Transportation Research Part B, Environmental Modeling and Software, Energies, the European Journal of Operational Research, Transportation Research Record, and many other journals.

**Christopher Knittel** is the William Barton Rogers Professor of Energy Economics in the Sloan School of Management and the director of the Center for Energy and Environmental Policy Research at the Massachusetts Institute of Technology. He joined the faculty at MIT in 2011, having taught previously at UC Davis and Boston University. His research focuses on environmental economics, industrial organization, and applied econometrics. He is a research associate at the National Bureau of Economic Research in the Productivity, Industrial Organization, and Energy and Environmental Economics groups. Professor Knittel is an associate editor of The Journal of Industrial Economics, Journal of Transportation Economics and Policy, and Journal of Energy Markets. His research has appeared in The American Economic Review, The American Economic Journal, The Review of Economics and Statistics, The Journal of Industrial Economics, The Energy Journal and other academic journals.

**Deb Niemeier** is a professor in the Department of Civil and Environmental Engineering at the University of California, Davis. Her research interests focus on sustainability, climate change, the complex interactions between policy, energy use and land use, and productivity and innovation in public agencies.



# Dynamics of Transport Infrastructure, Exports and Economic Growth in the United States

by Tingting Tong, T. Edward Yu, and Roland K. Roberts

*This paper focuses on the dynamic relationships among transport infrastructure, exports and economic growth in the United States using a multivariate time-series analysis. Results suggest that the formation of highways and streets affects economic growth indirectly through enhancing the capital stock of non-transport infrastructure and crowding in private capital. The reverse causality from economic output to highway and street infrastructure is observed. Aggregate capital stock of non-transport infrastructure, excluding national defense, has sustainable positive effects on economic output and exports over a number of years. Empirical evidence also shows that highway and street infrastructure and non-transport infrastructure Granger cause exports.*

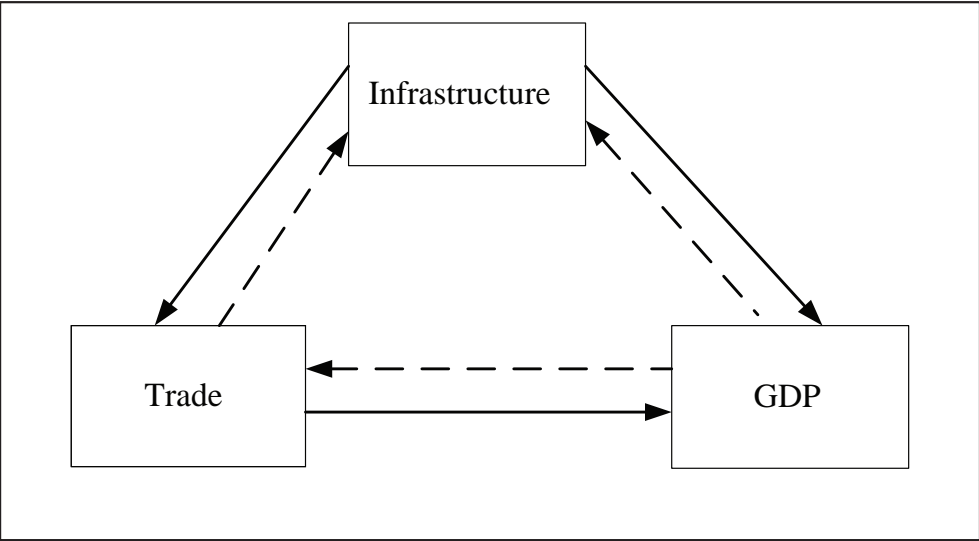
## INTRODUCTION

Government spending on transport infrastructure has long been considered a means to enhance economic development in both developed and developing countries. The significance of transport infrastructure investment has been clearly revealed in the U.S. government's proposals and policies over decades. For example, in President Clinton's 1992 presidential campaign document, he proposed a "Rebuild America Fund" to allocate \$20 billion annually for four years in four critical areas, including transportation, information network, environmental technology, and defense conversion (Clinton 1992). President G. W. Bush signed the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) in 2005, allocating more than \$286 billion over five years to maintain and improve the surface transport infrastructure of the nation. To address the economic recession in the late 2000s, President Obama signed the American Recovery and Reinvestment Act (ARRA) in 2009 that included \$48 billion for transport infrastructure. In 2011, Mr. Obama proposed investing an additional \$50 billion to modernize national highways, transit, rail, and aviation infrastructure systems in the American Jobs Act. In June 2012, a new surface transportation bill of \$105 billion over two years, Moving Ahead for Progress in the 21st Century (MAP-21), was signed into law to reauthorize the federal-aid highway program.

Interestingly, regardless of the aforementioned policy focus, a consensus remains elusive about the effects of transport infrastructure on economic growth at the aggregate level (Pereira and Andraz 2012). The potential connection between economic development and transport infrastructure investment in the United States has been at the forefront of academic debates over decades. A number of empirical studies suggest that government expenditures on public infrastructure, including transportation, can potentially increase productivity or reduce cost of production and, hence, increase economic growth (e.g., Aschauer 1989, Munnell 1990, Fernald 1999, Glass 2008, Pereira and Andraz 2012). Alternatively, others find no significant effect or even a negative impact on national productivity (e.g., Holtz-Eakin 1994, Garcia-Mila et al. 1996, Ewing 2008). Notwithstanding the diverse perspectives regarding transport infrastructure investment, the recent global economic recession has encouraged some policy makers to utilize this fiscal policy tool to promote economic recovery, reinforcing the debate about the economic impact of infrastructure investment.

The role of trade in the relationship between transport infrastructure and economic growth typically has been ignored in previous literature. Trade could contribute to both economic growth

**Figure 1: Dynamic Relationships Among Transport Infrastructure, Trade and Economic Output**



and transport infrastructure (see Figure 1). The export-led growth hypothesis suggests that exports can be an engine for economic growth to increase employment and income in the exporting country, increase the efficiency of resource allocation, and achieve economies of scale (Marin 1992, Giles and Williams 2000). Similarly, trade expansion potentially stimulates the need for and development of transport infrastructure (Borrone 2005, Lee and Rodrigue 2006, Beningo 2008). Conversely, economic growth and infrastructure development in a country can affect trade. Domestic economic conditions, including strong product demand and/or agglomeration economies, can promote the growth of exports (e.g., Leichenko 2000, Zestos and Tao 2002). In addition, researchers have confirmed a positive relationship between transport infrastructure and trade through lower transportation cost or better infrastructure quality (Limao and Venables 2001, Nordas and Piermartini 2004).

The aim of this research is to revisit the long-term impact of transport infrastructure on U.S. economic growth by incorporating trade as an element of the analysis. Including trade in the model can mitigate the omitted-variable problem, thus improving the three-way impact estimates. Our hypothesis is that enhancing transport infrastructure can increase economic output in the United States. The hypothesis is empirically tested using a multivariate time-series framework, which can address the issue of nonstationary data and provide a clearer understanding of the long-run relationships among these variables. Most importantly, the analysis provides policy makers updated and more accurate information for more efficient allocation of scarce budget resources to infrastructure investments.

The remainder of this article is organized as follows: a brief literature review about the relationships among economic growth, trade and infrastructure is provided in the next session, followed by an explanation of the analytical methods. A description of the data and empirical analysis are then presented. Policy implications and conclusions are offered in the final section.

**LITERATURE REVIEW**

The economic impact of transport infrastructure investment (either in terms of government spending on transport infrastructure per year or the accumulated stock of transport infrastructure capital) has been scrutinized since the work of Aschauer (1989). Thorough and updated surveys of the

relevant literature are available in Baird (2005) and Goetz (2011). Goetz included the summary of the literature prior to 2000 by Bhatta and Dremman (2003) and analyzed 55 additional papers published on ISI Web of Science from 1999 to 2009. Among more than 100 reviewed studies, most find that investment in transport infrastructure supports one or more indicators of economic growth. Specifically, 43 of the 55 more recent studies confirm the positive role of transport infrastructure investment. A brief summary of various perspectives on the role of transport infrastructure is presented below.

Aschauer (1989) estimated the impact of “core” infrastructure (streets, highways, airports, and water systems) on economic growth and productivity in the United States during 1949–1985, and reported elasticities of government capital ranging from 0.38 to 0.56, and Munnell (1990) estimated an elasticity of output with respect to infrastructure near 0.34 in a national study. However, these estimates have been criticized because of the issues of spurious relationships, simplified structural form and the aggregated data used for analysis (Gramlich 1994). Using the data from 48 contiguous states, Munnell and Cook (1990) reported a lower output elasticity of public capital of 0.15. The use of less aggregated state or county data by others also yielded smaller positive effects of transport infrastructure on economic growth (e.g., Berechman et al. 2006, Pereira and Andraz 2012). In addition, a number of case studies for particular states or counties suggested positive impacts of highway and street infrastructure development on local or regional economic activity (e.g., Babcock and Leatherman 2011, Wang et al. 2013). Other researchers measured the “broader” economic effects of transport infrastructure by considering the spillover (indirect) effects on neighboring geographic areas, attempting to enhance the precision of the effects of infrastructure (Cohen 2010, Tong et al. 2013). Besides, others confirmed the positive effects of transport infrastructure on activities in the private sector (e.g., Hodge et al. 2003, Horst and Moore 2003).

Conversely, a few studies found no effect (or mixed effects) of infrastructure capital on economic growth. For instance, Tatom (1993) found no effect of public capital on productivity growth after making adjustments for a spurious regression problem. Similarly, Garcia-Mila et al. (1996) generated a state-level production function with three forms of public capital—highways, water and sewage systems, and all other public capital—as inputs, and found no evidence of their effect on productivity. Another group of studies considered the spillover effects of transport infrastructure and reported that the development of transport infrastructure in one location may simply relocate economic activity from that location to others, yielding no (or negative) impact on regional economic output (Holtz-Eakin and Schwartz 1995, Chandra and Thompson 2000, Chalermpong 2004). Moreover, some argued that, because the modern transport system already exist in the nation, additional infrastructure investment has little impact on economic output, and the impact, if any, varies across regions (Ewing 2008, Peterson and Jessup 2008).

In addition to the mixed effects of transport infrastructure on economic growth found in previous empirical studies, the direction of the causal relationship remains unclear. Kessides (1996) suggests that simultaneity makes research concerning the impact of transport infrastructure on economic growth tenuous, because economic growth can lead to development of the transport system. Extending the related literature, Fisher (1997) discussed the potential importance of accounting for the possible reverse impact of economic growth on public capital development. The ambiguity about the causal relationship between transport infrastructure and economic growth suggests the need for further research on the economic benefits of investment in transport infrastructure (Nguyen and Tongzon 2010).

Another group of studies has focused on the relationship between transport infrastructure and trade. Many studies have concluded that infrastructure development has a positive effect on trade through lower transport costs. Using a panel of bilateral trade-flow data for 1988-2002, Francois and Manchin (2013) concluded that transport infrastructure not only increases trade volumes, but also increases the probability of trade occurring. Park and Koo (2005) suggested that the impact of telecommunication investment on agricultural trade in importing OECD countries is more important

than in exporting countries. In addition, Nordas and Piermartini (2004) suggested that quality of transport infrastructure is an important determinant of trade expansion, and port efficiency is the most crucial among all infrastructure indicators.

Some studies suggested that growth in international trade stimulates public infrastructure development. Since trade is a demand determinant for transport and logistics, growth in international trade will affect their growth (Lee and Rodrigue 2006). Growth in trade between the United States and China has placed greater demands on the U.S. transportation system over the last two decades (Beningo 2008). Wilson et al. (2005) measured the relationship between trade facilitation and trade flows in manufactured goods across 75 countries during 2000-2001. They concluded that differences in the quality of logistics and trade facilitation were related to trade in all regions.

Another strand of literature involves the interaction between foreign exports and economic growth. Most studies concluded that trade benefits economic development by increasing income and employment. For example, countries that trade a higher proportion of their GDP have higher incomes (Frankel and Romer 1999, Irwin and Tervio 2002); exports contribute to economic development via job creation at the state level in the United States (Coughlin and Cartwright 1987, Nishiyama 1997); and Marin (1992) failed to reject the export-led growth hypothesis for the United States, Japan, United Kingdom, and Germany. Conversely, many researchers have found evidence of reverse causality between exports and economic growth. For instance, Leichenko (2000) investigated the causal relationships among exports, employment, and production in U.S. states and regions during 1980-1991 and found bidirectional causality between exports and state economic growth.

Although substantial literature has investigated the causal relationships between public infrastructure and economic growth, trade and economic growth, or public infrastructure and trade, little research has evaluated the interactions among these three closely related factors, except recent studies of developing countries by Khadaroo and Seetanah (2008) and Sahoo and Dash (2012). Khadaroo and Seetanah (2008) applied a vector error correction model to evaluate the impact of public infrastructure (divided into transport and non-transport), trade openness, private capital, and education level of labor on Mauritius' GDP. Their results suggest that all factors had positive impacts on output over 1950–2000, while GDP did not affect public infrastructure capital. Sahoo and Dash (2012) included trade, infrastructure, and labor and capital inputs in the production functions for South Asian countries to evaluate the effects of public infrastructure on output. They concluded that infrastructure development and exports positively affected output and observed a feedback impact from output to infrastructure development.

## METHODOLOGY

This study adopts vector autoregression (VAR) models to evaluate the dynamic relationships among economic output, trade, and transport infrastructure. The VAR model has been commonly used when dynamic feedback among evaluated variables is hypothesized (e.g., Cullison 1993, Kamps 2005). An additional advantage is that *a priori* causality directions are not needed between variables (Sturm 1998), which fits the purpose of this study well. In a VAR model, each variable is explained by its own lagged values and the lagged values of the other endogenous variables (Sims 1980).

Before applying the typical VAR model, integration/non-stationarity of the time-series variables is examined through unit root tests, because conventional asymptotic theory is not applicable to hypothesis testing of non-stationary series (Sims et al. 1990). Hence, the Augmented Dickey-Fuller test (ADF, Dickey and Fuller 1979) was employed to test whether each variable is stationary. The ADF test can be presented as:

$$(1) \quad \Delta A_t = \alpha + \rho A_{t-1} + \sum_{i=1}^n \varphi \Delta A_{t-i} + \mu_t$$

where  $A_t$  is the given time series,  $\Delta$  is the first difference operator, and  $\mu_t$  represents an i.i.d. residual term. The optimal lag length,  $n$ , is determined by the Schwarz Bayesian criterion (SBC, Schwarz 1978). The null hypothesis of the ADF unit root test is the coefficient of the lagged variable equals zero ( $\rho = 0$ ). Failing to reject the null indicates a unit root exists in the data series. The Phillips-Perron unit root test (PP, Phillips and Perron 1988) was also conducted. This test has a similar null hypothesis, but uses a nonparametric adjustment to the ADF test allowing for dependence and heterogeneity in the residuals.

If ADF and PP unit tests suggest that more than one of the evaluated variables are integrated, a cointegration test must be conducted to determine if the linear combination of those variables is stationary. If cointegration is found among the variables, a vector error correction model (VECM) is appropriate. However, the commonly used cointegration tests developed by Engle and Granger (1987) and Johansen (1988) have size distortion if the variables have roots close to unity but not exact unit roots (Elliott 1998). Moreover, the estimation of the VECM is sensitive to the results of the cointegration test, which likely results in severe over rejections of the null hypothesis (Clarke and Mirza 2006).

The statistical inference issue of unit roots and cointegration tests is addressed in the lag-augmented VAR (LA-VAR) model suggested by Toda and Yamamoto (1995). The LA-VAR model can be estimated without taking differences of the data and applying a Wald test for causality between variables. Most importantly, it is applicable to variables that are stationary and integrated or cointegrated (Kawakami and Doi 2004); hence, avoiding the statistical-inference uncertainty of the cointegration test in the VECM model. A comparison of common methods for detecting Granger non-causality found that the LA-VAR method exhibits consistent performance over a wide range of data-generating processes and performs better in controlling Type I error probability (Clarke and Mirza 2006).

A conventional VAR model of  $n$ -vector time series variables, with  $k$  lags is written as:

$$(2) \quad V_t = \gamma_0 + \gamma_1 T + \sum_{i=1}^k \beta_i V_{t-i} + \varepsilon_t$$

where  $V_t$  is an  $n \times 1$  vector of series at time  $t$ ,  $\gamma_0$  is an  $n \times 1$  vector of constants,  $\gamma_1$  is an  $n \times 1$  vector of coefficients,  $T$  is a time trend,  $\beta_i$  are  $n \times n$  matrices of coefficients, and  $\varepsilon_t$  is an  $n \times 1$  vector of i.i.d. innovations (residuals) with  $n \times n$  covariance matrix  $\Sigma$ . Similar to Khadaroo and Seetanah (2008), six variables were considered in the present study (i.e.,  $n=6$ ), including aggregated economic output ( $Y$ ), aggregated exports ( $X$ ), transport infrastructure ( $H$ ), non-transport public capital ( $G$ ), private capital ( $K$ ), and labor ( $L$ ), to capture the completeness of their interactions in an extended classical economic growth model. The LA-VAR model is generated by adding additional lags up to  $d_{max}$ , which is determined by the maximum order of integration in the system. For example, if the maximum order of integration of evaluated variables were one (i.e., taking first differences of the variables to make them stationary over time),  $d_{max}$ , and the LA-VAR model would be:

$$(3) \quad V_t = \gamma_0 + \gamma_1 T + \sum_{i=1}^{k+d_{max}} \beta_i V_{t-i} + \varepsilon_t$$

A modified Wald test can be conducted on the first  $k$  order of a LA-VAR ( $k + d_{max}$ ) system to test if any given variable is Granger caused by other variables (Granger 1969). The Granger causality test examines whether a variable is predicted by its own past information and the past information of other evaluated variables. Therefore, the null hypothesis imposes the following restriction on equation (3):

$$(4) \quad H_0 = \beta_1 = \beta_2 = \dots = \beta_k = 0$$

Rejecting the null hypothesis implies that the past information of other variables Granger causes the variable at time  $t$ .

Although the Granger causality test identifies causal relationships among variables, it cannot show other endogenous variables' responses to a one-time shock to an endogenous variable. Also, as the coefficients of a VAR model are difficult to interpret, an innovation accounting based on a moving average representation (MAR) may be an alternative means to illustrate the dynamic structure of evaluated variables (Sims 1980, Swanson and Granger 1997). An impulse response function generated from the MAR of equation (3) is used to explain how long and to what extent one variable reacts to an exogenous shock to another variable over time. These responses are revealed by the generalized impulse response functions (GIRF) proposed by Koop et al. (1996) and Pesaran and Shin (1998). Unlike the orthogonalized impulse responses that use a Cholesky decomposition to define the contemporary relationships of the variables (Sims 1980), the main advantage of this generalized approach is that the responses are invariant to the ordering of variables (Hurley 2010). The statistical significance of each GIRF is evaluated by 95% confidence intervals using standard error generated by the Monte Carlo method (Lütkepohl 2000). The method generates the non-standard asymptotic distribution of the standard error using 6,000 randomly sampled replications.

## DATA

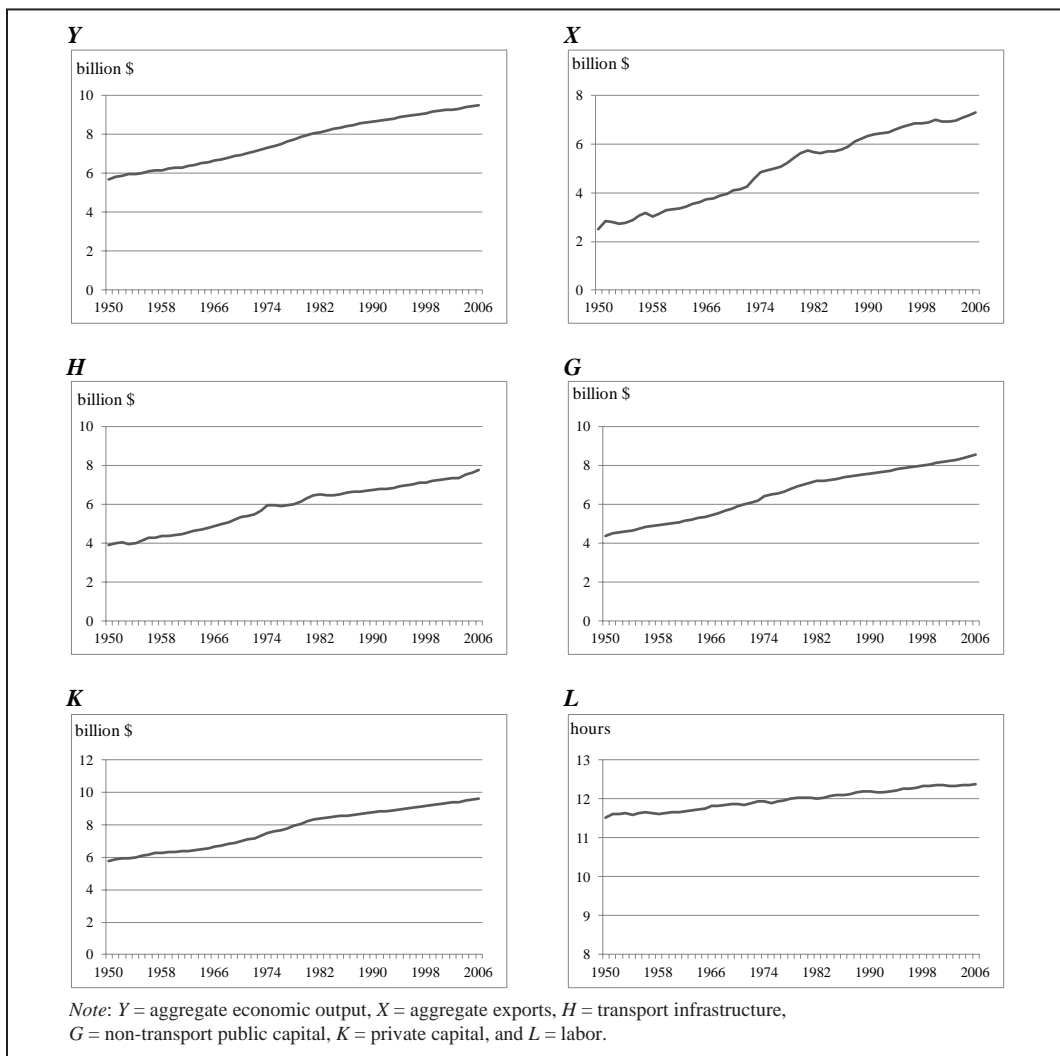
Aggregate economic output ( $Y$ ) is measured by gross domestic product (GDP), while the trade variable ( $X$ ) is measured by the value of exports. The value of exports is selected as a proxy for trade in the analysis since exports are more relevant in the trade and growth literature. Also, Zestos and Tao (2002) suggested the value of exports Granger causes GDP in the United States, but found no evidence of causality from imports to GDP. The transport infrastructure variable ( $H$ ) is measured by the value in current dollars of the net stock of government fixed assets in highways and streets after accounting for depreciation. This study uses highway and street infrastructure to represent transport infrastructure because highway and street infrastructure is the largest single category of public infrastructure capital (Bhatta and Drennan 2003) and is commonly used in the literature when evaluating the economic impact of transportation infrastructure (Baird 2005). The U.S. Bureau of Economic Analysis shows that highway and street infrastructure accounted for 32% of the estimated \$9.2 trillion in government fixed assets in 2010, excluding national defense (USBEA 2011).

Non-transport capital ( $G$ ) is measured by the value in current dollars of the net stock of government fixed assets, excluding national defense and highways and streets. Private capital ( $K$ ) is measured by the value in current dollars of private nonresidential fixed assets, consisting of equipment, software, and structures; and labor ( $L$ ) is hours worked by full-time and part-time employees in domestic industry. Annual data for all six variables were obtained for 1950 through 2006 from the U.S. Bureau of Economic Analysis (USBEA 2011). All variables are measured in billions of dollars (except  $L$ ) and converted to logarithms (Figure 2). The observed upward trends suggest the existence of unit roots.

## EMPIRICAL RESULTS

The ADF and PP unit root tests are summarized in Table 1. For most data series in levels, both tests fail to reject the null of a unit root with or without trend. Both tests find variables are generally stationary after taking first differences, suggesting the maximum order of integration,  $d_{max}$ , is one. The optimal lag length,  $k$ , suggested by the SBC criterion is also one. Based on  $d_{max}$  and the optimal  $k$ , equation (3) becomes a two-lag LA-VAR. Residuals from the U.S. LA-VAR model are well behaved. The test for normality of the residuals is not rejected ( $p$ -value of 0.97). Lagrangian multiplier (LM) tests for third and fourth order autocorrelation fail to reject the null of white noise residuals ( $p$ -values



**Figure 2: Plots of the Variables in Nature Logs**

of 0.30 and 0.18). In addition, the multivariate LM tests for first order autoregressive conditional heteroskedasticity (ARCH) residuals ( $p$ -value of 0.15) suggest a constant residual variance.

Table 2 presents the results for the Granger causality tests from the LA-VAR procedure. Highway and street infrastructure capital ( $H$ ) does not Granger cause economic output ( $Y$ ). However, evidence suggests a strong causal effect (1% significance level) of economic output on highway and street infrastructure. Non-transport public capital ( $G$ ) and private capital ( $K$ ) Granger cause aggregated economic output at 5% and 10% levels, respectively, with no significant causal effects from the other direction. Results suggest both highway and street capital and non-transport infrastructure capital Granger cause exports ( $X$ ) at the 5% and 10% levels, respectively. This finding is consistent with previous literature that found a positive effect of transport infrastructure on trade (e.g., Limao and Venables 2001, Nordas and Piermartini 2004, Francois and Manchin 2013). However, the reverse causal impacts from exports to highway and street capital or non-transport public infrastructure capital are not observed.

Table 1: Unit Root Test Results

Variable	Levels			
	ADF		PP	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend
<i>Y</i>	-0.65(1)	-0.46	-1.05	-0.53
<i>X</i>	0.04(1)	-2.35 (1)*	-0.62	-1.68
<i>H</i>	-0.35(2)	-1.95(1)	-0.32	-1.50
<i>G</i>	-0.36(1)	-1.42(1)	-0.78	-1.11
<i>K</i>	-0.43(1)	-1.70(1)	-0.57	-1.23
<i>L</i>	-0.49(2)	-3.53(1)**	-1.41	-3.02
	First difference			
	ADF		PP	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend
<i>Y</i>	-5.58(0)***	-5.57(0)***	-5.97***	-5.99***
<i>X</i>	-6.08(1)***	-6.04(1)***	-6.16***	-6.07***
<i>H</i>	-5.55(1)***	-5.5(1)***	-4.99***	-4.95***
<i>G</i>	-3.61(0)***	-3.56(0)**	-3.62***	-3.57**
<i>K</i>	-3.14(0)**	-3.12(0)	-3.09**	-3.07
<i>L</i>	-6.29(1)***	-6.24(1)***	-7.33***	-7.20***

Note: \*\*\*, \*\*, and \* denote significant at 1%, 5%, and 10%, respectively. Lag lengths included in parentheses are determined based on SBC. *Y* = aggregate economic output, *X* = aggregate exports, *H* = transport infrastructure, *G* = non-transport public capital, *K* = private capital, and *L* = labor.

Table 2: Granger Causality Test Results Based on the Toda-Yamamoto Procedure (1995)

	<i>Y</i>	<i>X</i>	<i>H</i>	<i>G</i>	<i>K</i>	<i>L</i>
Dependent Variable	Modified Asymptotic Wald Statistics k(1)					
<i>Y</i>	-	0.01	0.57	4.58**	2.90*	0.04
<i>X</i>	0.58	-	5.01**	3.26*	0.10	0.07
<i>H</i>	7.36***	0.16	-	0.01	0.35	2.89*
<i>G</i>	1.4	0.17	5.53**	-	0.21	1.43
<i>K</i>	0.26	0.27	4.71**	1.94	-	0.18
<i>L</i>	0.44	0.62	0.08	0.88	2.09	-

Note: \*\*\*, \*\*, and \* denote that the null hypothesis of Granger non-causality is rejected at the 1%, 5% and 10% significance levels, respectively. *Y* = aggregate economic output, *X* = aggregate exports, *H* = transport infrastructure, *G* = non-transport public capital, *K* = private capital, and *L* = labor.

A causal relationship is also found between the public infrastructure capital variables—highway and street capital Granger causes non-transport infrastructure at the 5% level. This causal relationship implies that other public infrastructure capital increases when accessibility improves. After the road systems are put in place, development of the non-transport infrastructure (e.g., office buildings, schools, and power lines) follows. A similar causal relationship is observed between highway and street infrastructure and private capital—highway and street infrastructure Granger causes private capital stock at the 5% level. This result suggests that improved accessibility attracts private capital investment, i.e., the crowd-in effect. In addition, a weak causal effect of labor ( $L$ ) on highway and street infrastructure is observed at the 10% level.

The GIRF relating GDP ( $Y$ ), exports ( $X$ ), highway and street capital ( $H$ ), non-transport public capital ( $G$ ), private capital ( $K$ ), and labor ( $L$ ) to each other based on the estimated LA-VAR are depicted in Figure 3. Each panel in the figure presents a variable's response (the bold line) and the corresponding 95% confidence interval (the dash lines) to a one-time shock in another variable over 20 years. The number on the vertical axis represents the change in the evaluated variable (a scale of 0.01 refers to a 1% change), while the number on the horizontal axis is the number of years following one positive shock in another variable.

In panel (a1), the effect of increased exports on economic output is positive in the contemporaneous year (only effects that are significant at the 5% level are discussed onwards unless otherwise indicated). A one-time positive shock in transport infrastructure capital does not create a significant effect on national GDP (a2), while an increase in non-transport public capital positively affects economic output for six years (a3). Panels (a4) and (a5) show that a one-time increase in private capital and labor can also contribute to economic output over three to four years.

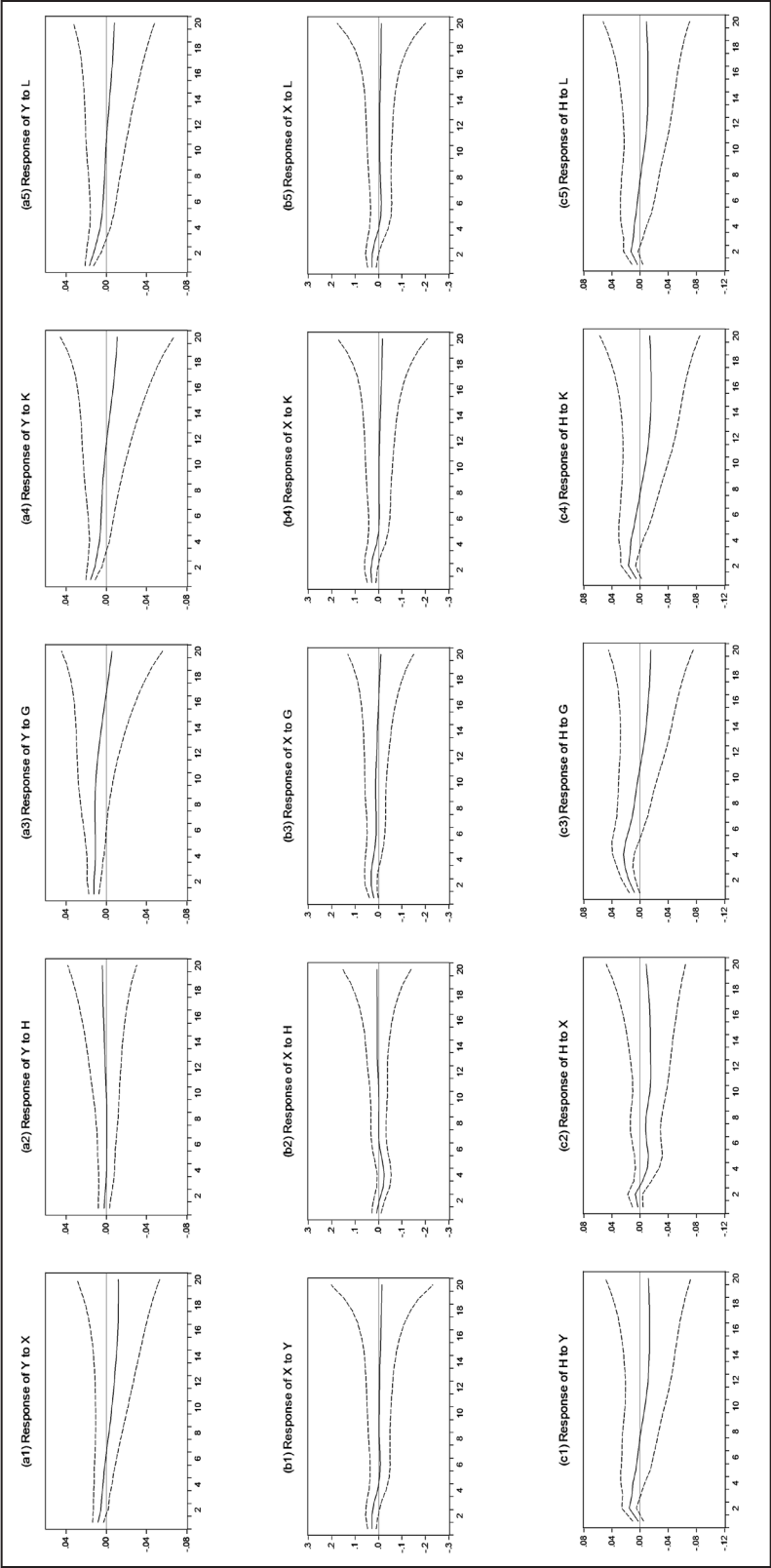
Panel (b1) shows that an increase in aggregated output enhances exports instantaneously and into the following year. An increase in non-transport public capital stimulates national exports over a three-year horizon (b3). Exports also expand instantly when private capital and labor increase (b4 and b5). The GIRF in panel (c1) suggests that a one-time positive shock in aggregated output has a positive lagged effect on government spending on highways and streets, while a one-time expansion in non-transport infrastructure capital creates a positive impact on highway and street infrastructure capital over six years (c3). Similar to the impact of output, a one-time increase in private capital posts a lagged impact on highway and street infrastructure (c4).

The GIRFs for non-transport public infrastructure in panels (d1) through (d5) show that one-time shocks in aggregated output, exports, highways and streets, private capital, and labor all positively affect the formation of non-transport public infrastructure capital. The GIRFs for private capital show that an increase in highway and street capital affects private capital formation in the contemporaneous period in panel (e3), while investment in non-transport public infrastructure capital positively produces a longer impact on private capital in panel (e4). These results provide evidence that public infrastructure investments attract (or crowd-in) private capital development. Also, a one-time expansion in GDP, exports, non-transport infrastructure capital, and private capital elicit positive impacts on labor use (f1, f2, f4, and f5, respectively).

## CONCLUSIONS AND POLITICAL IMPLICATIONS

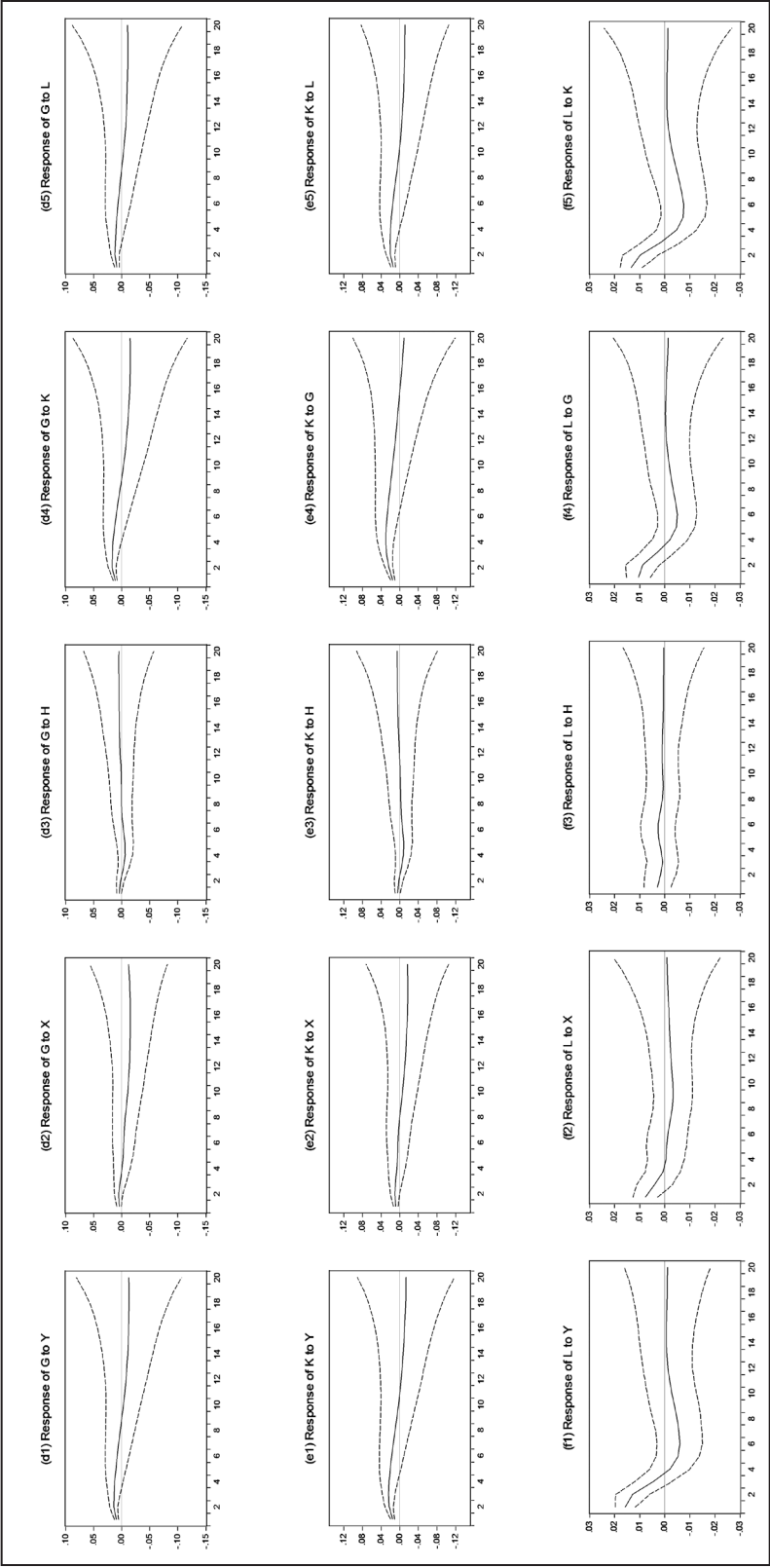
This paper analyzes the dynamic relationships among transport infrastructure, economic output, and exports in the United States using the LA-VAR approach developed by Toda and Yamamoto (1995). The results can be summarized as follows. First, in contrast to some previous studies supporting a direct economic impact of transport infrastructure, results from both Granger causality tests and generalized impulse response functions in our study do not suggest a direct effect of transport infrastructure on aggregated economic output, while causality from economic output to transport infrastructure formation is observed. Second, aggregate non-transport infrastructure capital (e.g., educational structures, power, sewer and water systems, and residential, office and

Figure 3: Generalized Impulse Responses of Each Variable to One Standard Deviation Shock in Another Variable



Note: The number on the vertical axis represents the change of a given variable (a scale of 0.01 refers to a 1% change), while the number on the horizontal axis corresponds to the number of years after the one-time shock. Dash lines represent 95% confidence interval of the response.  $Y$  = aggregate economic output,  $X$  = aggregate exports,  $H$  = transport infrastructure,  $G$  = non-transport public capital,  $K$  = private capital, and  $L$  = labor.

Figure 3: continued



Note: The number on the vertical axis represents the change of a given variable (a scale of 0.01 refers to a 1% change), while the number on the horizontal axis corresponds to the number of years after the one-time shock. Dash lines represent 95% confidence interval of the response.  $Y$  = aggregate economic output,  $X$  = aggregate exports,  $H$  = transport infrastructure,  $G$  = non-transport public capital,  $K$  = private capital, and  $L$  = labor.

commercial structures), excluding national defense, has sustainable positive effects on economic output and exports over several years. Third, evidence shows that both transport and non-transport public infrastructure Granger cause aggregated exports. Fourth, impulse response functions suggest that economic output and exports react to each other immediately. Finally, results suggest that the development of non-transport infrastructure capital creates multiple-year positive impacts on private capital formation and employment.

Similar to Cullison (1993), our findings suggest that expanding transport infrastructure capital, represented by highways and streets, provides relatively short and indirect impacts on aggregated economic output compared to expanding non-transport public infrastructure. The relatively vague economic impact of transport infrastructure capital found in this study is of little surprise, since a developed economy, where substantial highway and street infrastructure already exists, may experience a weaker influence of transport infrastructure investment than observed in developing economies (Talley 1996). Also, public transport infrastructure, such as interstate highways, may only affect the spatial allocation of economic activity, leaving the total net economic impact unaffected (Chandra and Thompson 2000). This finding does not suggest overlooking the contribution of transport infrastructure capital, since both causality tests and impulse response functions imply that improving road systems and enhancing accessibility will affect the formation of both non-transport public infrastructure capital and private capital, which have positive impacts on economic output.

Several policy implications are suggested from the findings of our research. First, as concerns have arisen about the deteriorating 1950s Interstate Highway System and its effects on private sector productivity and the nation's economy, enhancing the nation's transport infrastructure may be crucial to stimulating the stagnant economy. Based on the findings of this study, investment in transport infrastructure will encourage private capital formation and assist in the formation of other public infrastructure, both of which in turn support economic growth. The resulting economic growth will then encourage an increased allocation of resources toward public transport capital formation, perpetuating a cycle of public investment, private investment and economic growth. The recently reauthorized surface transportation bill, MAP-21, is an example of the Obama Administration's intention to stimulate the economy through enhanced public transport infrastructure investment.

Second, the insignificant direct impact of transport infrastructure capital on economic output may imply that the nation's highways and streets are not well managed (e.g., issues of congestion and traffic safety) or maintained, hence, lowering the economic impact of investment in the nation's road systems. Talley (1996) indicated that spatial accessibility and transportation quality-of-service are important when evaluating the economic impact of transport infrastructure investment. Moreover, the road system may not be efficiently utilized, limiting its contribution to the national economy. Thus, along with increasing the transport infrastructure capital stock, greater economic impact may result from policies that better manage and utilize the nation's road system.

Third, given current global economic stagnation and the domestic budget crisis, the results suggest that the U.S. government efficiently allocate scarce budget resources toward crucial public infrastructure formation. Allocating resources to highway and street infrastructure can encourage the cycle of public investment, private investment, and economic growth, while investing in non-transport public infrastructure can provide positive sustainable effects on economic output and exports. As suggested by Garrison and Souleyrette (1996) nearly two decades ago, policy makers should encourage innovations integrating transportation services with improvement in other sectors to enhance and sustain the value of transport infrastructure.

The current study aggregated all highway and street infrastructure into one category. Future research is needed to explore the economic impacts of highway and street infrastructure by disaggregating it into several categories since not all categories would have the same impact on GDP (e.g., interstate highways versus county roads). The economic gains from spending on highway networks linking shipping ports or investment in the state highways with the highest likelihood for increasing local private capital investment can be analyzed, compared, and used to prioritize



budget allocations. Also, additional measures of highway infrastructure management, such as government spending on Intelligent Transportation Systems and their operation, or on reducing the hours of congestion on highways, can be included to further evaluate the impact of transportation infrastructure on the national economy.

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**Tong** is currently a Ph.D. student in the Department of Economics at Georgia Institute of Technology. She obtained her M.Sc. in agricultural economics from University of Tennessee in 2012. Her research interest is in labor economics and transportation economics.

**Yu** is an assistant professor in the Department of Agricultural & Resource Economics at the University of Tennessee. He received an M.Sc. from Iowa State University and a Ph.D. from Texas A&M University. His research focuses on agricultural logistics, bioenergy markets, and the nexus of trade, transportation and the environment.

**Roberts** is a professor in the Department of Agricultural & Resource Economics at the University of Tennessee. He received an M.Sc. from Utah State University and a Ph.D. from Iowa State University. He is teaching microeconomics and research methodology and has conducted research on a vast array of issues, including production economics, farm management, policy analysis and international development.





# Identifying Traffic Safety Practices and Needs of Local Transportation and Law Enforcement Agencies

by Kirolos Haleem, Albert Gan, Priyanka Alluri, and Dibakar Saha

*As part of the effort to implement the Strategic Highway Safety Plan (SHSP), state departments of transportation are looking to reach out to local and law enforcement agencies. This paper presents a study by the Florida Department of Transportation (FDOT) to identify the existing safety practices and needs of local transportation agencies and law enforcement offices in Florida. Two comprehensive online surveys targeting local transportation agencies and law enforcement agencies are developed. The survey for local transportation agencies includes 39 questions on topics including standardization of crash analysis methods, training needs, and working with FDOT. For law enforcement agencies, the survey includes 25 questions covering topics on enforcement locations, traffic violations and safety campaigns, use of crash reports, and working with transportation agencies. Results from both surveys and lessons learned are discussed.*

## INTRODUCTION

A Strategic Highway Safety Plan (SHSP 2013) is required under the Safe Accountable Flexible Efficient Transportation Equity Act – A Legacy for Users (SAFETEA-LU 2005) as part of the Highway Safety Improvement Program (HSIP 2013). The plan aims to provide a comprehensive framework for reducing highway fatalities and serious injuries on all public roads by integrating the four E's of highway safety: engineering, education, enforcement, and emergency medical services (EMS). The framework allows highway safety programs and partners in a state to work together in an effort to align goals, leverage resources, and collectively address the state's safety challenges. The Moving Ahead for Progress in the 21st Century (MAP-21 2013) continues the HSIP role as a core federal-aid program and requires states to develop, implement, evaluate, and update SHSP. As part of the effort to implement SHSP, state departments of transportation (DOTs) are increasingly looking to reach out to local and law enforcement agencies.

This paper describes an effort by the Florida Department of Transportation (FDOT) to identify the existing safety practices and needs of local transportation agencies and law enforcement offices in Florida. As local roads make up a large percentage of a state road network system, local transportation agencies play an important role in the state's overall safety performance. Working with these agencies, knowing their needs, and helping them meet their needs are critical to the success of the SHSP implementation. While local transportation and law enforcement agencies both aim to improve traffic safety, their approaches and needs are different (Gan et al. 2012). For example, a law enforcement officer may be more interested in identifying enforcement locations based on crash frequency over a shorter period (e.g., three months), while a safety engineer uses multiple years of crash data and exposure to prioritize locations for safety improvements.

As part of the study, two online surveys were conducted targeting local transportation agencies and the law enforcement community to identify their practices and needs. While the surveys were rather comprehensive in scope, including 39 questions for local transportation agencies and 25 questions for law enforcement agencies, this paper covers only those that are more likely to be of interest to the general readers. The surveys are easily transferable to other state DOTs that are willing to reach out to their local agencies.

## **LITERATURE REVIEW**

As part of the survey design effort, a literature search was first conducted to identify relevant studies. It was found that studies that investigated traffic safety procedures and needs from the perspective of local transportation agencies and law enforcement officers were very limited. The majority of studies targeting law enforcement officers were found to focus on addressing data quality issues in crash reporting (Knezek and Hansen 2007, Bailey and Huft 2008, Mickee 2008), a better allocation of traffic safety personnel (Coffman and Monsere 2006), the impact of law enforcement on prohibiting hand-held cell phone use while driving (Nikolaev et al. 2010), and the officers' attitudes and problems encountered in enforcement (Hurst 1980, Jonah et al. 1999, Schrock et al. 2002, Chang and Shih 2012). For example, Knezek and Hansen (2007) designed the "Police Technical Assistance Program" for supporting the New Jersey Department of Transportation safety mission. As part of this program, assessments were conducted and technical assistance provided to reduce the reporting errors on New Jersey's crash reports. The project succeeded in changing the structure of the crash reporting form that was accepted by municipal law enforcement officers.

Mickee (2008) designed a law enforcement outreach survey to explore the data quality issues provided by law enforcement officers and to identify possible cost-effective solutions for the problematic lack of unreliable crash data in Massachusetts. Mickee (2008) emphasized two important criteria for a proper design of online surveys: surveys should have easy questions that could be answered in approximately 20 minutes and surveys should avoid open-ended questions as much as possible. Nikolaev et al. (2010) evaluated the impact of law enforcement on prohibiting cell phone use while driving in New York. They observed lower fatality crash rates after enforcement on banning cell phone use compared with crash rates before banning.

Studies targeting transportation agencies were limited compared with those targeting law enforcement agencies. Studies targeting transportation agencies focused mainly on methods to collect standard roadside information (Lee and Mannering 1999), perspective on various transportation modeling packages (Boile and Ozbay 2005), and opinions on potential benefits from technological innovations, e.g., electronic data entry and geographic information systems (GIS) (Cherry et al. 2006).

Lee and Mannering (1999) developed a standardized method to collect roadside information and estimate accident severity likelihood resulting from roadside attributes. The authors conducted a national survey of DOT agencies in the U.S. to investigate various states' practices regarding the collection of roadside information. The majority of responses agreed that the removal of unnecessary fixed objects along the roadside was essential, more so than relocation. Boile and Ozbay (2005) conducted a survey to obtain the perspective of different software users regarding the strengths and limitations of the most widely used transportation modeling packages. They illustrated that there was an increasing demand for sound graphical interface, GIS integration, and land use integration packages, as found in TransCAD and CUBE. Thus, the current study is considered the first to identify the existing safety practices and needs of local transportation agencies and law enforcement offices as part of the effort to implement the SHSP.

## **SURVEY DESIGN AND ADMINISTRATION**

To identify the existing safety practices and needs of local transportation agencies and law enforcement offices, two separate online surveys targeting local transportation agencies and law enforcement offices were designed. Local transportation agencies include both county and city public works departments. Each county public works department constructs and maintains the county's roads, bridges, canals, sidewalks, street signs, pavement markings, traffic signals, and storm-water drainage facilities. The city public works department maintains and improves the city's infrastructure by conducting reviews for plans submitted by the involved county and FDOT.

Both departments have safety-related responsibilities as part of their work. For example, local county agencies rely on police crash reports to identify problematic (i.e., high crash) locations at intersections and corridors based on various crash types. Afterward, they adopt countermeasures as recommended by FDOT and National Cooperative Highway Research Program (NCHRP) reports. Local city departments address traffic safety issues and rely on police reports to identify problematic locations within the borders of the city.

Law enforcement offices have police officers who complete crash reports for every crash. Law enforcement officers deal with traffic safety problems while stressing education and enforcement. For example, they initiate safety programs to alert drivers of potential crash risk, e.g., DON'T TEXT AND DRIVE, and they use speed trailers (i.e., devices that visually display drivers' real-time speeds compared to the speed limit) to enforce speeding violations. Law enforcement officers could also perform crash analysis to assist in their enforcement campaigns by prioritizing the most hazardous intersections with specific safety issues, e.g., speeding, pedestrian crashes, and bicyclist crashes.

According to previous studies, e.g., Mickee (2008), online surveys are preferred for opinionated questionnaires for their cost-efficiency. A comprehensive list of questions in both surveys has been prepared while taking into consideration the criteria provided by Mickee (2008) for designing online survey questions. The list was further shortened to fit the planned completion time of 30 minutes for the local transportation agencies survey and 20 minutes for the law enforcement offices survey. The research team then went through each question with the FDOT project manager from the State Safety Office. The surveys were distributed in the fall of 2011.

To initiate a perspective about the adopted safety analysis procedures, on-site visits to two local transportation agencies in the South Florida region were conducted, which were the Miami-Dade and Broward Counties' Public Works Departments. These two agencies were selected on the basis of: (1) conducting traffic safety analysis as part of their duties and (2) being located in the South Florida region to be close to Florida International University. Face-to-face interaction with the traffic safety engineers in both agencies helped to fine-tune the survey questions. In addition, the two surveys were pretested by sending out the survey links to several graduate students to ensure that the survey instrument worked as intended.

The survey of local transportation agencies was comprehensive, including 39 questions covering the following eight areas of interest:

1. use of crash data
2. identification of high crash locations
3. project selection, implementation, and evaluation
4. crash analysis software systems
5. crash analysis standardization
6. crash analysis documentation
7. training
8. working with FDOT

An invitation email along with a link to the survey questions was sent out to a broad list of local county and city transportation agencies in Florida using the Safety Office Emailing System. Reminder emails were sent to non-responding recipients. A total of 37 responses were received and the responding agencies were geographically diverse, covering the entire state, including five from Northern Florida, 12 from Southern Florida, five from Eastern Florida, seven from Western Florida, and eight from Central Florida. In addition, the agencies represented both rural and urban regions, where the northern region is mostly rural.

The survey targeting law enforcement agencies included 25 questions covering the following four areas of interest:

- a. selection of enforcement locations,
- b. traffic violations and safety campaigns,

- c. crash reports, and
- d. working with local transportation agencies.

The State Safety Office also assisted in sending out the law enforcement agencies survey through each District Community Traffic Safety Team (CTST) coordinator. Florida CTSTs are groups of highway safety advocates who are committed to solving safety problems through a multi-disciplinary approach. The CTST individuals represent each of the four E's and consist of local city, county, state, and private industry representatives, as well as local citizens. Each FDOT district has a CTST coordinator who works closely with the CTSTs in their jurisdiction. The survey was sent out through each district CTST coordinator to a broad list of local law enforcement agencies. Furthermore, to increase the response rate, multiple reminder emails were sent to non-responding recipients.

In total, 46 law enforcement agencies responded to the survey. The responding agencies were classified as 30 county sheriff offices, 14 city and university police departments, and two district offices of the Florida Highway Patrol (FHP). Of the 46 responding agencies, 13 were from Northern Florida, seven were from Southern Florida, 14 were from Eastern Florida, seven were from Western Florida, and five were from Central Florida. Again, the responding agencies were well represented and included different spatially-diverse agencies from across the five geographic regions of Florida. In addition to sending the invitation email, follow-ups were performed to obtain clarifications on some of the responses.

A precise response rate for each survey could not be calculated. The surveys attempted to reach out to as many agencies as possible by making use of existing mailing lists (i.e., the Safety Office Emailing System for distributing the local transportation agencies survey and the assistance of each district CTST coordinator for distributing the law enforcement agencies survey). The precise number of subscriptions in these mailing lists could not be determined as the number of emails in these lists was not made known to the research team. In addition, it is expected that these mailing lists, like any others, are likely to contain a number of invalid emails.

## LOCAL TRANSPORTATION AGENCY SURVEY RESULTS

While the number and type of crashes are readily available, the objectives of the study could only be accomplished through the expert opinions of traffic safety professionals. The survey results for four select areas from the 37 local transportation agencies are summarized in the sections below.

### Crash Analysis Standardization

**Uniformity of Crash Analysis Methods and Procedures.** Local transportation agencies have been using several crash analysis software tools. Some tools that were developed in-house include the Accident Reporting System (ARS), a crash mapping system, and other GIS crash analysis systems.

Identifying the opinions of local transportation agencies about the uniformity of crash analysis methods could help determine the feasibility for statewide standardization of crash analysis methods. As shown in Figure 1(a), over 70% of responding local agencies either agreed or strongly agreed to standardize crash analysis procedures across the state. Close to 25% of the agencies were neutral, while a minority (5%) opposed standardization. It can be inferred that there was a general consensus on standardizing crash analysis methods and procedures across Florida. Important reasons justifying standardization included:

- Standardization would be beneficial when applying for grants.
- Standardization results in consistent, predictable, and repeatable results.
- Standardization provides cost effectiveness.
- Standardization protects analysts from potential liabilities.

On the other hand, the following were some of the opinions that discouraged the standardization process:

- It is difficult for all agencies to have access to the same data.
- There is too much inconsistency between agencies.
- The same methods and procedures might be very expensive for rural counties compared with urban counties.
- A standard method might not work well for all types of safety issues, e.g., fatal crashes.

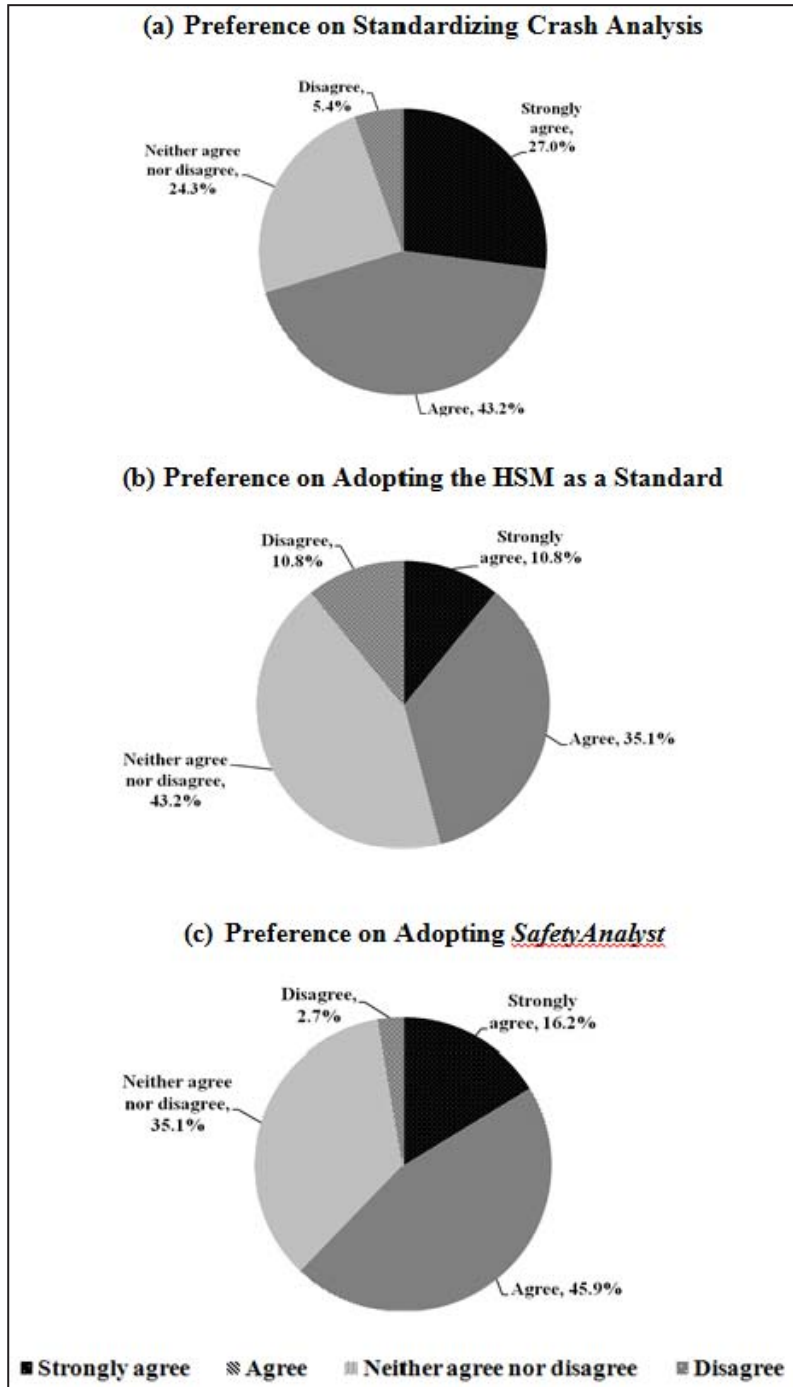
**Adoption of the Highway Safety Manual as Standard for Crash Analysis.** The Highway Safety Manual (HSM) (AASHTO 2010a), released in July 2010, provides analytical tools for quantifying effects of potential changes at individual sites. Although the manual is in the initial stages of its adoption, states and local agencies are looking for ways to implement it. The respondents were provided a link in the survey to the HSM homepage to learn more about the manual. As shown in Figure 1(b), about 46% of responding local agencies either agreed or strongly agreed to adopt the HSM as a standard for crash analysis, 43% were neutral, while the rest (11%) opposed adopting the manual.

Some responding agencies indicated that they support the HSM adoption as it provides the guidelines and specific procedures for conducting crash analysis. Another strong reason to adopt the manual was to maintain consistency in the policies and procedures for evaluations. One of the agencies wished that the HSM adoption would lead to an initiative to set aside local funds to pursue safety projects. On the other hand, the lack of analysis of limited access facilities (i.e., freeways), the lack of state-specific crash reduction factors (CRFs), and the lack of extensive data were the three main reasons for the agencies' existing reluctance in adopting the manual. Of the 37 responding agencies, 11 were unfamiliar with the manual to provide a response.

**Deployment of SafetyAnalyst.** *SafetyAnalyst* (AASHTO 2010b) is a state-of-the-art analytical tool for making system-wide safety decisions that incorporates all the steps in the roadway safety management process. The software incorporates the advanced empirical Bayes (EB) approach and acts as a complete "safety toolbox" for any safety office. Although data requirements are intense, once the data are imported the analyses are easy requiring minimum statistical expertise. Again, the respondents were provided a link in the survey to the *SafetyAnalyst* homepage to learn about the tool.

From Figure 1(c), 62% of responding local agencies either agreed or strongly agreed to take advantage of *SafetyAnalyst*; 35% were neutral and a minority (3%) disagreed. The survey responses showed that the local agencies had a motivation to adopt *SafetyAnalyst*. The agencies hoped that *SafetyAnalyst* could be provided free of charge, along with low-cost training tools. However, at this time, FDOT cannot provide it for free since the tool is maintained by the American Association of State Highway and Transportation Officials (AASHTO).

Figure 1: Pie Charts of Key Survey Results





**Adoption of Standard Web-Based GIS Application.** Since different local agencies adopt multiple GIS systems for crash analysis, it is important to obtain their opinion about standardizing web-based GIS applications. It was found that the majority of responding local agencies (62%) either agreed or strongly agreed on the statewide adoption of a standard web-based GIS system for crash analysis. The responding agencies considered GIS applications to be efficient, accurate, and manageable compared with the existing non-GIS methods. Many agencies also indicated that a GIS system would enable engineers to spatially map crashes, spatially identify crash locations, and produce reports showing traffic crash statistics. Moreover, a web-based GIS system could increase the accuracy of crash data and the speed with which crash data could be obtained and analyzed.

Although most agencies embraced the idea of a standard GIS application, 8% of responding agencies were against it. These agencies were concerned about the costs associated with the tool in addition to the resources to be allocated. One agency felt that a standard GIS system could restrict some of their employees. Further, the non-uniform nature of data being collected and analyzed was considered to be a hurdle to standardize the GIS applications.

If a standard procedure for crash analysis is to be adopted, the respondents identified the following as key issues that have to be accounted for: differences between the old and new crash report forms, crashes involving vulnerable road users (i.e., elderly people, bicyclists, and pedestrians), differences between urban and rural agricultural communities, and lack of short-form crash reports. Note that Florida used to have a standard crash report that had been adopted until December 31, 2010. As of January 1, 2011, a new crash report has been released and is currently the standard for crash reporting. Compared with the previous crash report, the current one is more detailed and requires more time to complete.

### **Training on Crash Analysis**

With the release of the recent safety analysis tools, the HSM and *SafetyAnalyst*, training on their adoption for crash analysis is essential. This section of the survey sought to determine whether FDOT should provide training on crash analysis procedures for local agencies. It was found that more than 90% of responding local agencies either agreed or strongly agreed and the remaining 10% were neutral. The responding agencies were interested in seeking training in the following priority areas:

- thorough analysis of crashes, interpretation of data using statistical methods, and provision of engineering solutions
- use of the HSM and *SafetyAnalyst*
- use of the data in the crash reports
- application of CRFs
- process of conducting field reviews
- use of GIS applications for crash analysis
- methods to improve safety of vulnerable road users, e.g., bicyclists and pedestrians

When asked about the preferred mode of training, a majority of responding agencies (21 agencies) preferred face-to-face meetings, followed by online web-based training and webinars, which received equal preference.

### **Working with FDOT District Office**

A good working relationship between local agencies and state district offices is beneficial in improving the state's traffic safety practice. It was found that 62% of responding local agencies worked with their district office only when a situation arose, 22% held regular meetings for coordination of efforts, 8% held meetings with CTST, while 3% could not recall their recent encounter with their

district office. This shows that more coordination between both major traffic safety stakeholders is beneficial.

When asked about ways to improve traffic safety in each agency's area, 24.5% of local agencies wished to work more closely with FDOT and 13.5% would like to get trained by FDOT. The remaining 62% were already working closely with their respective district offices. This shows that FDOT is successful in coordinating crash analysis across the agencies. Based on their responses, the following were the key barriers that have been preventing the agencies from working closely with their district office, in order of priority:

- lack of funding
- staff limitations
- geographical location of local offices, e.g., the FDOT Central Office is far away from the local agencies
- differences in priorities and concerns
- time constraints
- restricted access to statewide tools and training

Local agencies were also asked about the recommended assistance with FDOT to improve traffic safety in their jurisdictions. Key suggestions, in order of priority, included:

- provide more funding to purchase safety-related equipment and crash analysis software tools
- increase communication, coordination, and information exchange efforts
- provide training courses on safety analysis
- provide more exposure on the Road Safety Audit tools
- implement less restrictive policies
- emphasize safety concerns of vulnerable road users, i.e., pedestrians and bicyclists
- encourage participation in quarterly meetings with the Safety Office and the CTST, and in the Safety Summit meetings (the Safety Summit brings in multi-disciplinary individuals who deal with traffic safety)
- implement a standard crash analysis software that all agencies can use
- prioritize safety-related projects

### **Safety Concerns, High Crash Locations, and Project Selection and Evaluation**

According to the Federal Highway Administration (FHWA) Systemic Safety Project Selection Tool (Preston et al. 2013), the identification of focus crash types and high risk factors is the highest priority in the systemic safety planning process. Furthermore, the prioritization of candidate locations (i.e., identification of high crash locations [HCLs]) and appropriate selection of improvement projects are crucial steps in this process. This is because incorrect identification of HCLs often results in less cost-effective solutions and biased prioritization processes. From the survey responses, the highest safety concerns were speeding-related, distracted driving, intersection-related, and red-light running crashes. Furthermore, the responding agencies identified specific crash types, e.g., pedestrian, bicycle, rear-end, angle, and left-turn crashes, as potential safety concerns. Particularly, speeding, pedestrian and bicycle crashes, and rear-end crashes were commonly listed as major safety issues.

The survey responses also indicated that the majority of local agencies rank HCLs by crash frequency, crash rate, crash type, safety index, or crash severity. Besides these methods, several local transportation agencies used the following approaches:

- use web-based crash analysis systems
- use GIS analysis and compare locations with those published statewide, as well as with specific district
- use observations made by law enforcement officers and field investigations
- directly use the list of HCLs provided by FDOT

- use FDOT crash records
- perform crash analysis only when improvement projects are scheduled or upon request

While selecting safety improvement projects, the majority of responding local agencies (14 agencies) used the benefit-cost (B/C) ratio. Other methods included field visits, requests from citizens and law enforcement officers, CRFs from the HSM, engineering judgment, and Road Safety Audits. Close to 43% of responding agencies evaluated all implemented projects to determine their effectiveness, 30% assumed that treated locations were improved, while 27% evaluated a sample of implemented projects. Local agencies mostly used before-and-after crash data analysis to determine the effectiveness of the implemented countermeasures. Other evaluation procedures included the number of complaints after the improvement projects were implemented, public opinion, field observations, continuous monitoring of locations, and observation of traffic operations following the project implementation.

## Summary of Results

Key findings from the survey of the local transportation agencies were:

- The majority of local agencies were receptive to the idea of standardizing the crash analysis method for agencies in the state.
- Some agencies preferred to consider the HSM as a standard, mandating its adoption, while some others preferred to have the HSM only as a guide, as the HSM analysis was considered to be too cumbersome. Some agencies were also unfamiliar with the HSM to formulate an opinion about its adoption.
- Local agencies were generally interested in adopting *SafetyAnalyst*. For extensive adoption, the responding agencies wished for the software to be provided free of charge along with low-cost training tools.
- The majority of local agencies agreed that a statewide standard web-based GIS system should be adopted for crash analysis.
- The majority of local agencies agreed that FDOT should provide statewide training on crash analysis.
- Face-to-face meetings were by far the most preferable mode of providing training on crash analysis, followed by online training and webinars.
- Providing more funding to local agencies, increasing communication and coordination efforts (i.e., via Road Safety Audits), providing additional training courses, and launching less restrictive policies were the most important needs of the local agencies.
- Speeding, pedestrian crashes, bicycle crashes, and rear-end crashes were the highest safety concerns to the majority of local agencies.
- Agencies have been using different methods for evaluating safety improvement projects.

## LAW ENFORCEMENT OFFICE SURVEY RESULTS

This section summarizes the survey results from 46 law enforcement offices on questions related to enforcement locations, traffic violations, safety campaigns, use of crash reports, and working with transportation agencies.

### Selection of Enforcement Locations

When asked about the specific locations for enforcement of traffic violations, 83% of the responding agencies stated that they regularly focus on specific locations, mostly locations with relatively high prior citation records. However, two-thirds of responding law enforcement agencies analyzed crash records to identify enforcement locations. One of the approaches was to rank the three most

hazardous signalized intersections with respect to total crash count every month, and conduct traffic enforcement at these intersections. After enforcement, one-month before-and-after crash data were compared. Crash data analysis was also performed by time of the day, day of the week, and contributing factors.

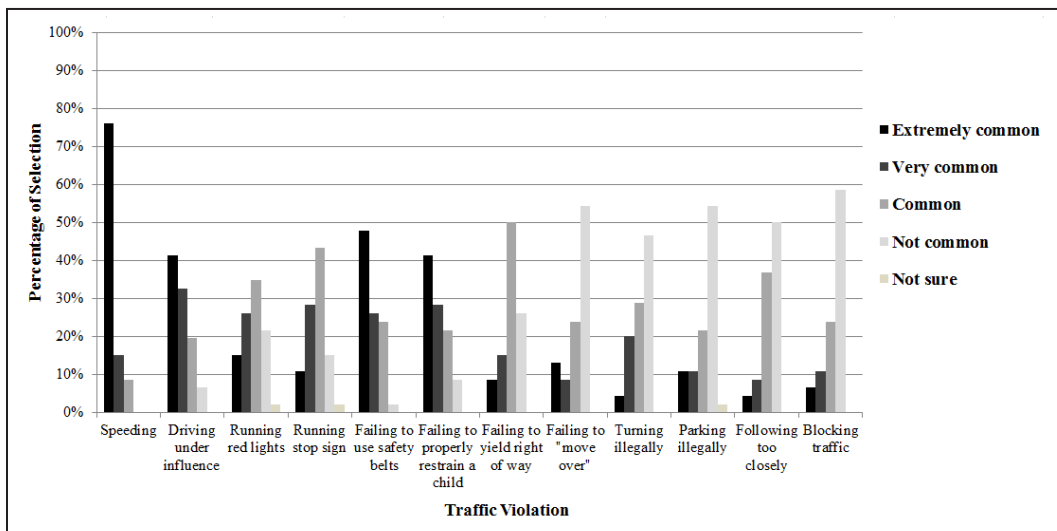
Other popular methods included identifying the top ten locations based on recent short-term crash history. A few law enforcement agencies plotted crashes on GIS maps, while other agencies reviewed actual police reports in addition to analyzing crash summary data. Besides analyzing crash records, several methods were adopted for identifying enforcement locations, such as: citizen complaints, surveys conducted annually to identify HCLs for specific time periods, review of dispatched calls, and the statewide list of HCLs.

Among the above identified methods to identify enforcement locations, 41% of agencies identified citizen complaints as the most common method, followed by frequently observed violations by patrolling officers (33%) and analysis of crash records (22%). Requests from local elected officials were among the least common methods. A majority of respondents (87%) noted that they would make use of FDOT's crash location maps for enforcement, while 7% were neutral. This shows that the majority of the agencies are willing to use the available assistance from FDOT.

## Traffic Violations and Safety Campaigns

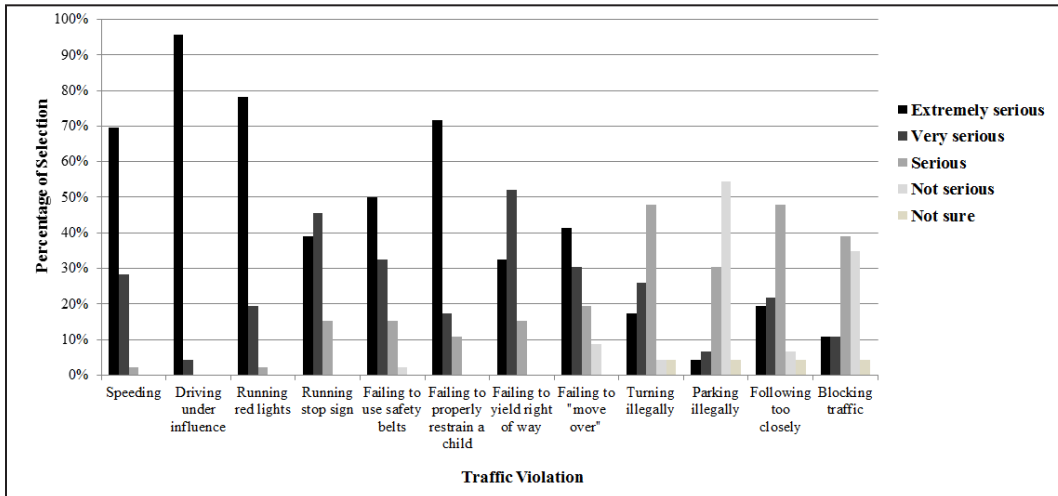
**Frequency and Seriousness of Traffic Violations.** This section identifies the frequency (Figure 2) and seriousness (Figure 3) of different types of traffic violations to highlight the necessary safety campaigns to be prioritized by law enforcement officers. Note that these violations were mainly identified from the standard crash report. The results in Figures 2 and 3 were generated from the responses of the law enforcement officers while calculating the percentage of selection of each traffic violation under each category. It should be noted that both figures were based on the impressions of the respondents, and not based on actual data.

**Figure 2: Frequency of Occurrence of Different Traffic Violations**



As shown in Figure 2, the five most common traffic violations were speeding (75%), failing to use safety belts (50%), failing to properly restrain a child (40%), driving under influence (DUI) (40%), and running red lights (15%). On the other hand, the five most uncommon violations included traffic blockage (60%), failing to move over (55%), illegal parking (55%), following too closely (50%), and illegal turning (45%).

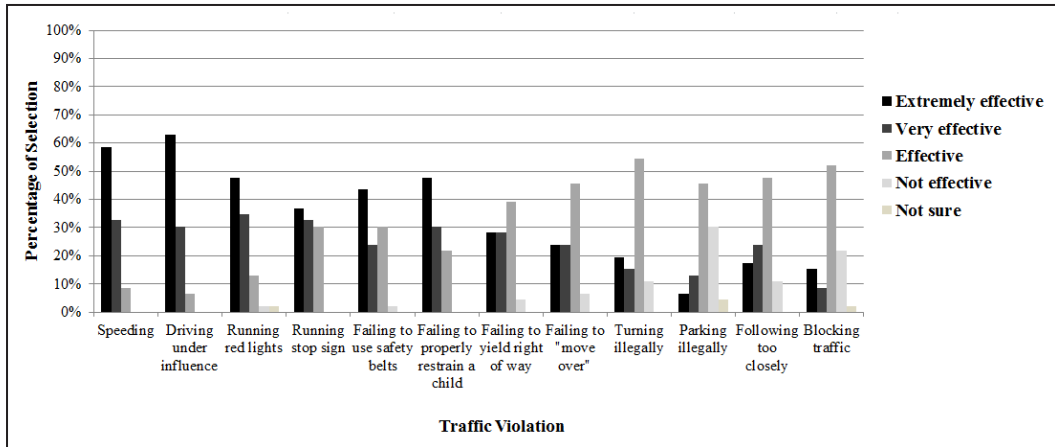
**Figure 3: Seriousness of Different Traffic Violations**



As shown in Figure 3, the extremely serious traffic violations were DUI (95%), running red lights (80%), failing to properly restrain a child (70%), and speeding (70%). The most trivial traffic violations included illegal parking (55%), traffic blockage (35%), failing to move over (10%), following too closely (5%), and illegal turning (5%). The results indicated that DUI, speeding, running red lights, and failure to properly restrain a child were seen as the most serious and most common violations, possibly because they could result in severe injury crashes. DUI was also cited as one of the highest risk factors of road safety in the study by Erke et al. (2009).

**Effectiveness of Enforcement of Traffic Violations.** This section discusses the opinions of law enforcement officers about the effectiveness of enforcing different traffic violations. As shown in Figure 4, the enforcement of DUI and speeding (60% each), running red lights and failure to properly restrain a child (50% each), and failure to use safety belts and running stop sign (40% each) were perceived as extremely effective. On the other hand, enforcement of illegal parking (30%), traffic blockage (20%), following too closely (10%), and illegal turning (10%) were considered ineffective. It is observed that those violations to be strictly enforced were also identified as the most serious violations.

**Figure 4: Effectiveness of Enforcement of Different Traffic Violations**



**Effectiveness of Safety Campaigns.** Law enforcement officers usually conduct safety campaigns to tackle traffic violations. It was found that over two-thirds of the responding agencies follow up with an evaluation to assess the effectiveness of their safety campaigns. Law enforcement officers used several methods for evaluation, which testifies to the diversity of the evaluation procedures implemented. In order of the frequency of adoption, the four common evaluation procedures were:

- comparing reduction in traffic violations pre and post safety campaigns
- conducting pre and post traffic surveys
- comparing before-and-after crash data
- comparing citizen complaints pre and post safety campaigns

### Use of Crash Reports

Law enforcement officers are responsible for completing the crash report, the primary source of information for conducting crash data analysis. Therefore, the training they receive is vital. It was found that 57% of responding officers either agreed or strongly agreed that they received adequate training in completing the crash report, 22% were neutral, while 21% either disagreed or strongly disagreed on receiving adequate training. This indicates that most police officers acquire the required knowledge to fill out a crash report.

The main challenge in filling out a crash report was being lengthy and time-consuming. One interesting response was that “the report is considered difficult to understand without instructions manual.” Another major issue was the time the officers took to do the paperwork or fill out the crash report electronically. On the other hand, the law enforcement officers considered crash location as the most useful information in the crash report, possibly since they could use this information for enforcement purposes. Much of the respondents’ interest was geared toward crash type, crash cause, and manner of collision (or the first harmful event). Further, information on speeding, distracted driving, seatbelt usage, and DUI were of interest to the law enforcement officers.

### Working with Local Transportation Agencies

**Working Relationship with Local Transportation Agencies.** In identifying the current working relationship with local agencies, it was found that 51% of the respondents held regular meetings with local transportation agencies for discussion and coordination of efforts; 29% worked with transportation agencies only when a situation arose; and 20% could not recall their recent encounter



with local transportation agencies. This shows that most law enforcement agencies were proactive in coordinating with local transportation agencies.

It was also observed that most of the barriers hindering the relationship included limited resources (budget, time, and manpower), minimum communication, lack of organized meetings, and politics; however, very few (five) agencies indicated that there were no barriers. To improve traffic safety, the law enforcement agencies provided the following key suggestions to local transportation agencies:

- organize more meetings with transportation agencies, e.g., through Road Safety Audits
- provide more assistance at DUI and safety check points
- provide more funding, e.g., to allow education and enforcement for pedestrians and bicyclists
- report any changes in the roadway cross-section/design
- receive continuous updates about changing traffic laws

**Technical Assistance from FDOT.** From the survey responses, it was noticed that the law enforcement community was interested in getting assistance from FDOT to help improve traffic safety and crash reporting. Specifically, the law enforcement officers were interested in technical assistance from FDOT on:

- up-to-date crash statistics in the jurisdiction's region
- funding to purchase items for traffic safety
- information on traffic counts and local crash data
- crime and traffic mapping

As for the software tools, the law enforcement agencies would like to be provided with:

- online crash database
- maps
- electronic crash reports
- electronic ticket writer for crash reporting
- major traffic tracking software for smaller agencies
- standard computer program to fill out and retrieve crash reports

## Summary of Results

The following were the key findings from the survey of the law enforcement community:

- Most law enforcement officers monitor locations with high prior citation records.
- Citizen complaints, observed frequent violations by patrolling officers, and analysis of crash data were the most common methods of selecting enforcement locations.
- The majority of agencies were interested in receiving assistance from FDOT for enforcement purposes, e.g., using the HCL maps provided by FDOT.
- Speeding, failing to use safety belts, failing to properly restrain a child, and DUI were the most common violations.
- Traffic blockage, failing to move over, illegal parking, and following too closely were the least common violations.
- Enforcement of DUI, speeding, running red lights, and failure to properly restrain a child were perceived as the most effective measures to improve traffic safety.
- Enforcement of illegal parking, traffic blockage, following too closely, and illegal turning were considered to be least-effective in improving traffic safety.
- DUI and running red lights were the most serious traffic violations.
- Most agencies followed up with an evaluation to assess the effectiveness of the implemented safety campaigns.

- The most useful information in the crash report for the majority of law enforcement officers was the crash location.
- The majority of agencies held regular meetings with local transportation agencies for coordination of efforts.
- The majority of agencies emphasized a need to organize more meetings with transportation agencies and to get more assistance from them, especially at DUI and safety checkpoints.
- The police officers desired technical assistance from FDOT, which mainly included up-to-date crash statistics and funding to purchase items for traffic safety.

## CONCLUSIONS

The SHSP aims to integrate the four E's of highway safety: engineering, education, enforcement, and EMS. To implement SHSP, state DOTs are increasingly looking to reach out to local agencies and law enforcement officials. This paper described an effort by FDOT to identify the existing safety practices and needs of local transportation agencies and law enforcement offices in Florida. This study attempted to find out current traffic safety practices and needs from the perspective of local transportation and law enforcement agencies. Two online surveys were developed targeting local transportation agencies and the law enforcement community in Florida. Both surveys are easily transferable to a larger audience in other state DOTs that are willing to reach out to their local agencies. Furthermore, both surveys supplement SHSP's effort with ways to improve the coordination between various safety agencies (i.e., state DOTs, local transportation, and law enforcement) to enhance traffic safety on all public roads.

Both the local transportation agencies and the law enforcement agencies emphasized the need to organize more frequent Road Safety Audit meetings to proactively improve traffic safety of public roads. In addition, both agencies agreed that speeding-related crashes were of highest safety concern and their continuous enforcement would be a major benefit. Also, conducting extensive campaigns to reduce DUI, running red lights, failure to properly restrain a child, running stop sign, and failure to use safety belts violations could be beneficial. Although some local agencies were reluctant to adopt the HSM and *SafetyAnalyst* due to extensive data requirements, required statistical expertise, and resource constraints, adequate training on these tools is expected to encourage their adoption.

Survey responses from local agencies revealed that over 70% of responding agencies agreed to standardize crash analysis procedures and over 90% agreed that FDOT should provide statewide training on crash analysis, and face-to-face meetings were by far the most preferable mode of training. The law enforcement agencies survey responses showed that speeding, failing to use safety belts, failing to properly restrain a child, and DUI were the most common violations. Law enforcement officers use diverse evaluation procedures to assess effectiveness of safety campaigns, such as comparing before-and-after crash data and comparing reduction in traffic violations pre and post safety campaigns. Two-thirds of responding law enforcement agencies analyzed crash records to identify enforcement locations. Besides analyzing crash records, citizen complaints, surveys, review of dispatched calls, and the FDOT list of HCLs were the other methods used to identify locations for enforcement.

The study identified several important lessons for other state DOTs to consider in order to improve traffic safety analysis procedures and practices. For example, one of the lessons learned from both survey responses is to improve coordination between various districts and related local transportation agencies, as well as between transportation agencies and the law enforcement community. This coordination could be organized via face-to-face meetings or webinars to discuss commonly identified safety issues and possible solutions, changes in the roadway cross-section, and changes in traffic laws. The study also highlighted suggestions from local agencies for better assistance with state DOTs, e.g., provision of training courses on safety analysis, greater exposure to the Road Safety Audit tools, more flexible information exchange, and provision of police reports

in a timely manner. In addition, addressing law enforcement officers' concerns about police reports and training police officers to correctly code the crash report are essential to improve the accuracy in crash reporting. More funding for local transportation and law enforcement agencies to conduct safety studies is also essential.

Results from the two surveys could be directed toward crash standardization, e.g., for inter-agency collaboration and data sharing. Based on the survey results, state DOTs could compare and identify the common practices and needs of the local transportation agencies and law enforcement agencies to assist in standardizing crash analysis procedures. Further research efforts could compare the results from this study with those from other states to determine how the crash analysis practices and needs vary and concur across states.

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**Kirolos Haleem** is a research associate in the Department of Civil and Environmental Engineering at Florida International University (FIU), Miami. Haleem received his master's and Ph.D. degrees in civil engineering from the University of Central Florida (UCF) in 2007 and 2009, respectively. His areas of expertise are traffic safety analysis, application of statistical models and data mining techniques in transportation engineering, traffic operations, traffic simulation, and ITS. At FIU, he conducts traffic safety research and supervises Ph.D. and master's students.

**Albert Gan** is a professor of transportation engineering in the Department of Civil and Environmental Engineering at Florida International University (FIU) and is also the deputy director of the Lehman Center for Transportation Research at FIU. Gan's areas of research include highway safety, traffic simulation, ITS, GIS, transit planning, and demand modeling. He has authored or co-authored more than 150 refereed papers, technical reports, and articles.

**Priyanka Alluri** is a research associate in the Department of Civil and Environmental Engineering at Florida International University, Miami. Alluri graduated with a Ph.D. in civil engineering focusing on transportation safety from Clemson University, South Carolina. Her research interests include safety data analysis, development of SPFs and CMFs, applications of the Highway Safety Manual and SafetyAnalyst, trends in highway safety, GIS in transportation safety, and human factors and driving behavior.

**Dibakar Saha** is a senior Ph.D. student at Florida International University, Miami, with emphasis in transportation engineering. His research interests mainly focus on highway traffic safety analysis and ITS.





# An Optimization Approach Applied to Fair Division Transportation Funding Allocation Models

by Carlos M. Chang and Edith Montes

*The problem of multiple necessities and limited funds is common in the transportation field. Funding allocation for a transportation agency often involves prioritizing the allocation of funds across a number of participants who have their own needs and preferences. If a participant believes that the final allocation is unfair, then this perception could result in the generation of envy. In this paper, a genetic optimization technique is applied to a Fair Division Transportation Funding Allocation Model (FDTFAM) to minimize the total envy based on the participant's own priorities and the budget constraints.*

## INTRODUCTION

The problem of distributing limited funds across a number of participants with their own priorities is a common management problem. This dilemma has always been an issue for decision makers when allocating funds. The funding allocation problem is usually addressed by decision makers using expert judgment, which involves either subjective criteria, weighted formulas with pre-established priorities, or a combination of both. To obtain consensus on the funding allocation criteria is very difficult due to multiple interests and different perspectives from each participant requesting the funds.

Traditional transportation funding allocation methods generally use formulas based on population and number of highway miles managed by the participant. However, these methods may result in more funding to larger cities or districts. This outcome may be perceived as unfair by smaller cities or districts. This perception regarding the final allocation of funds could result in the generation of envy. Envy is felt by a participant if he or she perceives that less funding is received when compared with other participants. In terms of financial allocation, envy is the expression of an unbalanced distribution of funds affecting the overall economic growth in the region with the addition of social discomfort. This paper provides an innovative funding allocation approach based on fair division methods. The approach considers individual preferences from the participants to prioritize the projects requested for funding. The objective is to minimize the envy received by each participant under budget constraints. The mathematical formulation of envy and the funding allocation model used to minimize the total envy, and the application of an optimization genetic technique to solve the model are major contributions of this research.

## Envy Definition

Envy is expressed in terms of the differences among allocated to requested ratios of each participant. The higher the envy, the higher the difference between each participant's ratios of allocated to requested funds. These ratios represent the percentage that each participant received with respect to total requested funds; i.e., a 1.0 ratio means that the participant received 100% of the requested funds and there is no envy felt by this participant.

FDTFAM uses Equation 1 to calculate the envy felt by the  $i^{th}$  participant with respect to the  $j^{th}$  participant. For instance, if the  $i^{th}$  participant received less than the  $j^{th}$  participant, then participant  $i$

will feel envy of participant  $j$ . However, if participant  $i$  received more than participant  $j$ , no envy is felt from  $i$  to  $j$ .

$$(1) \quad \varepsilon_{ij} = \{|\rho_i - \rho_j|\}$$

where:

$\rho_i$  = Allocated to requested funding ratio of  $i^{\text{th}}$  participant

$\rho_j$  = Allocated to requested funding ratio of  $j^{\text{th}}$  participant

$\varepsilon_{ij}$  = envy perceived by the  $i^{\text{th}}$  with respect to the  $j^{\text{th}}$  participant only if  $(\rho_i - \rho_j) < 0$ , 0 otherwise

## FUNDING ALLOCATION METHODS IN TRANSPORTATION PROJECTS

There are different methods to approach funding allocation. Traditional methods include formulas set by a given agency to prioritize projects requested for funding. These formulas assign weights to performance measures or indicators to determine the level of priority for each individual project. However, these methods may lead to the public's disagreement if decisions are perceived as unfair or not equitable. On the other hand, optimization methods are meant to maximize or minimize a given objective. Generally, these methods are used to maximize benefits with budget constraints or to minimize costs subjected to certain constraints. Optimization methods aim to provide optimal solutions to a given problem.

Chan et al. (2003) suggests a genetic-algorithm (GA) optimization solving technique to allocate the total funds available to the district agencies in order to achieve target performance. The funding allocation problem considers the overall objective of the agency as well as the district target objectives by using a two-stage algorithm. The first stage uses the regional or district objectives and constraints to generate possible solutions to the problem. Then, the second stage analyzes the solutions obtained in the first stage using the objectives and constraints of the individual agencies. The results of the proposed technique is shown in terms of the network pavement condition and compared to the results of typical funding allocation methods. This paper shows an innovative solution method; however, the two-stage algorithm cannot be used to solve multi-objective problems while solving all objectives simultaneously. Tsunokawa and Van Hiep (2008) presented an optimization approach for the allocation of a system-wide budget among road assets. This method uses the net present value (NPV) as the common denominator for prioritizing the funding allocation in all asset subsystems. Using an asset subsystem optimizer (ASSO), the NPVs are used to generate the NPV functions to find the optimal allocation among all subsystems. Once the optimal budget allocation is obtained, the ASSO is used to find the optimal management strategy using the optimally allocated budget.

Most recently, innovative funding allocation methods have been used to maximize the benefits of funds invested in projects. Despite the method used for maximizing funding allocation, there is a pre-established criteria that applies to all the participants when setting priorities for project selection. Individual preferences of participants may be based on a different criteria based on their own perspective and local needs. This paper presents a fair division funding allocation transportation model (FDTFAM) to incorporate individual preferences in the decision-making process. The model is based on fair division concepts of proportionality, envy-freeness, equitability, and efficiency.

## LITERATURE REVIEW ON ENVY AND FAIR ALLOCATION METHODS

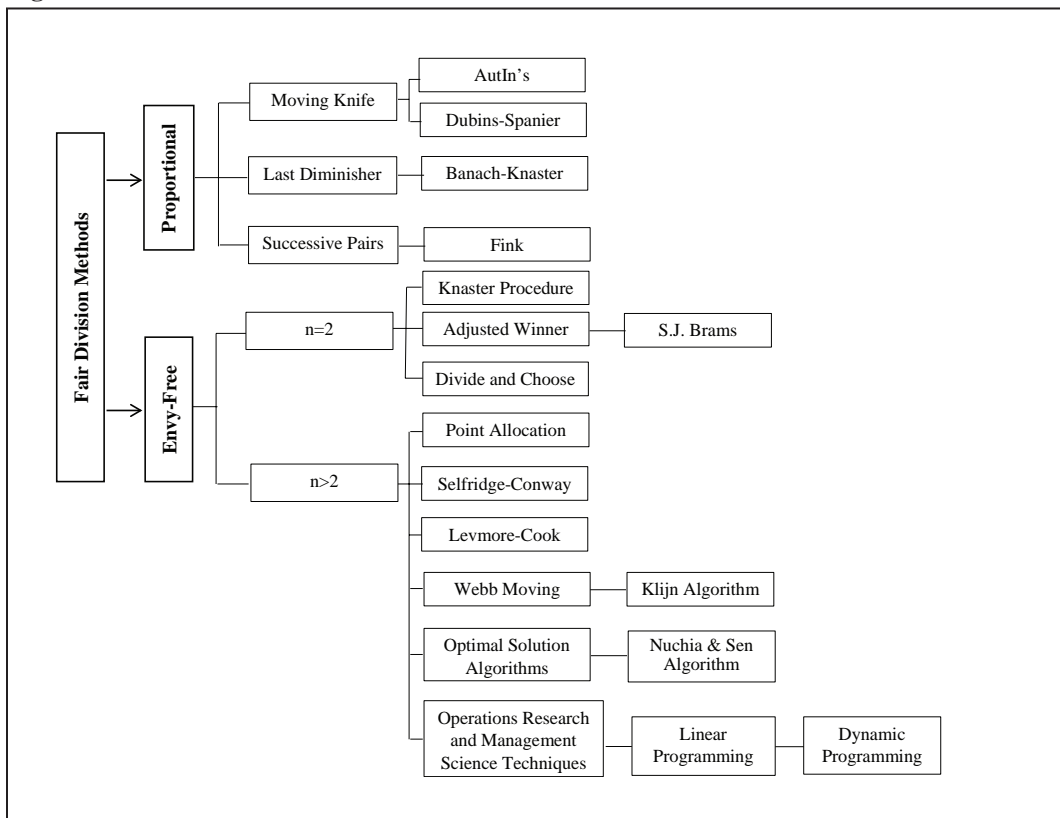
The problem of dividing resources fairly can be generalized by defining the allocation of a resource over  $n$  number of participants expecting to receive a portion of the resource. In order to achieve fair division, it is desired that the procedure implemented satisfies four requirements. First, the procedure must lead to a proportional distribution, i.e., each participant expects to receive at least  $1/n$  of the resource. Second, the procedure must be envy-free, i.e., each participant believes that the

received amount is fair and there is no reason to exchange their share. Third, the procedure must be equitable; i.e., individual valuation of the portion received by one participant is equal to the valuation of the other participants. Fourth, the procedure must be efficient or Pareto optimal, i.e., no other allocation would benefit one participant without affecting another (Nuchia and Sen 2001). The achievement of these four fair division characteristics simultaneously could be guaranteed only for two participants (Dupuis-Roy and Gosselin 2009). In most real problems, there are more than two participants, and it is very unlikely in practice to fully achieve proportional, envy-free, equitable, and efficient solutions (Brams and Taylor 1996).

There are several fair division theoretical methods that attempt to solve the problem of dividing any type of resource among several participants while trying to achieve a proportional, equitable, fair, and envy-free allocation for all. These methods have been used to achieve a fair allocation of divisible and indivisible goods, such as the Divide and Choose Procedure (Barbanel and Brams 2004), the Moving Knife (Barbanel and Brams 2004), the Last-Diminisher “Trimming Algorithm” (Austin 1982), the Successive Pairs Algorithm (Austin 1982), the Knaster’s Procedure (Brams and Taylor 1996), the Adjusted Winner (AW) Procedure (Brams and Taylor 1993), and the Point Allocation (Saunders 2011).

All fair division methodologies strive to make allocations based on two main characteristics: proportionality or envy-freeness. Therefore, fair allocation methods can be classified into two groups: proportional and envy-free methods. A proportional allocation method attempts to assign the funds in a manner that all the participants receive the same amount. An envy-free allocation method strives to distribute the items based on the participants’ preferences; funds are assigned to the participant who shows more desire for it. Figure 1 shows an overview diagram of current fair division methods (Chang et al. 2011).

**Figure 1: Overview of Fair Division Allocation Methods**



## Proportional Methods

**The Moving Knife.** The moving knife procedure is inspired and illustrated by the process of how to fairly divide a cake among several participants and to satisfy preferences with the fewer amounts of cuts (Barbanel and Brams 2004). To illustrate this procedure, consider that a resource  $A$  is a rectangular cake of length  $X$  with constant width. It is to be divided into  $x_n$  pieces; where  $n$  represents the number of participants. In order to divide the cake, one of the participants places a knife on the left side of the cake and perpendicular to the length  $X$ . Then, the participant moves the knife continuously to the right of the cake and makes a cut when one of the other players calls for it. It is perceived that the knife has moved a distance  $x_i$  that yields at least  $1/n$  of the cake (Barbanel and Brams 2004). After the cut is made, the piece is given to whoever placed the call and then leaves. If two or more persons call for a cut, the piece will be given randomly to one of them. This process continues for  $n-1$  remaining participants until one participant is left.

**Last-Diminisher “Trimming Algorithm.”** The Last-Diminisher trimming algorithm method is not continuous. In this procedure, participant 1 cuts a piece of size  $1/n$  and participant 2 takes the piece and trims it if he believes that its size is greater than  $1/n$ . The piece is passed successively and trimmed until it reaches Participant  $n-1$ . The participant  $n$  can take the piece to conclude, otherwise it is allocated to the last person who trimmed it. This process is repeated with the remaining pieces until only one participant is left (Austin 1982).

**Successive Pairs Algorithm.** In this method, the problem considers that a resource has already been divided among  $n$  participants and each participant owns at least  $1/n$ . Let's assume that a new participant is included in the division of the resource. Now, the resource has to be distributed for  $n+1$  participants. Consequently the original participants share has been converted to  $1/(n-1)$ . Participants 1 through  $n-1$  are now required to divide their pieces into  $n+1$  equal parts. After this division has been performed, the new participant is allowed to choose one part from participants 1 through  $n-1$ . This will guarantee that each of the participants receives at least  $(n)/(n+1)$  from  $1/(n)$  (Austin 1982).

Proportional methods assume that the goods are divisible; but in the real world, a combination of divisible and non-divisible goods is very common, e.g., machinery, equipment, and buildings. Proportional methods are useful when the item to be distributed is continuous. The other main limitation of proportional methods is that they only guarantee envy-free allocations in distributions between two participants (Brams and Taylor 1996).

## Envy-free Methods

**Knaster's Procedure.** In Knaster's procedure, there is a set of assets  $A$  that have to be distributed among  $P$  participants. The Knaster's procedure resembles an auction because each good is assigned to the highest bidder. The total funds to be allocated is divided among the participants and requires that each individual owns some initial amount of money placed as a deposit. This deposit is used to pay those individuals who receive less or nothing at the end of the bidding as compared to everybody else (Chang et al. 2011).

**Adjusted Winner (AW) Procedure.** The AW algorithm was proposed by Brams and Taylor (1994) to provide an envy-free, equitable, and efficient solution. The goods are divided as in the Knaster's procedure without the need of a deposit, and then adjusted to make the number of points of each participant equal to each other (i.e., the goods are redistributed to achieve equitability).

**Divide and Choose Protocols.** The Divide and Choose method where “one divides and the other chooses” is one of the oldest methods. In this method, each participant receives at least  $1/n$  of the

good in question, where  $n$  is the number of participants. The proportion is defined by the participants' own evaluation. Let's consider the problem where two individuals resolve to share a divisible good. This problem can easily be solved in two steps: first, one participant divides the good, and then the second participant chooses the share portion (Barbanel and Brams 2004).

**Point Allocation.** In point allocation, a hypothetical number of points, e.g., 3, 5, or 10 are used to formulate a preference list by each participant. This allocation is based strictly upon decision makers' judgments. In this procedure, each participant assigns a value to any good in consideration; then, the participant with the highest scores per good obtain the corresponding item. An envy ratio (assigned score to actual score) is calculated to assess the envy-freeness of the allocation (Saunders 2011).

**Envy-Free and Optimal Solution Algorithms.** Fair division methods aim to achieve envy-freeness in the allocation of goods; however, it does not provide optimal solutions. The development of algorithms that improves envy-free and efficient allocations at the same time has gained more interest. Procedures which contain similar notions to Knaster's have been developed to find envy-free and efficient solutions to the fair division problem. Aragones (1995) proposed an algorithm that finds envy-free solutions where the number of participants is equal to the number of items. The items are a set of indivisible objects and a fix monetary amount. The benefit that the participants receive from the allocation is approximated by a quasi-linear utility function. To be initialized, the algorithm requires a Pareto efficient allocation of the resources. Another algorithm developed to determine envy-free and efficient allocations was proposed by Klijn (2000). This algorithm was developed for resource allocation in the public sector (Foley 1967) to achieve equity, envy, and efficiency, and was based in a derivation of the money Rawlsian solution (Varian 1974). Klijn's algorithm is similar to Aragones's but it does require an initial Pareto allocation of the objects. It is set with a random allocation followed by a directed graph with nodes that correspond to the objects. The vertices of this graph represent the indifference or envy among the participants. The algorithm eliminates the envy vertices in order to provide an envy-free and efficient allocation solution.

Another approach to improve envy-free procedures was proposed by Nuchia and Sen (2001). In their approach, the participants are referred to as agents. A two-stage protocol is used to identify all possible exchanges between the agents in order to improve the efficiency in envy-free allocation procedures. A graph  $G = (V, E)$  is defined where the vertices represent the agents. Each vertex is assigned a weight representing the net gain in utilities from a possible envy-free exchange. The exchange is possible only if both agents have a gain in utilities. The iteration of the protocol continues until no additional improvement can be achieved.

**Application of Optimization Solving Techniques to Fair Division Methods.** Fair division methods are difficult to solve when trying to achieve a perfect envy-free result. Different optimization techniques could be applied as a solving technique to fair division problems. For example, a linear programming approach using the concepts of side payments was developed by Kuhn (1967). In 2007, the problem of allocating indivisible objects between two participants was formulated as an Integer Linear Programming problem in Dall'Aglia and Mosca (2007). In this technique, dynamic programming is used in combination with a branch and bound technique (Adjusted Winner procedure) to find an optimal solution using the backtracking procedure of the knapsack algorithm.

The common fair division problem tends to be NP-complete (Nondeterministic Polynomial) and desires to minimize envy (Vetschera 2010). There are no fast solutions known for NP-complete problems. However, there are several approaches to achieve a fair division of goods minimizing envy among participants. For example, Lipton et al. (2004) focus on setting an upper bound to minimize envy in which the bound is determined by a utility function. Nevertheless, this algorithm is only useful when the participants' utility functions are the same. Rudolph Vetschera (2010) considered the fair division problem with

two participants for a set of indivisible items and applied a branch and bound technique to solve the problem. In this approach, the bounds ignore the indivisibility of the items and the different participants' valuations.

As we have described, the literature review on fair division methods is very broad but focused mainly on theory and abstract examples. In a real situation, there are usually more than two participants requesting funds and competing for indivisible projects. Therefore, it is very unlikely to fully achieve simultaneously the four fair division characteristics of proportional, envy-free, equitable, and efficient solutions when there are several participants requesting funds. In spite of this limitation, the application of fair division methods strive to make allocations among several participants focusing mainly on proportionality and envy-freeness.

## THE FAIR DIVISION TRANSPORTATION FUNDING ALLOCATION MODEL

Fair division models aim to provide a fair share of the resource based on the own participant's valuation of the resource; therefore, they will not envy the others. Envy occurs when a participant feels that the share received is unfair when compared with the others. Börgers (2010) and Brams & Taylor (1996) describe that a fair share of a particular participant could be represented as his/her own valuation of the resource divided by the total number of participants.

The Fair Division Transportation Funding Allocation Model (FDTFAM) combines concepts of the Point Allocation and Adjusted Winner (AW) methods. FDTFAM applies the Point Allocation concepts to define the preferences of the participants. Preference or desirability of a project represents how desirable a certain project is to the participant based on his/her own criteria, and it is expressed by distributing a total of 100 points among the projects in the participant's wish list (Chang et al. 2011). The concepts of the AW method are used to minimize the envy. The optimum solution of the FDTFAM looks for envy-free, equitable, and efficient allocations taking into consideration the participant's preference or desirability.

### FDTFAM Mathematical Formulation

FDTFAM aims to minimize total envy and to maximize the participants' desirability subjected to budget constraints. Desirability represents how desirable a certain project is to the participant. The mathematical model of the FDTFAM is shown in Equations 2 through 6. These equations were inspired by the envy definitions (Brams and Taylor 1996) and the point allocation method (Saunders 2011).

$$(2) \text{ Maximize } D : \sum_{i=1}^N P_{ik} X_{ik}$$

$$(3) \text{ Minimize } E : \sum_{i=1}^N \varepsilon_i X_{ik}$$

Subject to:

$$(4) \sum_{i=1}^N C_{ik} X_{ik} \leq b \quad k = 1, 2, 3, \dots, m$$



$$(5) \sum_{k=1}^m X_{ik} \geq 1 \quad \forall i = 1, 2, \dots, n$$

$$(6) X_{ik} \in \{0, 1\}$$

Where:

E = objective function for minimizing total envy

D = objective function for maximizing total desirability of projects selected for funding

$\varepsilon_i$  = envy perceived by the  $i^{th}$  participant

$P_{ik}$  = desirability assigned by participant  $i$  to project  $k$

$X_{ik}$  = 1 if participant  $i$  requested project  $k$  and funds are allocated; 0 otherwise

$C_{ik}$  = cost assigned by participant  $i$  to project  $k$

$b$  = total budget available

$i$  = represents each participant

$N$  = total number of participants

$k$  = represents each project requested by the participant

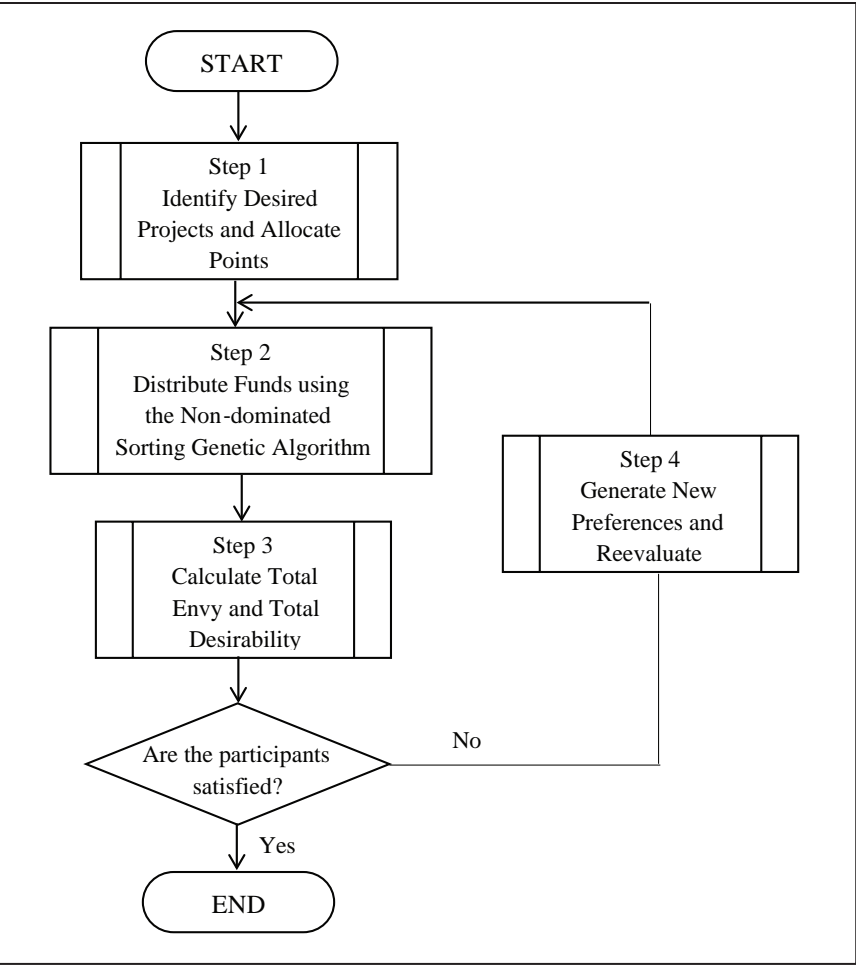
$m$  = total number of projects requested by a participant

FDTFAM will result in a low overall envy by selecting projects with high desirability based on the participant's individual preferences. Participants are given 100 points to distribute among their wish lists of projects to express their desirability or preferences. The points assigned to a project measure the desirability or preference that a participant has for that project. Higher desirability is expressed by a higher assignment of points. In this method, each participant follows his/her own criteria to prioritize the projects requested for funding.

### Funding Allocation and Total Envy

Envy ratios are calculated in the process and added together to calculate the total envy produced by the final allocation of funds. Also, the total desirability is calculated by adding the preference points that each participant obtained at the end of the funding allocation process. If the total envy due to the allocation is equal to zero, or the participants are satisfied with the allocated funds, then the process stops; if not, another wish list of ranked projects with assigned points is requested of the participants. In practice, it is very unlikely to achieve a total envy equal to zero when allocation involves more than two participants. Therefore, the process is repeated until all the participants are satisfied, or envy is minimized, with the final allocation. Figure 2 shows a flow chart summarizing the steps of the funding allocation process.

**Figure 2: Step by Step Fair Division Transportation Funding Allocation Process**  
(Source: Chang et al. 2011)



**Genetic Solving Technique for the FDTFAM**

The mathematical formulation of FDTFAM is solved using a Non-dominated Sorting Genetic Algorithm (NSGA-II). Genetic algorithms provide solutions to multi-objective problems, and are able to search for multiple solutions, thus preventing a local optimum. This algorithm uses an evolutionary process (natural selection) with substitutes for evolutionary operators, including selection, genetic crossover, and genetic mutation. In the selection process, only the best adapted survive; in this case, the answers that best accomplish the goals are recorded and used as possible solutions. The genetic crossover resembles the chromosome interchange taking place in evolution, possible individual solutions are interchanged in random sets of alternative solutions. The genetic mutation resembles a random mutation in an individual; in this case, it leads to a different solution from a random set of solutions. The population is sorted into a hierarchy of sub-populations based on the ordering of Pareto dominance. A solution is Pareto dominated if the solution increases the allocations of one participant while making the other participants' allocations decrease. Once the population is sorted, the members of each sub-group is evaluated, and the resulting groups and similarities are used to promote a diverse set of non-dominated solutions. NSGA varies from a

simple genetic algorithm only in the manner that the selection operator works. The crossover and mutation operators remain as usual. Before the selection is performed, the population is ranked on the basis of an individual's non-domination. A solution is non-dominated if it improves one objective without affecting the other objectives (Srinivas and Kalyanmoy 1994).

The NSGA-II was used to solve the FDTFAM because it is part of the genetic algorithms. As previously mentioned, this algorithm is recommended for the funding allocation problem because it searches for multiple combinations of solutions by using crossovers and mutations among sets of solutions or populations to guarantee that the solution is not just a local optimum.

## CASE STUDY

A case study is presented in this paper to show the application of FDTFAM to allocate funds among competing projects. FDTFAM can be used by departments of transportation (DOTs), metropolitan planning organizations (MPOs), or any other agency. The methodology was tested by the Texas Department of Transportation (TxDOT) using real data and a number of case scenarios (Chang et al. 2013).

In the case study, 10 participants are competing for funding. It is assumed that the participants are MPOs with different population sizes under their jurisdictions. An MPO is a policy-making organization made up of local government representatives and governmental transportation authorities for urbanized areas with populations greater than 50,000. Small MPOs will have a population of 50,000 to 200,000; medium MPOs a population of 200,001 to 1,000,000; and large MPOs a population greater than 1,000,000. Table 1 shows the population and size of each participant in the case study.

**Table 1: Population and Size Assignment of Participants**

Participant	Population	Size
1	86,793	S
2	120,877	S
3	194,851	S
4	405,027	M
5	405,300	M
6	800,647	M
7	1,714,773	L
8	1,716,289	L
9	6,087,133	L
10	6,539,950	L

Since FDTFAM considers each participant's project preference without requesting their individual criterion to define the priorities, the model is not directly affected by the project location. The number of requested projects, the desirability assigned to each project, and budget constraints are factors that will influence the funding allocation results.

Table 2 describes the five different scenarios used to allocate funds among the projects requested by the 10 participants. The manner that points were assigned to the desired projects by the participants varies in each scenario.

**Table 2: Project Funding Allocation Scenarios**

Scenario	Description
1	All participants assigned preference points to all projects in a range of: 1-15
2	Participant 8 (large region) gave 86 points to the highest cost project, and assigned 1 point to each of the remaining projects. The rest of the participants have same points per projects per category as in scenario 1(point's range: 1-15)
3	Points based on percentage of project cost with respect to total requested
4	Each participant has a different total number of points based on population. The total number of points for each participant was calculated based on the population served. Participant 1 has the smallest population served (86,793) and participant 10 has the largest (6,539,950). So, while participant 1 gets the baseline 100 points, participant 10 gets 7,535 population-based points because it is 75.35 times more populous than participant 1
5	Participant 8 (large region) asks for 15 projects while the rest of the participants only ask for 10 projects. Participant 8 tries to get more funding by increasing the total expected funds

The scenarios were developed to reproduce current practices observed in the recent past. In Scenario 1 the participants show their true preferences. In Scenario 2, one participant tries to manipulate the outcomes to obtain one project funded by assigning almost all of its points to that project. In Scenario 3, participants prioritize their project preferences based on the project costs. In Scenario 4, participants distribute their points among projects based on population. In Scenario 5, a participant tries to manipulate the outcome by requesting more projects than really needed in an attempt to obtain more funds.

To solve this multi-objective optimization problem, SolveXL software was selected due to its technical capabilities, ease of use, and ability to work with Excel spreadsheets. SolveXL is an add-in for Microsoft Excel, which uses evolutionary (genetic) algorithms to solve complex optimization problems. The application is written in C++ and opens an interface to interact with Microsoft Excel. It has a user friendly Wizard with built-in help that allows the user to configure the tool easily and to perform optimization using regular Excel formulas. The model can be set up in the same way as the Excel Solver. SolveXL is able to solve many types of single- and multiple-objective problems using genetic algorithms (SolveXL 2013).

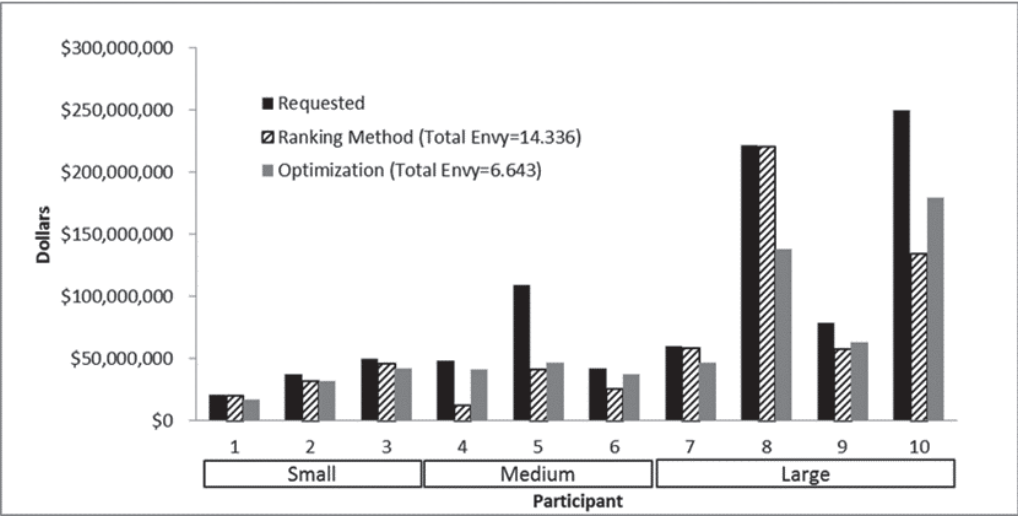
To compare the results obtained by the optimization method, the case study was also solved with a ranking method developed for the Texas Department of Transportation (TxDOT) (Chang et al. 2013). In the ranking method, the projects are ranked from the highest to the lowest desirability based on the distribution of points provided by each participant. The project with the highest desirability is selected for funding first. The second project in the ranked list is “bubble up” to the top of list and selected for funding if money is available. Projects in the wish list continue to “bubble up” for funding until the budget is exhausted, or the ranked list of projects ends. This method is called the Dynamic Bubble Up technique (DBU) because it “bubbles up” projects from the bottom to the top for funding (Chang 2007).

All five scenarios were solved with FDTFAM using the ranking (bubble up technique) and the optimization solving technique for the purpose of comparison. The results obtained in each scenario are summarized as follows.

Scenario 1

In scenario 1, all participants assigned preference points to all projects in a range of 1-15. The results show that the optimization method resulted in a lower total envy of 6.643 as compared with the ranking method, which obtained a total envy of 14.336. Participants that received almost all the requested funds in the ranking method received less funds in the optimization method as shown in Figure 3. It is observed that the small participants received higher allocated amounts of funding, which were very close to the requested funds. This indicates that this group of participants will have the smallest envy. On the other hand, the medium sized participants observed the highest envy. This group had the highest envy because participant 5 requested very high cost projects. The total allocated funds to medium sized participants were even higher than two of the large participants.

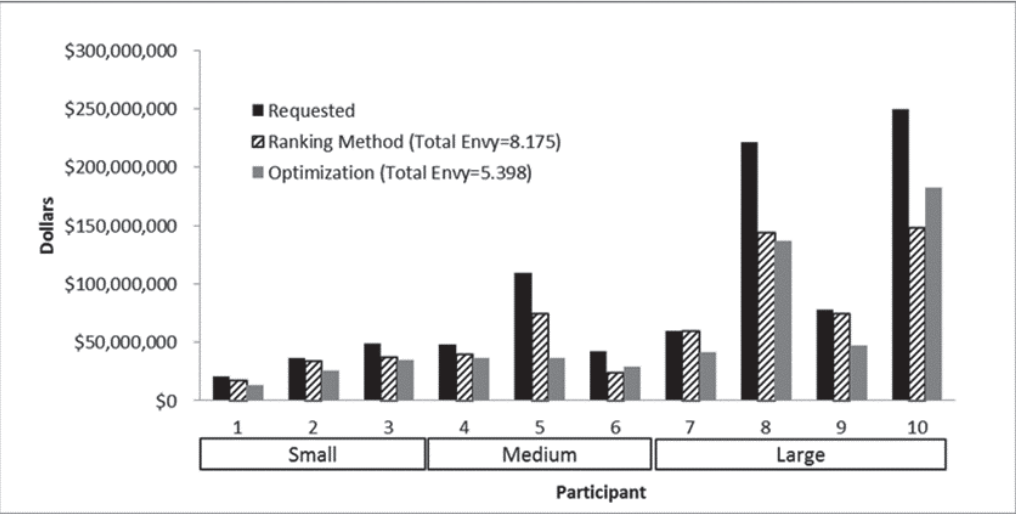
Figure 3: Comparison of Funding Allocation Results in Scenario 1



Scenario 2

In scenario 2, participant 8 (large) assigned its 86 points to the highest cost project, and 1 point to each of the remaining 14 projects. The rest of the participants have the same points per projects as in scenario 1 (points range: 1-15). This scenario simulates a situation in which a participant tries to manipulate the allocation in his/her own favor by assigning very high preference to one project. In this scenario, the optimization method resulted in a lower total envy of 5.398 as compared with the ranking method, which obtained a total envy of 8.175. Participant 8 obtained lower total funds because it assigned very high preference points (86 pts.) to one project. Using the ranking method, participant 8 obtained \$143,800,494 in scenario 2 and \$220,437,683 in scenario 1. In the optimization method, it received \$136,741,309 in scenario 2 and \$137,772,553 in scenario 1. These results are shown in Figures 3 and 4. Participant 8 did receive funding for the project with the highest preference points because the desirability of this project was significantly higher than the other projects but the total funds were lower. In this scenario, the medium-sized participants obtained the highest envy ratios.

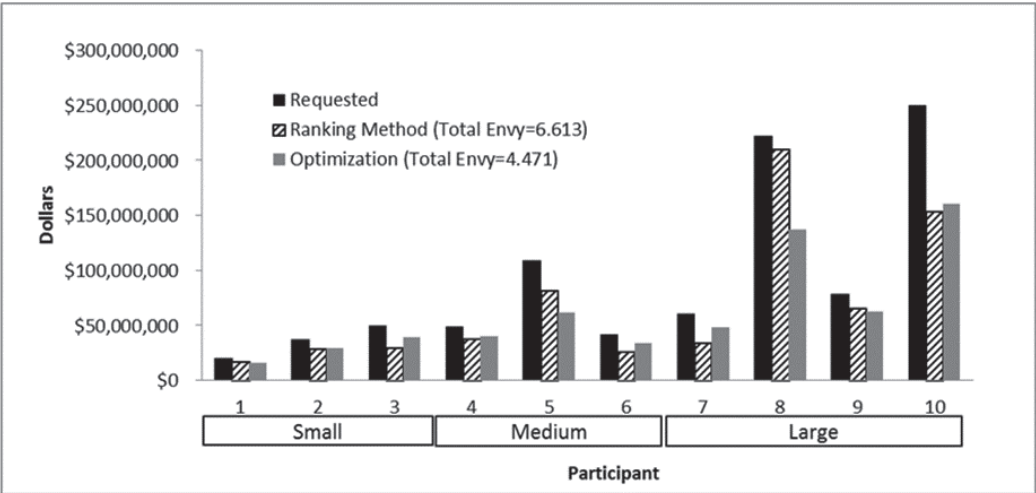
Figure 4: Comparison of Funding Allocation Results in Scenario 2



Scenario 3

In scenario 3, preference points were based on the percentage of the project cost with respect to total funds requested by the participant. The results show that the optimization method resulted in a lower total envy of 4.471 as compared with the ranking method with a total envy of 6.613. This scenario shows the lowest total envy as compared with all the other scenarios. In this scenario, the participant’s preference points are based on the project cost. Projects with higher costs were assigned a higher desirability, resulting in higher allocated/requested ratios. Funding allocation results of scenario 3 are shown in Figure 4. The participants with the highest envy were the large-sized participants.

Figure 5: Comparison of Funding Allocation Results in Scenario 3

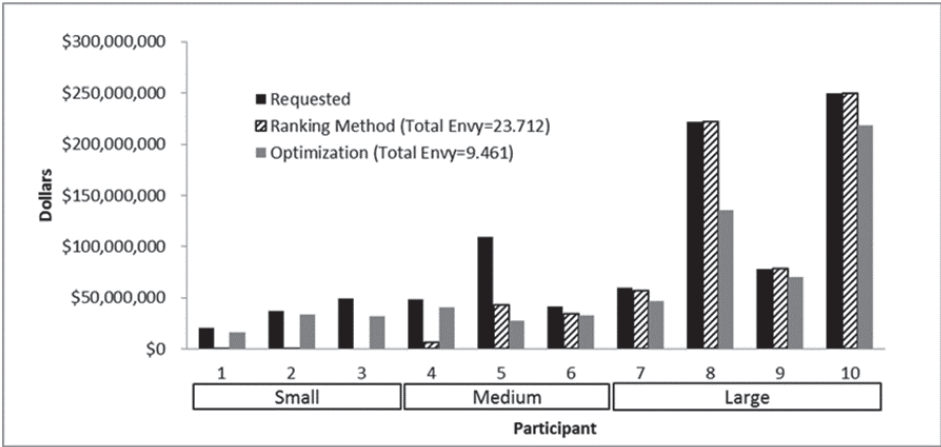




Scenario 4

In scenario 4, each participant had a different total number of points based on population. The total number of points for each participant was calculated based on the population under their jurisdiction. Participant 1 had the smallest population (86,793) and participant 10 had the largest population (6,539,950). For instance, while participant 1 gets the baseline 100 points, participant 10 gets 7,535 population-based points. The optimization method resulted in a total envy of 9.461 and 23.712 with the ranking method. The distribution of points based on the population resulted in a higher total envy because smaller participants received fewer preference points to distribute among projects. Figure 6 shows that large participants obtained almost all their requested funds and the small participants received almost none of the requested funding. This resulted in the highest total envy when compared with other scenarios.

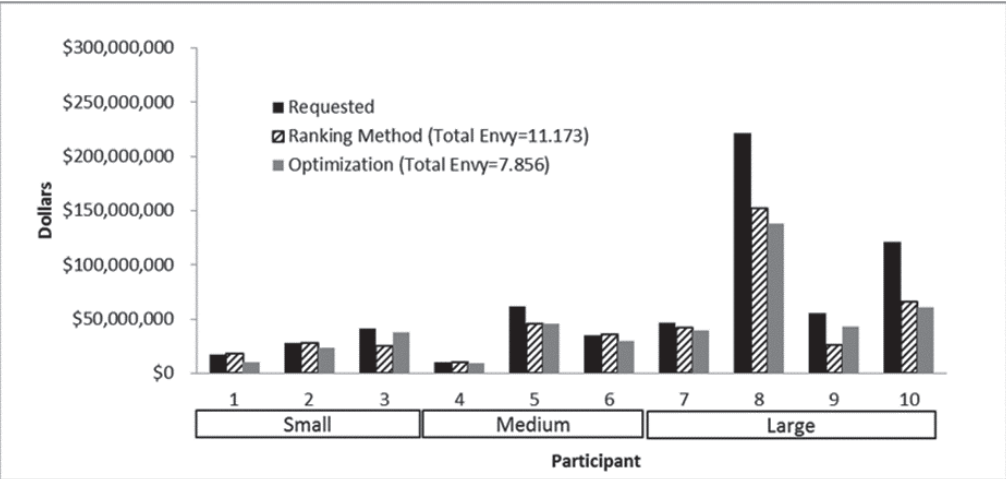
Figure 6: Comparison of Funding Allocation Results in Scenario 4



Scenario 5

In scenario 5, participant 8 (large) requested 15 projects while the rest of the participants only asked for 10 projects. Participant 8 increased the number of projects in an attempt to obtain more funding by increasing the total amount of requested funds. Figure 7 shows that the optimization method resulted in a total envy of 7.856 and the ranking method had 11.173 of total envy. Using the ranking method, participant 8 obtained \$152,087,683 of \$221,587,683 as shown in Figure 6. This represents a lower allocation when compared with scenario 1 where the same participant obtained \$220,437,683 of \$221,587,683. Participant 8 did not obtain extra funding due to the lower points assigned to the projects requested for funding. The largest difference between allocated to requested amounts occurred for large participants (Figure 7). The low allocated/requested ratios for large participants demonstrate that the model cannot be manipulated by increasing the number of projects to obtain more funds. In this scenario, participant 8 requested more projects than the others but had to distribute its 100 points over a larger number of projects than the other participants. This low allocation of points is interpreted by the model as low preference; therefore, no extra funding was allocated for those projects.

Figure 7: Comparison of Funding Allocation Results in Scenario 5



Ranking Versus Optimization as a Solving Technique

Figures 3 through 7 showed the total funds allocated per participant. The results from the ranking and from the optimization methods were compared for each scenario. It was observed that the optimization method did minimize the envy and maximized the project’s desirability. The optimization method provided better results from a fair perspective approach than the ranking method.

Figures 8 and 9 show the results obtained in the ranking and optimization methods per group of participants (small, medium, large). It is observed that total envy is increased in the groups with the largest disadvantage in terms of size, either population or highway miles; for example, participants with a small population or low highway miles. Figure 8 shows that Scenario 4 results in the highest total envy (23.712) since large participants received more funding than small participants. On the other hand, the scenario with the lowest total envy was scenario 3 (6.613) in which desirability was assigned based on the cost of the projects as compared with the total funds requested per participant.

Figure 8: Total Envy per Scenario Using the Ranking Method

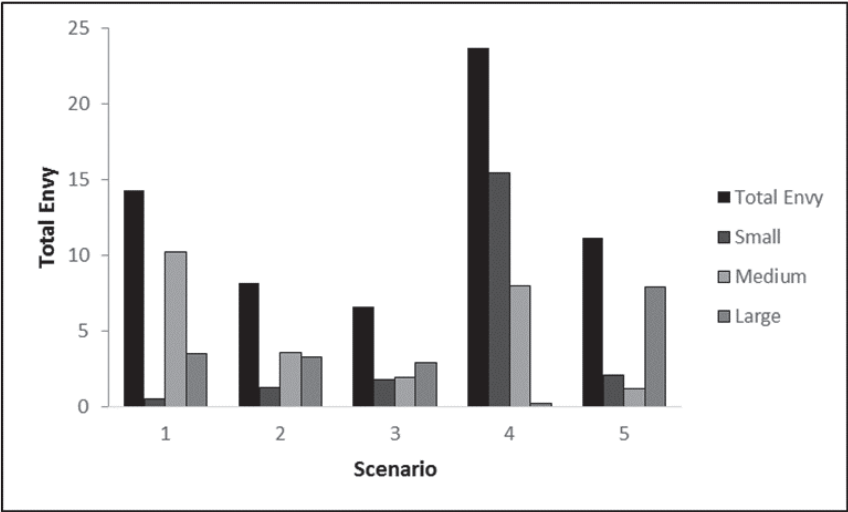
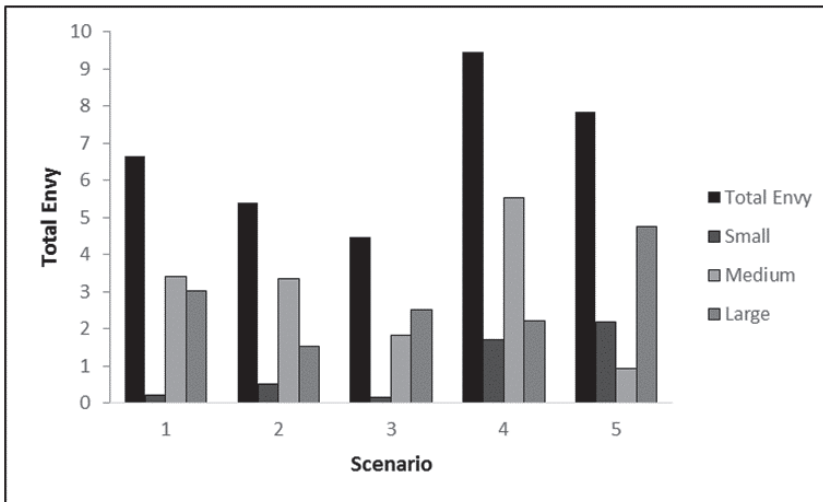


Figure 9 also shows that scenario 4 resulted in the highest total envy (9.461) while scenario 3 in the lowest total envy (4.471). It is worth mentioning that even though the ranking and optimization methods found the same scenarios for the highest and the lowest envy, the selected projects were different. These differences in project selection are caused by the approach used to solve the funding allocation problem. The ranking method maximizes desirability while the optimization method maximizes desirability and minimizes envy at the same time. The projects selected for funding using the optimization method correspond to the optimal solution to the funding allocation problem.

**Figure 9: Total Envy per Scenario Using the Optimization Method**



## CONCLUDING REMARKS

The FDTFAM uses fair division concepts to minimize envy and to maximize the participant's desirability of projects requested for funding. Due to its flexibility, FDTFAM can be applied by agencies in a project-to-project based selection resulting in the highest desirable allocation of funds, and the lowest total envy as perceived by the participants.

FDTFAM can be solved using a Dynamic Bubble-Up Technique, which is based on the ranking method, or an optimization genetic algorithm method. The ranking method strives to maximize desirability per scenario while the optimization method aims to minimize envy and maximize desirability simultaneously. It was observed from the results of the case study that the optimization method provides more even allocated/requested ratios in the final project selection. The smaller differences for allocated/requested ratios among participants result in a lower total envy when compared with the ranking method.

It is also noted that one participant cannot manipulate the fairness of the allocation process. In the absence of knowing the other participant's preferences, attempts at manipulation can result in lower funds allocated to this participant. If a participant tries to trick the allocation process by assigning very high points to only one project or by requesting more funds than really needed, it results in lower total funds allocated to this participant and consequently a higher envy when compared with the other participants.

FDTFAM can be applied at different management levels and in any area of interest in a DOT. The major advantage of FDTFAM is that the individual preferences of each participant are taken into consideration in the funding allocation process. Therefore, the application of FDTFAM to allocate funds among competing projects will result in more proportional, equitable, efficient, and envy-free allocations as perceived by the participants requesting funds. In this sense, FDTFAM is

an alternative approach to traditional methods based on pre-established formulas for prioritizing funding allocations. The implementation of FDTFAM in the funding allocation process will provide decision makers with first-hand information about the participants' project priorities and budget needs. This will result in more defensible project funding allocations when justifying formulated budgets.

## Acknowledgments

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**Carlos M. Chang, Ph.D., P.E.** Dr. Chang is an assistant professor in the Department of Civil Engineering at the University of Texas at El Paso (UTEP). Dr. Chang's major areas of interest are pavement evaluation and design, pavement management, construction management, knowledge management, infrastructure management, and asset management. He conducts research and teaches courses in his areas of expertise. Among his research sponsors are the National Highway Cooperative Research Program, Metropolitan Transportation Commission in California, the Texas Department of Transportation, and the City of El Paso. Dr. Chang is the academic advisor of the Chi Epsilon Chapter at UTEP and member of the American Society of Civil Engineering. He is recognized as an international consultant and has participated as an expert in major highway projects. He is registered as an international consultant at the Inter-American Development Bank. Dr. Chang is the former chair of the International Road Federation Asset Management Task Force. In 2011, 2012, and 2013, Dr. Chang received the "Engineering Award for Connecting Professional Practice and Education" from the National Council of Examiners for Engineering and Surveying.

***Edith Montes** received a bachelor of science degree in civil engineering from the University of Texas at El Paso (UTEP) in May 2011. She is currently working on her master of science in civil engineering at UTEP. Montes is a graduate research assistant in the Department of Civil Engineering of UTEP. Her thesis topic is "Fair Division Methods for Funding Allocation."*

## Book Reviews

*Bergqvist, Rickard, Wilmsmeier, Gordon, and Cullinane, Kevin, eds. Dry Ports – A Global Perspective: Challenges and Developments in Serving Hinterlands. Surrey, England and Burlington, Vermont: Ashgate Publishing Limited, 2013. ISBN 9781409444244*

# Dry Ports – A Global Perspective: Challenges and Developments in Serving Hinterlands

by Isaac Shafran

This book is a welcome addition on a timely subject that has recently received increasing attention on a worldwide basis, reflecting the importance of inland freight shipping and logistics to improve the competitiveness of businesses and countries worldwide. There is no accepted definition of the term “dry port” in the industry, so the editors use the term broadly to include various initiatives to better connect and integrate inland transportation locations to coastal ports.

The book is organized into four parts by geographic area, i.e., Europe, Africa, Asia, and the Americas. The book was edited by three European researchers: Bergqvist, Wilmsmeier, and Cullinane. The individual chapters were authored by more than 20 practitioners, consultants, and academicians from around the world. After a brief general introduction by the editors, each of the chapters presents a case study in a geographic area.

The potential scope and the geographic coverage are so broad that it is not practical to deal comprehensively with the challenges and the ongoing developments that are influencing hinterlands around the world. Instead, the editors focus on 12 case studies in a few countries in each continent, each covering specific examples of different types of analysis and/or developments related to inland transportation. The combined chapters provide an overview of some of the recent historical evolution in port hinterland development in several of the major economies around the world, as well as a few examples in smaller countries. The case studies demonstrate the complexity of the issues and the variety of approaches used around the world.

The different types of projects and services covered include intermodal terminals, rail corridors, port community systems, rail and intermodal services, logistics zones, etc. Developments are discussed in specific corridors or regions in 13 countries, four in Europe (Sweden, Netherlands, Spain and UK), four in Africa (South Africa, Tanzania, Ethiopia, and Niger), two in Asia (India and China), and three in the Americas (the United States, Brazil and Chile). Some of the case studies deal only with one specific aspect (e.g., Port Community System in Valencia, Spain), while others describe “dry port” historical developments and/or ongoing initiatives throughout the entire country (e.g., in India).

## Evolving Definition of “Dry Port”

The book’s introduction discusses briefly the evolution of the dry port term and concept. Several definitions are presented. The editors found the first use of the term in an UNCTAD 1982 report, *Multimodal Transportation and Containerization*, which defined a dry port as an inland terminal or location used by steamship lines in their bills of lading.



The important role of private initiatives that led to containerization and intermodal transportation developments, particularly in the United States, is not highlighted. Further, the many significant inland port developments in the United States (similar to what the book considers as “dry ports” in other countries) are not covered in any detail.

In the United States, the term “dry port” has not been extensively used. Instead, “inland port” has been more widely used. The “inland port” concept came up mainly for two purposes: as a way to expand a port’s hinterland in order to serve additional inland markets, or to consolidate cargo from the adjacent inland region for shipping to/from a port by rail. The Virginia Port Authority developed the Virginia Inland Port located along the Norfolk Southern line near Front Royal in the late 1980s. The VIP was designed and marketed to compete with Baltimore’s more attractive inland location to handle Mid-Atlantic bound or originated cargo.<sup>1</sup>

Since then, as global trade expanded and the supply chains of large manufacturers as well as retailers in the United States reached farther, many railroads, ports, and other industry providers began to collaborate to develop terminals similar to VIP, with direct rail connections between seaports and “inland ports.” Columbus Rickenbacker Airport developed an inland port with rail service to East, Gulf, and West Coast ports. Huntsville, Alabama, also developed a rail facility at its airport. Other recent examples include: the Greer, SC, Inland Port and proposed inland port developments in Cordele, GA; Pt. St. Lucie and Miami, FL; Casa Grande, AZ; Joliet, IL; etc.

The two chapters describing developments in the United States only briefly mention some of these “inland ports,” which have been mostly port, airport, or private industry initiatives. Instead, these two chapters emphasize rail industry initiatives, federal programs, and institutional issues. A more complete overview of historical and planned “inland port” developments in the United States would add to the book’s global perspective on dry ports.

Dry ports are generally viewed in the book as similar to inland ports in the United States, i.e., inland rail terminals, where cargo is transferred between modes, or a location where diverse cargo handling, warehousing, and other logistics services are concentrated to serve an inland region some distance away from a seaport. Considering the diverse use of the term, the editors do not attempt to use the term consistently throughout the book. Several different definitions are used in the individual chapters and different types of facilities are discussed as “dry ports” (e.g., inland terminal, hub, inland container depot, CFS, trade corridors, etc.) reflecting initiatives and practices in different countries under different regulatory and operational systems and the extent of their available intermodal services.

The editors further conclude a “dry port” can be viewed as an approach to develop efficient facilities and services for inland distribution of cargo, regardless of local conditions, geography, or diverse regulatory and operational settings. The main objectives of dry ports are summarized as: relieving port congestion, addressing limited space at the seaports, increasing port hinterlands and their competitiveness, increasing the efficiency of cargo movements and global supply chain logistics, as well as reducing environmental impacts of heavy truck movements and rail traffic in urban areas near ports.

## The Case Studies

After the Introduction (Chapter 1), each of the remaining chapters describes some type of development or service that may influence hinterlands and/or specific issues or analysis regarding inland transportation, logistics, and distribution in different regions, corridors, or countries. The chapters are not organized to cover the same topics for each of the case studies. Accordingly, there is quite a range in the level of detail and the extent to which each chapter discusses dry ports and hinterlands.

Some of the topics covered include the history, existing situation, the development, operational, and financial issues involved, and the challenges being faced in the individual region or countries.

Other chapters are mainly a broad discussion of recent developments in a large geographic area, either presenting specific project or corridor developments, or focusing on policy issues, technical aspects or financial challenges faced. Two chapters deal with research on specific topics: service quality vs. price in India and potential for logistics zones in Chile.

A brief summary of each of the chapters or case studies is available in the following link: <https://www.dropbox.com/sh/d7uvrrvujwlv4rn/kmFcVArTMF>.

## General Observations

In general, the main value of the book is its global perspective both in terms of diverse topics and geographic coverage. It should be of great interest to any reader who wants to gain knowledge about the range of approaches in use around the world to better serve hinterlands. The global coverage also highlights differences in the level of intermodal services and infrastructure in developed and emerging economies.

Some of the chapters are very well written and organized, concisely covering the intended topic in the geographic region as well as highlighting key development issues and obstacles. That includes most of the chapters that describe existing and proposed dry port developments, such as the case studies regarding dry ports in Sweden, India, and China. The two chapters describing developments in the United States are also well organized, but at times these two chapters overlap. Some of the other chapters are not as clearly focused on the subject covered in the book.

Although the book's main value is its global geographic coverage, its approach makes for a lack of unifying theme and inconsistent treatment of the subject in each geographic market. The chosen approach makes the book more a compendium of papers on different subjects tied sometimes artificially under the broad topic of "dry ports," which is not consistently defined. Some of the chapters actually have little to do with dry ports, and present interview or research results regarding issues associated with inland freight movements that are not specifically related to dry port development, e.g., the case study of service vs. quality for public vs. private facilities in India, the results of interviews with a rail terminal and distribution services operator in the UK, and the chapter on Brazil's foreign trade dedicated areas. The UK and Brazil chapters only peripherally relate to dry ports. The chapter on intermodal corridors in the United States is an excellent summary of rail corridor intermodal developments, but also only peripherally refers to new terminals or "dry ports" along the corridors. The case study on the Southeast Drenthe Region in the Netherlands is basically a strategic feasibility assessment of the concept in one specific area.

In summary, the reader is provided with a good list of issues and challenges in serving changing hinterlands spread out throughout the chapters. All these topics are covered to some extent, but with few general conclusions or comparative analysis of the case studies. The conclusions and comparisons between the different approaches mainly relate to developed economies. Most of the conclusions are not applicable in developing economies where dry ports in many countries are viewed as ICDs (inland container depots) and CFSs (container freight stations). In Africa, India, Brazil, and other emerging economies, there is still much to be done to provide an adequate intermodal infrastructure and modern customs clearance systems and procedures.

The book would benefit from a more focused objective aimed at a specific audience – it is not quite a textbook, research paper compendium, summary of actual historical experience, review of actual practices, or presentation of planning or analytical approaches. It is all of that at times but often it is hard to follow how the material presented is tied to the title "Dry Ports."

One final comment must be noted. The quality of the written and other material in the book is uneven. As previously noted, some chapters are well written as would be expected in any professional publication, with adequate maps or explanations supporting the text. However, some chapters have no maps (e.g., no maps are included in Chapters 4, 6, 8, or 13). There are also sections that have poor grammar and some difficult to understand translation, resulting in unclear or incomplete sentences

and typos (e.g., in Chapter 8). Some incorrect terms are used (such as the use of “double stock” instead of “double stack” rail services in Chapter 10). Further, some statements can be viewed as leaving out important relevant information, particularly regarding the role of private initiatives that has been historically so important in the evolution of hinterlands.

Some example of topics not well covered are listed below (additional discussion can be found in the following link: <https://www.dropbox.com/sh/d7uvrrvujwlv4rn/dlIXBfML0b/Bergqvist-clos%20obs%20insert.is.docx>):

1. In the Brazil chapter, private industry role in the dedicated foreign trade areas and the implication on port capacity, operations, and efficiency.
2. In the chapter on dry port potential in the U.S., the impression is given that the railroads developed double stack services, when it was a steamship line that sponsored the initial double-stack train services.
3. In the same chapter, the important role of port authorities in developing inland rail terminals is only briefly mentioned.
4. In the chapter on intermodal freight corridor developments in the United States, adjacent rail yard projects are not covered in any detail.
5. In the same chapter, the dominance of domestic containers in the United States is noted, but there is no mention of the role of APL in marketing backhaul services in their double-stack trains and the introduction of higher cube non-standard 53 ft. containers to serve domestic shippers.

Some of these topics highlight the important role of private industry in hinterland development. Ports, carriers, and logistics providers continually seek greater efficiencies through more efficient facilities and networks that provide opportunities for faster routings and lower costs. This global competitive environment triggers opportunities for innovations in inland distribution and logistics, which are mainly private initiatives in most of the world. Further, changing trade patterns and policies heavily influence hinterlands. Practical solutions are then often dependent on the size, shape, and access to the seas of the various countries, regions, and corridors around the world as well as the actions of private shippers and transport operators, not only governmental policies or actions.

## Endnotes

1. The VIP project is not mentioned in the introduction of the book in describing the history and evolving use of the term “dry ports.”

*Isaac Shafran is a former corporate vice president at The Louis Berger Group, Inc., where he was in charge of the Airports and Ports Division until his retirement in 2010. He has been involved as a senior advisor on projects in the United States and throughout the world. Prior to joining Berger, he was associate administrator and director of development of the Port of Baltimore. He has worked on several policy, institutional and NCHRP freight studies. He served as chairman of the TRB Committee on Freight Transportation Planning and Logistics and as president of the TRF Washington Chapter.*

*Haeg, Larry. Harriman vs. Hill: Wall Street's Great Railroad War. Minneapolis, MN: University of Minnesota Press, 2013. ISBN 978-0-8166-8364-2*

## The Last Great Stock Market Corner

By William Huneke

*Harriman vs. Hill* concerns an epic in U.S. financial history. This story includes some of the great characters in American history: Theodore Roosevelt, J.P. Morgan, James J. Hill, Edward Harriman, Jacob Schiff, Mark Hanna, and Justice Oliver Wendell Holmes, Jr., just to name a few. The epic includes some dramatic episodes like the assassination of President William McKinley, which, because it vaults Roosevelt into the presidency, brings on the last act: the *Northern Securities* case.

The story begins with the desire of Hill and his Great Northern-Northern Pacific syndicate's desire to get a connection to Chicago. To do so, Hill focused his efforts on acquiring control of the Chicago, Burlington & Quincy (CBQ). This effort put Hill in direct conflict with Harriman and his Union Pacific (UP).

Harriman and Schiff had recently reorganized the UP out of bankruptcy. The UP also lacked a connection to Chicago. Moreover, the CBQ paralleled and competed with the UP in many markets, particularly in Nebraska. Harriman believed if a rival, like Hill's railroads, controlled CBQ, it would imperil the UP's future.

Both parties proceeded to put offers in front of Charles E. Perkins of the CBQ, who insisted on a \$200 per share cash offer. After much dickering, Perkins accepted Hill's offer, much to the consternation of Harriman. Schiff and Harriman approached Hill and his chief banker, J.P. Morgan, about a compromise, framed as a "community of interest," only to be dismissed out of hand. Morgan then headed off for a long European vacation while Hill returned to his St. Paul headquarters: major strategic errors.

Harriman and Schiff realized that Hill had organized his takeover of the CBQ by placing ownership inside the Northern Pacific (NP). This meant that control of the NP also meant control of CBQ. Harriman and Schiff also realized that it might be possible to buy control of NP by buying up its common and preferred stock in the open market. So while Morgan and Hill were away, Harriman and Schiff started buying.

At this time there was no Securities and Exchange Commission, nor were there any regulations regarding announcing any attempt to acquire controlling interest. Harriman and Schiff could commence their buying campaign in secret. This caught everyone off guard, most notably Hill and Morgan.

NP's price exploded. On Monday, April 29, 1901, it opened at 108¾ and closed at 119. A buying frenzy ensued. By the following Tuesday, NP stock sold for 143½. At first it was not clear what was behind the frenzy. When Hill realized the NP was in play and his allies were actually selling NP stock, he countermanded those decisions and ordered unlimited purchases of NP stock.

At the same time, speculators were trying to guess when the frenzy would break and tried short selling. The shorts were crushed. A panic ensued. Speculators tried to cover their positions by selling other positions. The prices of other securities collapsed. Many Wall Street firms teetered. A resolution could only be achieved with peace between the forces contesting control of the NP.

Hill realized he had a tactic he could use to assert control over the NP: after January 1, 1902, the NP Board could retire the preferred stock. At that point, control of the common would mean control of the NP. Moreover, while Harriman and Schiff might have more combined preferred and common stock, Hill had the most common stock. When Hill met with Harriman and Schiff, Hill revealed his intent to force retirement of the preferred. This forced a resolution: a resolution that included lending NP securities to resolve the exposure of many speculators and brokerage firms.

For the contending parties, the resolution created a “community of interest,” which permitted each side to appoint an operating officer to direct the workings of the consolidated companies: CBQ, NP, and Great Northern (GN). The community of interest was formalized by having a holding company hold the securities of the three companies. The holding company was Northern Securities.

President McKinley had been a friend of Big Business and his administration had been complacent in applying the antitrust statutes. McKinley’s assassination made Roosevelt president. Roosevelt had a much different approach to antitrust. Furthermore, he saw an antitrust action against Northern Securities as a way to attract western farmers to his reelection bid.

The *Northern Securities* case dissolved Northern Securities. It was the first time federal authority had applied antitrust law to a railroad merger. It represented a more aggressive application of antitrust law in general and it revealed a more aggressive regulatory stance by the Roosevelt administration toward the railroad industry. Justice Holmes issued one of his classic dissents, including the quote: “Great cases like hard cases make bad law.”<sup>1</sup> Holmes’s thundering dissent provoked an equally famous quip from Roosevelt: “I could carve out of a banana a judge with more backbone than that.”<sup>2</sup>

Hill unwound Northern Securities by providing a pro rata share of the securities in the three underlying companies. This angered Harriman, who much preferred getting just his NP securities instead of minority shares in CBQ, GN, and NP, especially since this method left Hill and his allies in effective control of the three railroads.

While this is a fabulous story that the author relates reasonably well, there are some annoying facets to the way the author tells it. Instead of just telling the story from the record, the author often borders on a novelistic approach by speculating on what the actors were thinking with phrases like: “Hill must [have] daydreamed through the drone of the High Mass, his mind wandering to the evening.”<sup>3</sup>

The author attempts to add local color to make the reader get a sense of the times but stumbles over basic facts: the White House is across the street from Lafayette Square, not three blocks away. In London, it is Euston Station and Hyde Park, not Eustis Station and Hyde’s Park. He also uses anachronistic names like referring to the Hudson River as the North River.

Perhaps the most frustrating feature of the book is the way the author and editor chose to handle footnotes. These are handled as endnotes, which would be fine except there are no numbers where they occur. Instead, they are presented as a list with pages at the end, which makes the reader need to search the individual page to apply them back to the text. This is poor practice.

Still, this is a great story. The reader will enjoy the conflicts and may desire to find out more about the great characters.

## Endnotes

1. Quoted in Haeg, *Harriman vs. Hill*, page 278.
2. Quoted in Haeg, *Harriman vs. Hill*, page 279.
3. *Ibid.*, page 106.

**William Huneke** received his Ph.D. from the University of Virginia. His dissertation concerned the economic and financial history of the Union Pacific, 1862-1898. He has more than 30 years’ experience in economics, management consulting, information systems, and business analysis in the commercial and government sectors. He has taught undergraduate and graduate business classes at the University of Maryland. Currently, he is chief economist, Surface Transportation Board. Views in this review are solely the author’s and do not represent those of the Surface Transportation Board, nor of its members.

# Transportation Research Forum

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## 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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*Ph.D Dissertation:*

Jessup, E.L. "Transportation Optimization Marketing for Commodity Flow, Private Shipper Costs, and Highway Infrastructure, Impact Analysis." Dissertation (Ph.D). Washington State University, 1998.

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U.S. Senate. Committee on Foreign Relations, *Investigations of Mexican Affairs*. 2 vols. 66th Cong., 2nd session, 1919-20.

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