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Source: *Journal of the Transportation Research Forum*, Vol. 52, No. 2 (Summer 2013), pp. 27-43
Published by: Transportation Research Forum
Stable URL: http://www.trforum.org/journal

A Framework for Determining Highway Truck-Freight Benefits and Economic Impacts

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This paper proposes a method for calculating both the direct freight benefits and the larger economic impacts of transportation projects. The identified direct freight benefits included in the methodology are travel time savings, operating cost savings, and environmental impacts. These are estimated using regional travel demand models (TDM) and additional factors. Economic impacts are estimated using a regional Computable General Equilibrium (CGE) model. The total project impacts are estimated combining the outputs of the transportation model and an economic model. A Washington State highway widening project is used as a case study to demonstrate the method. The proposed method is transparent and can be used to identify freight specific benefits and generated impacts.

INTRODUCTION AND BACKGROUND

Though the Washington State Department of Transportation (WSDOT) has a long standing Mobility Project Prioritization Process (MPPP) (WSDOT 2000), which is a Benefit-Cost Analysis (BCA) framework used for mobility program assessment, it does not separately evaluate or account for the truck freight benefits of proposed highway infrastructure projects. It is therefore unable to evaluate and consider the economic impacts of highway projects that accrue to freight-dependent industries (those heavily reliant on goods movement) or non-freight-dependent firms (service sector) that are perhaps indirectly impacted by the productivity of the freight system. The established evaluation criteria of any transportation project largely influences the project selection and direction, thus for freight to become an integrated component of a managing agency's transportation program, it must be recognized and acknowledged through the project evaluation criteria (NCHRP 2007). Before implementing any freight project evaluation criteria, an agency must first be able to identify the measures that matter to freight and freight-related systems. At this time there is no known nationally accepted framework for analyzing the full range of freight-related impacts stemming from transportation infrastructure projects. Complex interactions with separate, but not isolated, effects among economic, environmental, and social components with sometimes conflicting priorities make freight impacts more difficult to measure than those of other highway users (Belella 2005).

To successfully compete in a new funding world with significantly reduced monies for transportation infrastructure, states must become even more pragmatic about the means by which they emphasize and prioritize investments. Identification of the necessity to include freight performance measures in local, state, and national transportation plans, and rise above anecdotal understandings of system performance, is becoming evident as more municipalities and state agencies move toward implementing freight-related plans (MnDOT 2008, Harrison et al. 2006). Therefore, WSDOT has undertaken the development of an improved methodology to assess highway truck-freight project benefits designed to be integrated into the department's existing prioritization processes. This paper lays out the development process of this effort and the resulting methodology. The contribution of this paper to the literature is to present a methodology that includes a truck-specific determination of the economic value of a project in addition to the economic impacts captured by a regional computable general equilibrium (CGE) framework. The proposed method is transparent, and can be used to identify freight-specific benefits and generated impacts.

The remainder of this paper is organized as follows: the second section provides a brief review of the state of practice in the evaluation of transportation infrastructure investments; the third section details the process by which the benefits to be included in the analysis were selected and the methodology subsequently developed; the next section applies the methodologies to a case study and provides its result; the last section offers conclusions of the proposed methodology as well as the limitations of the study and directions for future work on fully incorporating freight into state DOT investment decisions.

STATE OF THE PRACTICE

The most common approach to freight benefit cost analysis is a microeconomic consideration in which the analyst calculates the benefits as direct cost savings and travel time reductions (Weisbrod 2008). This is the approach characterized by the majority of benefit cost analyses (USDOT 2003, Lakshmanan 2011). In 2010, the American Association of State Highway and Transportation Officials (AASHTO 2010) released an updated resource for the benefit-cost analysis of highway projects. Known as *The Redbook*, the manual recognizes user benefit analyses in transportation planning as a fundamentally economic process, as opposed to simply that of an engineering issue. The manual identifies the need to use traffic performance data, including traffic volume, speed, travel time, and other data related to the segments under project consideration. These data are needed for both the current status of the segment as well as the expected data under any project alternative. Further, the manual breaks down the development of user cost factors based on values of time for various vehicle classes (i.e., auto, transit bus, and truck), occupancy rates of those vehicles, as well as their operating costs (fuel, oil, maintenance, tires, insurance, license, and registration), and accident rate cost parameters. These cost factors are then related to the obtained traffic performance data in order to determine user costs. Despite the enormity of considerations available in toolkits like *The Redbook*, they generally lack full consideration of regional economic impacts extending beyond the direct benefits of an improvement.

Economic Impacts

The need for a regional economic framework originates from the function freight transportation serves in the economy. Freight movement enables trade networks between industries and their market locations. Improvement to the routes reduces travel cost and thus production costs of goods, as well as reducing uncertainties and risk that come with unreliable delivery. Quick and reliable transportation allows for industry logistics reorganization that involves companies purchasing more transportation services and adjusting the number, size, and location of factories and warehouse to reduce logistics costs (FHWA 2008). Increased transportation efficiency and reduced logistics costs combine to increase industrial productivity and produce positive effects felt via job creation and economic activities (Weisbrod 2008, FHWA 2001a, FHWA 2001b, FHWA 2001c, Allen et al. 1994).

Regional economic and macroeconomic models have been developed to implement various functional interactions, like production and cost functions, to estimate relationships between infrastructure investment and productivity and long-term economic activity (NCHRP 1998). At the macro level, infrastructure investment is viewed as a direct injection to the economy that can be inserted as an additional factor of production alongside private capital and labor (FHWA 2004). Nadiri and Mamuneas (1996, 1998) measured the contribution of capital investment in highways to private productivity, finding that indeed it does contribute to growth and productivity at the industry and even national levels. Highway capital investment saw its largest impacts during the 1950s and 1960s at a point when capital was in short supply and the interstate system was under development.

Though the impact has since diminished, it remains positive. Generally speaking, broad agreement exists to suggest that transportation infrastructure investments positively contribute to the overall economy; however, the magnitude of that contribution remains debatable (FHWA 2004). In a 1990 work, Munnell (1990) found that public sector investment does produce a statistically significant impact on private sector output. Additionally, she found that a state's investment in public capital has a significant impact on the state's private employment growth (Munnell 1990). These potential impacts readily provide an impetus for more freight-inclusive benefit evaluation methods and to a greater degree, a regional economic framework that captures impacts to labor, markets, business and trade development, as well as increases in Gross Domestic Product (GDP) or Gross Regional Product (GRP), and other organizational changes, such as those related to facility consolidation, logistical adjustments, and location effects (USDOT 2003, Lakshmanan 2011, Peters et al. 2008, Lakshmanan and Anderson 2002).

In this light, federal and regional transportation agencies and several state departments of transportation have sought economic frameworks to capture the economic impacts in addition to the transportation performance benefits.

FHWA led the research on quantifying the full range of freight benefits associated with highway investments. The logistics reorganization benefits were captured as the consumer surplus of the induced freight users. The relationship between freight demand elasticity and transportation costs/performance were established based on the data collected from 55 corridors between 1992 and 2003. This method is not applied in the proposed framework for several reasons. Firstly, the freight demand elasticity does not reflect the current Washington State freight elasticity. Secondly, this elasticity represents general freight traffic and is not able to reflect the characteristics of different commodities in responding to the transportation improvements. Thirdly, the consumer surplus of induced demand does not reflect how the direct transportation-related benefits are transferred to other parties and generate economic impacts (FHWA 2001a, FHWA 2001b, FHWA 2001c).

The Port of Portland readily identified that not all transportation bottlenecks and delays are equal when it comes to its economic impacts on the region and its traded industries (Economic Development Research Group 2008). They have employed a three-step process to identify the types of projects that are economically significant. The steps include site-specific evaluations considering connectivity to key industrial sectors, vehicle usage characteristics like origin and destination, then finally, the magnitude of produced effects as they relate to travel time and predictability of travel time, size of same-day delivery markets, cost competitiveness of shipping rates, and access restrictions on trucks.

Kansas DOT (KDOT) and North Carolina DOT (NCDOT) developed highway project prioritization tools to assess the highway projects' economic impacts using the TREDIS economic modeling platform. The economic impact measures are direct and indirect employment, gross state product, personal income, and productivity (KDOT 2010, NCDOT 2011). Michigan DOT (MDOT) (2011) also developed methods to explore the economic effects of transportation investments on personal income, employment, business sales, and gross state product using the REMI (Regional Economic Model's, Inc.) economic model platform. Similarly, Indiana DOT evaluated the statewide long-range transportation plan by predicting the employees attracted from other states based on the improved market accessibility due to highway projects (Kaliski et al. 2010). This job creation was used as input to a REMI-based model to estimate the full economic impacts, including real personal income, gross state product, and output. Montana DOT (MDT) sought similar evaluative abilities in the development of its Highway Economic Analysis Tool (HEAT) based also on the REMI model. HEAT allows MDT to take travel performance metrics like travel time savings and ultimately relate them to commodity flows and subsequent benefit cost analyses (Cambridge Systematics 2005). Though many consider regional economic models like REMI and TREDIS to be state-of-the-art, given their proprietary (commercial) nature and the lack of complete transparency regarding their inner workings, some state agencies are hesitant to implement the models. Weisbrod (2008) provides a succinct discussion of the precursors to and evolution of these and other regional economic models to allow for an understanding of the necessary components of a valuable model framework. Early models covered the gamut of Input-Output (I-O) based impact models that relate highway spending to travel cost savings and the flow of business and household income. Further advances to the basic I-O models include an incorporation of the ability to include market access and location demand.

This brief literature review indicates that although the full benefits from transportation investments have been considered to be important, there is a need for a freight-specific framework that considers both the direct transportation-related benefits, and regional economic impacts using transparent economic models. This paper proposes a transparent, freight-specific methodology that relates the performance of the freight network to the regional economy through a regional CGE model framework. The next section lays out the steps used to identify project evaluation criteria, estimate those values, and calculate project benefits.

DEVELOPMENT OF A METHODOLOGY FOR BENEFIT EVALUATION

The set of benefits implemented in the methodology were developed from discussions with the Washington State Freight Plan Technical Teams, who were asked to identify the important impacts to the freight community of a truck freight infrastructure project and review the current project prioritization method employed by WSDOT. From these, many were removed due to a lack of data to support the calculation, or redundancy with WSDOTs current project prioritization process (the MPPP tool).

Learning from the System's Stakeholders

Freight benefits were identified through discussion and partnership with three state freight plan technical teams. These teams comprised experts involved in the movement of freight throughout Washington's intermodal system, and identified by the Washington State Department of Transportation's Freight Systems Division (2012a). The three teams were Urban Goods Movement, asked to focus on jobs, the economy, goods delivery, and clear air for all; Global Gateway, asked to focus on national and state import/export activities; and Rural Economy, asked to focus on farm-to-market and manufacturing goods movement. The discussion within the three technical teams was seeded by a presentation of evolving federal criteria. The teams were tasked with the identification of measurable benefits and potential data sources that are important to shippers, freight carriers, air quality stakeholders, labor, and federal, state, regional, and local governments, including ports. After consideration, the technical teams' list of prioritized benefits included:

- Improved travel times
- Improved travel time reliability
- Reduced truck operating cost
- Safety improvement
- Freight network connectivity improvement
- Network resiliency improvement (defined as the ability to recovery from a disruption)
- Improved air quality: truck emissions
- Economic output defined as long-term jobs (non-construction-related) and regional outputs

Reviewing Current Highway Mobility Project Prioritization Methodology (MPPP)

WSDOT has a long-standing MPPP tool supporting the highway mobility project prioritization process (WSDOT 2000). The benefits considered in the MPPP tool consist of travel time savings, operating savings, and safety improvements. Both the current performance of the roadway segment, as well as the expected performance under the project alternative, are needed to evaluate the project benefits. Travel time is calculated based on the average speed estimated using WSDOT speed-flow curves, which present the relationship between segment volume-capacity (V/C) ratio and operating speed. The segment V/C ratio is calculated based on the comparison between roadway capacity and the 24-hour traffic distribution predefined by WSDOT. The operating cost savings in the MPPP tool are estimated for the park-and-ride lot projects only, which is calculated as the cost savings of switching from driving alone to carpooling or taking transit. Operating cost savings for other modes and project purposes are not included in the MPPP tool. The safety savings are evaluated based on the number and monetary value of property damages, injuries, and fatalities. Collision reductions vary depending on the project types.

The MPPP benefit-cost tool provides a means of evaluating project efficiency and it makes up 65% of the project prioritization rubric (Other project evaluation criteria include: community support [14%], environment [8%], modal integration [7%] and land use [6%]). However, the tool does not separately evaluate, consider, or account for the truck freight benefits of proposed capital highway projects, nor evaluate the economic impacts of highway projects benefiting freight-dependent industries (heavily reliant on goods movement) or non-freight-dependent firms (service sector).

Proposed Methodology

Travel time, operating cost, the environment, and economic impacts will be estimated in the current method. Several measures identified by the technical teams are excluded. Safety is not included as it is estimated by the MPPP tool. Network connectivity can be captured through impacts on travel time. Travel time reliability is also excluded due to insufficient regional data sources as to reliability estimates, forecasts, and values. Although the FHWA and the America Transportation Research Institute (ATRI) have been collecting GPS data on system performance since 2002, these data are not sufficiently detailed to estimate reliability at the desired level of spatial detail, nor are we able to forecast reliability or value reliability with this data. In our approach, truck travel time is estimated from a regional travel demand model (TDM), which is deterministic and cannot reflect the actual travel time variability. The network resiliency is not included in the current framework due to lack of reliable data and methodologies to monetize resiliency. Both travel time reliability and network resiliency will be incorporated in future phases of this research.

The benefits analyzed in the proposed framework include:

- Improved truck travel times
- Reduced truck operating costs
- Environmental impacts linked to truck emissions
- Regional economic impact related to outputs such as long-term job creation and regional output

Direct Freight Benefit Models. Even though travel time savings have been included in the MPPP tool, in that method, travel time and speed are estimated using the speed-flow relationship of general traffic (both automobile and truck trips), which cannot reflect truck speed accurately. In addition, the current approach does not reflect the network effects when additional traffic is attracted to the improved segments from other roads. The proposed framework estimates truck travel time improvement using the change in truck vehicle hours traveled (VHT) estimated by the regional TDMs. VHT is computed by multiplying the link volume and link travel time. Network improvements are expected to reduce total system VHT when induced demand is not considered. TDMs employ a set of mathematical equations to replicate "real world" travel behavior and forecast future travel performance based on the household, land use, and transportation network data. In Washington State, most Metropolitan Planning Organizations (MPOs) have developed their regional TDMs to replicate current and forecast future travel patterns and travel conditions. For any project located in the areas that are not covered by the TDMs, we assume there is no travel time reduction outside of travel distance reduction, namely, trucks travel at free flow speed pre- and post-investment.

To convert the travel time savings to dollars, a value of truck travel time is used. Most transportation planning organizations will have a standard value. The value estimated by WSDOT is based on regional driver wage and fringe benefits. The operating cost reduction is monetized using the operating cost per time unit estimated by WSDOT, including fuel consumption, fuel taxes, truck maintenance and repair, engine oil change, truck lease or purchase payment, truck insurance premium, tire cost, and licensing and overweight-oversize permits. Details of the inputs and assumptions of value of travel time and operating cost estimation can be found in WSDOT (2009).

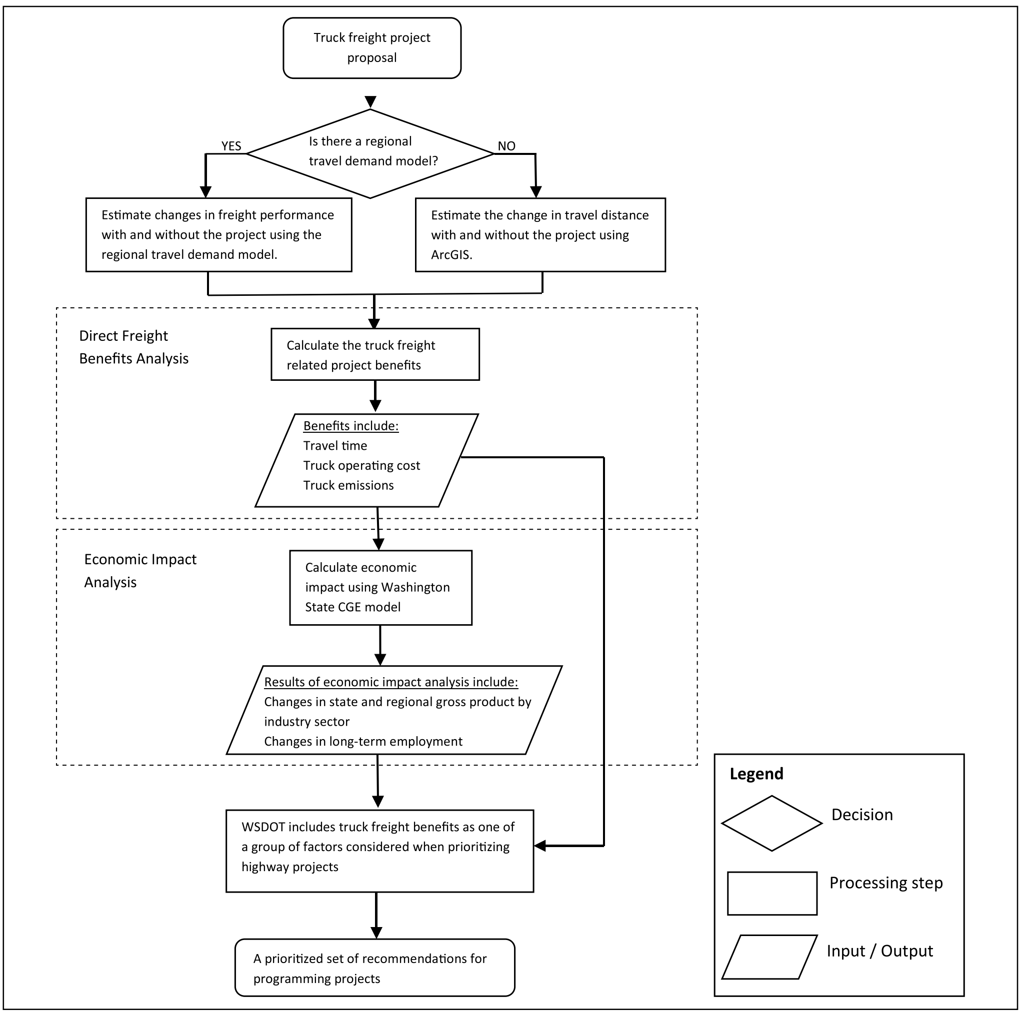
The value of any change in emissions from the project is evaluated as tons of desired air pollutants based on the operating speed, truck vehicle miles traveled (VMT), and emission rates (grams/mile). The operating speed and truck VMT are estimated from the TDMs (or speed-flow relationship when a TDM is not available). The regional emission rates vary depending on the truck operating speed estimates, road categories, and regional fleet information. They are estimated using the MOBILE6.2 developed and tested by U.S. Environmental Protection Agency (EPA) (2003). Five pollutants are analyzed in the framework including Carbon Monoxide, Carbon Dioxide, Nitrogen Oxide, Volatile Organic Compounds, and Particulate Matter 2.5. The monetary value per ton of each pollutant is consistent with the value employed in the Puget Sound Regional Council (PSRC) transportation benefit cost analysis, which was estimated based on reviews of existing research and represents a middle of the range of the available estimates (PSRC 2009). A major limitation of this method is the average travel speed cannot fully reflect the emission improvement due to less congestion and stop-and-go driving. The proposed method can only identify an improvement from either fewer VMT due to shorter trips or a change in travel speed. The mathematical version of the direct freight benefit model can be found in WSDOT (2013).

Economic Impact Models. Stemming from the transportation-related benefits to system users, there are economic impacts as businesses, consumers, and others respond to the transportation performance improvement and logistics cost reduction associated with infrastructure investments and improvements. These businesses may expand and grow as a result, possibly increasing employment, earnings, and total state revenue, which then may result in further statewide investment and increased personal consumption. These responses are captured in this methodology via an Economic Impact Analysis (EIA) using a Washington State Regional CGE model (Stodick et al. 2012). The travel time and operating cost benefits are utilized as inputs to the CGE model, with outputs composed of long-term employment and state/regional output by sector (industry).

The Washington State CGE model, developed by professors David Holland, Leroy Stodick, and Stephan Devadoss, is an adaptation of the Lofgren Model (Lofgren, Harris, and Robinson 2002) and has been used extensively for evaluating statewide economic impacts from a host of policy changes (Ghosh et al. undated, Holland and Devadoss 2006, Coupal and Holland undated). The model is a generic representation of the state's economy, although one developed to closely represent how its economy functions while adhering to traditional neoclassical economic theory. The underlying premise of CGE models is the Walrasian equilibrium, which states if all markets in a given economy are in equilibrium, then any specific or individual market will also be in equilibrium and therefore a market clearing price and quantity exists for any individual sector of the economy, as well as the whole regional economy (Wing 2004). The conceptual flow of activities is relatively simple and straightforward with all firms in an economy producing their own unique goods from factor inputs (labor and capital) which are provided by households. These goods, services, and commodities are then either utilized as inputs for other firms or consumed by households at the respective market clearing price. The model is solved utilizing the Generalized Algebraic Modeling System (GAMS) software and the PATH solver. In the proposed method, the direct transportation benefits (travel time savings and truck operating cost savings) are utilized as inputs to the CGE model to calculate regional economic impact stemming from the transportation costs reduction.

In summary, the project impacts on freight captured by the proposed methodology include direct transportation-related benefits as well as long-term economic impact. The transportation-related benefits are estimated based on either the outputs of the TDMs or the change in travel distance. The reduction of transportation costs is used as input to estimate the economic impacts on long-term job creation and regional output using the Washington State CGE model. The estimated project impact is one of the set of factors considered when prioritizing transportation projects. In addition, in order to support the transportation projects that improve efficient freight movement and promote regional economies, WSDOT classified roadways into five categories (T1 – T5) using the truck gross tonnage data, among which T1 and T2 roads represent the strategic economic corridors in Washington State and comprise 37% of all state route miles (WSDOT 2012b). The location of a highway project on a T1 or T2 corridor is one of many factors that are considered when prioritizing funding for projects. A schematic of the proposed truck freight highway economic impact analysis framework is shown in Figure 1.

Figure 1: Schematic of the Proposed Highway Truck-Freight Benefits and Economic Impacts Analysis Framework



CASE STUDY

A widening project on a major interstate in Washington was selected as the case study to evaluate the capability of the proposed framework in determining the full project impacts. This highway segment is a critical connector for the region and served approximately 5,000 to 7,000 trucks daily in 2011. It is also a strategic freight corridor carrying international and domestic trade. The freight demand using this route is projected to increase by 30% over the next 10 years, which will lead to considerable congestion and other negative impacts if this route cannot accommodate the growing demand. In light of this, WSDOT identified a widening project that supplemented the current four-lane highway with two additional lanes (one lane each direction). The segment length is approximately 10 miles.

The projected 2035 regional TDM outputs of build and no-build scenarios were provided by WSDOT using the relevant regional TDM, from which we calculated the changes in system total truck VHT and truck VMT to estimate the travel time savings, truck operating cost savings and environmental impact associated with the highway widening project. The estimated transportation related benefits were used as inputs to calculate the economic impacts using the Washington State CGE model. Details of the regional TDM, economic impact analysis, and calculated results are presented below.

Regional Travel Demand Model

The TDM relevant to the test project was employed to evaluate the pre- and post-investment traffic performance, including the freight specific performance. The model is a traditional four-step transportation planning model consisting of trip generation, trip distribution, mode choice, and trip assignment. It is used for estimating the daily travel patterns within the model area. The passenger and commercial traffic demand are estimated independently in the TDM (SRTC 2006). In contrast to the passenger travel demand estimated based on a household survey, the commercial travel demand is predefined by land use type, and truck trips are generated at different rates according to the land use type. For example, the commercial trip generation rate of CBD retail area is 5.95 while an industrial area is 1.33 (SRTC 2006). Future land use plans were provided by local DOTs. The commercial traffic is modeled in morning peak, middle day, evening peak and night time periods, respectively. The trip assignment is completed using an equilibrium assignment approach, by which travelers cannot reduce travel cost by shifting to other travel paths. Thus, once the transportation network is changed, the model is able to identify diverted traffic to the improved segments by reassigning the traffic. The model outputs include the segment traffic volume (passenger and truck traffic are estimated separately), average travel speed, and travel time. Segment-level truck VHT is calculated by multiplying the average travel time and the truck volume along the segment, and system total truck VHT is computed by adding together the segment-level VHT estimates.

Direct Freight Benefits Analysis Results

According to the TDM outputs, the system total daily truck VHT would decrease by 295 hours in a 2035 build scenario compared with the no-build scenario (approximately 1% of the total daily truck VHT), which would lead to reduction in travel time costs and truck operating costs. The travel time and truck operating cost savings were monetized using the truck costs per hour published by WSDOT (2009). The value of travel time and operating costs per hour are $27 and $48 respectively. Consistent with WSDOT practice, we assumed the annual benefits increased at a constant rate, equal to the total benefits in 2035 divided by number of project analysis years. The net present value was calculated by adding together the annual benefits over the 20-year analysis period with the discount rate of 4%, the same discount rate currently used by WSDOT. According to Table 1, more than $9,189,000 in travel time savings and $15,428,000 in operating cost savings would accrue to the freight system from 2016 to 2035. Though the system truck performance was improved, the emission costs would increase by $73,000 since the increased truck speed may lead to greater emissions when speed is higher than a certain threshold. The total transportation related benefits during the analysis period were calculated by adding together the travel time savings, operating cost savings, and emission impacts, and were equal to $24,544,000 as shown in Table 1.

Table 1: Summary of Transportation Related Benefit of Widening Project Over 20-Year Analysis Period (2016-2035), Thousands of 2010 Dollars

Benefit Category	
Truck travel time savings	$ 9,189
Truck operating cost savings	$15,428
Emission impacts	-$73
Total	$24,544

Economic Impact Analysis

Data. Reductions in transportation costs influence the production costs of freight dependent and other related businesses and industries. Responding to production cost changes, industries may alter their inter-sector relationships with the truck transportation sector and each other. These changes further contribute to the effects stemming from infrastructure investment on regional employment and output. Such economic impacts are captured by the Washington State CGE model. Data for the CGE model was generated from the most recent IMPLAN (2010) data (MIG 2010). Social Accounting Matrices (SAMs) detailing the economic exchanges occurring in the region are generated within IMPLAN, and exported to GAMS for CGE modeling. The CGE model then utilizes a set of equations and elasticities to reproduce the economy's inter-sector relationship in response to the produced counterfactual statements. Prior to introduction of the counterfactual, the models' parameters are calibrated such that it regenerates the original SAM. Example parameters used in calibration include various demand, substitution, and transformation elasticities. IMPLAN's basic structure contains 440 industries, of which we aggregate into 20 sectors in rough accordance with their 2-digit NAICS code.

Implementation: Conversion of TDM Outputs to Economic Impact Inputs. Four regional CGE models are constructed to evaluate the case study project. The four models are composed of two geographical scales, each with a short-run (SR) and long-run (LR) scenario. The SR variants assume capital is fixed across sectors and the region's total capital endowment is similarly fixed. Alternatively, a LR variant is established in which capital is mobile across sectors and the region-wide endowment is allowed to vary. The SR and LR variants effectively partition the results in a manner that displays the near term (e.g. first several years) economy response to the infrastructure, while the LR displays those impacts that could be expected once the economy has fully had an opportunity to adjust to the change. Unlike capital, both SR and LR models assume labor is mobile across sector and region. The labor closure considerations stem from discussions in Holland (2009), in which he suggests that lack of migration control at regional levels leave state borders and, to a greater extent county borders, more open to labor movement than national borders.

Though designed to represent the economy of Washington State, the Holland et al. (2006) model's geographic scale is dependent upon the scale generated in IMPLAN. Thus, to gain an understanding of the impact of changing model parameters of the SAM, as well as local purchasing coefficients, we model at both the state and county level. It is highly likely that the local industrial interactions modeled at the state level are different from those of a single county. For example, it is reasonable to expect that for some major industry input purchases, the county imports at a higher rate than the state if the state has a high supply of those commodities relative to the specific county. Given Washington's economy at the state level is highly correlated with that of the larger population centers found in Puget Sound, the state's purchasing pattern is very different from that of counties in other parts of the state. These changes may have significant impacts on the value and distribution of generated impacts of an infrastructure project.

Arguably, a transportation infrastructure project that reduces freight travel time and operating costs can be represented as an improvement in technology that permits the truck transportation industry to become more productive (increased efficiency) for a given level of capital and labor. These efficiencies are generally realized through reduced driver time on the road, resulting in reduced labor costs to the motor carrier and, increased trip miles per unit of time per vehicle, resulting in more productive individual vehicles; thus, potentially requiring fewer trucks to accomplish the workload and reduced vehicle repair and operating costs (FHWA 2002). As such, we develop a counterfactual to initiate the CGE models using the shift parameter (ad_A) for the truck transport industry's production function. This shift parameter, when adjusted, causes a shift to the industry's Leontieff-Constant Elasticity of Substitution (CES) production function (1). The production function is Leontieff-CES in such a manner that the intermediate inputs are in fixed proportions (Leontieff) while the factors of production possess CES technology.

(1) $QA_A = \frac{ad_A}{1-tb_A-\sum_C ica_{C,A}} * (\sum_{FF} del_{FF,A} QF_{FF,A}^{-rho_A})^{\frac{-1}{rho_A}}$, where

The shift parameter (2) is expressed as:

(2) $ad_A = \frac{(\frac{SAM_{TOTAL,A}}{PAO_A}) * (1 - tb_A - \sum_C ica_{C,A})}{(\sum_{FF} del_{FF,A} * QFO_{FF,A}{}^{-rho_A})^{\frac{-1}{rho_A}}}, where$

QA_A	=	Activity level (endogenous variable; where truck transport in the present model is the activity of concern)
tb_A	=	Indirect business tax rate of industry A (parameter calculated from initial data)
$ica_{C,A}$	=	Quantity of C (commodity) as intermediate input per unit of activity A (parameter calculated from initial data)
$del_{FF,A}$	=	Share parameter
$QF_{FF,A}$	=	Quantity of FF (factors of production) demanded by activity A (endogenous variable)
PAO_A	=	Initial activity price of A (user established)
rho_A	=	Exponent for production function
$SAM_{TOTAL,A}$	=	Social accounting matrix exported from IMPLAN
$QFO_{FF,A}$	=	Initial quantity of FF demanded by activity A (calculated from initial data)

For the present case, we are interested in the increased productivity within the region of consideration, as determined by the TDM, of the truck transport sector resultant of an infrastructure investment. An increase in the value of ad_A produces an increased QA_A for a set level of the factors of production. Thus the region's transportation industry has become more productive, producing a rightward shift in the supply curve. The CGE model does permit for the exchange of imports and exports for both domestic and foreign trade with the region under consideration. Composition of the export and import quantities with either of these regions is dependent upon relative prices.

The value assigned for the shift parameter is dependent upon the percent change in operating costs of the trucking industry. The percent change is a ratio based on benefits generated in the outputs of the TDM of the selected regional coverage as compared with the cost of the intermediate inputs (generated in IMPLAN) of the truck transport industry. Intermediate input costs include those purchases of goods and services used for production of trucking services, not including factors that may contribute to value added.

$$(3)\quad Percent\ Change\ in\ Costs\ of\ Production = \frac{TDM\ Benefit\ Output}{Intermediate\ Expenditures}$$

The TDM outputs produce 3.24% and 0.26% increases in productivity to the trucking industries of the County and the State of Washington, respectively (Table 2). These values are input to the CGE model to inform the counterfactual statement to the production function shift parameter.

Table 2: Productivity Change to the Transport by Truck Sector

Travel Demand Model Benefit Output	$ 4,533,563[a]
County Intermediate Expenditures (transport by truck)	$ 139,875,763
Statewide Intermediate Expenditures (transport by truck)	$1,760,368,000
Change in Truck Transport Productivity–County	3.24%
Change in Truck Transport Productivity–State	0.26%

[a] All dollars are in 2010 dollars. Benefits include single analysis year (year 2035) of reduced operating and travel time savings. Emissions not included.

Impact Results. Though there are multiple ways to display the results of economic impact models, the most common, straightforward, and relevant are in relation to changes in employment and regional output activity of the various industries that rely on freight or are otherwise impacted by its movement. Given the calculated TDM output changes (direct impacts) resulting from the case study (Table 2), Tables 3 and 4 display the regional economies' response to increased truck productivity at the county and state levels, respectively.

Short-run considerations are included here to suggest the initial reactions that may be expected following completion of the infrastructure improvement, under the defined SR closure rules. Under these conditions (*ceteris paribus)*, the prices paid for truck services are suggested to decrease by 1.94%. This price decrease corresponds to the increase in activity output of the sector in Table 3 (refer to complete CGE documentation for the relevant equations to generate price changes [Stodick et al. 2012]). At the state level, price change is an expectedly much smaller 0.18% drop. Regional economy-wide employment increases in both the county and state models by nearly the same value; 25 and 22 jobs, respectively. Additionally, output sales in the two regional economies also increase by rather similar values of $9.8 million and $10.5 million, respectively.

Long-run scenarios allow for the suggestion of the achievable degree of economic impacts once the various sectors are fully able to respond. Closure rules in the LR permit a relaxing of constraints upon the movement of capital within the economy. With this increased flexibility, the county and state-wide models begin to show more divergence in their results. Here, the county model shows a growth of 78 jobs, while the state comes in at 47. Similarly, the county model suggests output sales increases of $28.7 million, and the state $22.2 million. Looking specifically at the initial impact generating activity, reduction in truck transport prices, the county and state models suggest price reductions of 1.67% and 0.14%, respectively.

Interestingly, the results reveal that in all the CGE models (SR and LR), the truck transport industry has negative changes in employment numbers. At first glance, this may appear counterintuitive. However, these results can be thought about in relation to a cost of congestion study done previously in Washington State (Taylor 2011). Taylor's survey and subsequent input-output modeling suggests that freight-dependent companies may respond to increased congestion (reduced productivity) by

Table 3: Industry Sector Specific Results at County Level

Sector	Initial Employment Level	Change in Employment Numbers		Change in Activity Quantity (%)	
		SR	LR	SR	LR
Agriculture and Forestry	3,993	4.6	14.5	0.021	0.361
Mining	255	0.1	0.2	0.005	0.078
Utilities	624	0.1	0.5	0.005	0.070
Construction	15,060	3.3	2.8	0.015	0.018
Manufacturing	14,046	26.8	45.8	0.133	0.325
Wholesale Trade	10,292	3.1	5.6	0.019	0.053
Retail Trade	30,532	8.0	9.6	0.022	0.031
Transportation and Warehousing	4,331	-2.4	-2.6	-0.038	-0.060
Transport by Truck	2,594	-45.0	-38.0	1.934	1.729
Information Services	3,362	0.4	0.8	0.004	0.022
Financial and Insurance	18,142	0.7	1.6	0.002	0.007
Real Estate	10,769	1.9	3.1	0.001	0.026
Professional and Technical	14,881	2.7	5.0	0.011	0.033
Management	2,687	2.1	4.1	0.069	0.154
Administration	11,940	5.2	6.5	0.034	0.054
Waste Management	357	0.2	0.2	0.025	0.068
Social Services	44,525	-0.6	2.5	-0.001	0.005
Arts and Entertainment	5,232	1.6	2.1	0.019	0.038
Food Services	17,216	3.6	5.8	0.014	0.032
Other (Including Government)	53,470	9.1	7.8	0.014	0.014

adding trucks (increasing employment) and producing a societal benefit, while also decreasing the purchases of services and non-freight dependent goods as more is paid towards trucking services. An opposite reaction is simulated here. In the present case, the TDMs suggest congestion relief stemming from the case study producing a positive effect, in that it simulates consumers increasing purchases of services and non-freight-dependent goods (increased activity in Tables 3 and 4), as well as a negative effect that simulates the trucking industry's response of reducing employment. In other words, we witness consumer benefits in the form of increased purchasing activity, and a societal cost in terms of potential employment reduction on the part of trucking services as congestion is eased.

The economic analysis results show that $4.5 million direct transportation benefits (shown in the first row of Table 2) may generate additional $28 million county-level output, which may have significant impacts on project prioritization, and should not be neglected from the project cost efficiency assessment. A change in output, sales, is reflective of the difference between the product of the base producer price and regional output quantity as compared with that after initiating the counterfactual. It is also important to note, in a policy context, that the results here are presented for the single region of consideration; however, given that the balance of regional imports and exports is price relative, there are additional impacts to external regions as a result of economic activity transfer. For future project prioritization, the direct transportation benefits will be added to already established passenger benefits, and compared with the project cost over the analysis period (20

Table 4: Industry Sector Specific Results at State Level

Sector	Initial Employment Level	Change in Employment Numbers		Change in Activity Quantity (%)	
		SR	LR	SR	LR
Agriculture and Forestry	1.17E+05	4.8	13.7	0.002	0.012
Mining	3,281	0.2	0.4	0.002	0.012
Utilities	5,376	0.1	0.3	0.000	0.006
Construction	2.07E+06	3.4	2.5	0.001	0.001
Manufacturing	2.67E+05	20.6	27.0	0.005	0.010
Wholesale Trade	1.29E+05	6.6	6.8	0.001	0.002
Retail Trade	3.77E+05	6.6	6.8	0.001	0.002
Transportation and Warehousing	72,712	-3.4	-3.2	-0.003	-0.004
Transport by Truck	32,647	-39.8	-32.8	0.185	0.157
Information Services	1.09E+05	-0.6	-0.9	0.000	-0.001
Financial and Insurance	1.87E+05	2.4	2.5	0.001	0.001
Real Estate	1.76E+05	1.9	2.4	0.000	0.001
Professional and Technical	2.83E+05	1.2	2.3	0.000	0.001
Management	32,319	1.1	1.7	0.003	0.005
Administration	1.64E+05	4.0	3.4	0.002	0.002
Waste Management	15,062	0.1	0.1	0.000	0.000
Social Services	4.47E+05	4.6	6.8	0.001	0.002
Arts and Entertainment	85,615	1.3	1.3	0.001	0.001
Food Services	2.39E+05	3.3	3.8	0.001	0.002
Other (Including Government)	8.35E+05	8.5	6.2	0.001	0.001

years in general) to identify the project net present benefits and benefit-cost ratio. Meanwhile, the economic impacts will be considered as one of a group of factors when prioritizing projects.

CONCLUSION AND DISCUSSION

In this paper we propose a transparent truck freight highway benefit and economic impact analysis framework, which estimates both freight transportation-related benefits and regional economic impacts associated with freight investments. The transportation benefits consist of travel time savings, truck operating costs savings, and emission impacts calculated based on regional TDM outputs (or ArcGIS spatial analysis results). The travel time and operating cost savings serve as inputs to estimate the economic impacts on regional employment and output using Regional CGE models. A highway widening project was selected as a case study. Four scenarios were created to evaluate both short-run and long-run impacts at the County and Washington State level. The results indicate that freight investments improve transportation performance and lead to direct transportation-related benefits. These direct transportation benefits are then transferred to other parties and generate economic impacts via job creation and regional economic activity improvement. The results also reveal that the industrial base of a geographical region can significantly impact model results, particularly as the length of the run is extended and the economy fully responds. This finding suggests that modeled analyses aimed at policy-relevant improvements should consider the appropriate geographical scale of consideration, thereby considering the industrial makeup and truck usage needs of the regional economy. For future project prioritization, the total project benefits will be added to already established passenger benefits, and compared with the project cost over the analysis period to calculate the project net present benefits and benefit-cost ratio. In addition, the economic impacts will be considered as one of a group of factors when prioritizing projects.

Despite the proposed methodology's ability to better capture the project benefits to direct and indirect freight users, and enhance the state's infrastructure project prioritization, future improvements can be made from the following aspects. First, some critical performance measures identified by the technical groups are excluded from the framework, including travel time reliability and network resiliency, due to the lack of quality regional data, and will be included in the next phase of development. Second, more efforts are needed to infuse both dynamic transportation models with equally dynamic economic models such that feedback between the two is more fluid.

The ability to reliably provide defensible performance measures and enable projection of future responses to infrastructure investments is a vital need for transportation agencies as funding becomes increasingly competitive. This study takes a valuable step forward in the development a methodologically sound framework to infuse freight benefits and regional economic impacts into existing agency level prioritization processes. The proposed framework can be applied in other states with local TDMs, economic models, and other factors.

Acknowledgements

We would like to acknowledge Barbara Ivanov, director of the Freight Systems Division at Washington State Department of Transportation for her input and guidance, as well as the Washington State Department of Transportation for project funding.

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