(1) TECHNICAL MEMORANDUM INTRODUCTION, OBJECTIVE AND SCOPE

This technical memorandum covers findings and recommendations about the economic analysis and benefit-cost analysis related to toll evaluation projects on OR 217 and Cornelius Pass Road in Portland, Oregon. The objectives of the paper are to:

a) Quantify the economic effects of tolling scenarios on OR 217 and Cornelius Pass Road.

b) Explore the societal economic costs of tolling and identify the benefit levels that would be needed from toll-financed programs to achieve economic break-even.

c) Explore key economic externalities and other factors relevant to a tolling program for OR 217 and Cornelius Pass Road.

The economic analysis gives the change in earnings, output, employment and overall economic costs or benefits expected to result from the findings of the traffic analysis. The methodology uses system level travel demand model results from the Portland Metro Travel Demand Model, and traffic and revenue estimates provided by DKS Associates. The analysis of economic costs, as well as economic impact analysis is derived using the Transportation Regional Economic Impact System (TREDIS) model developed by EDR Group. The TREDIS methodology applies different time and per-mile vehicle operation costs based on assumed trip purposes, percent congested, commodities subject to freight delay, crash factors, emission factors and other operating characteristics. The number of factors involved precludes a simple or implicit replication of each calculation in the current report, however the underlying assumptions (including cost factors applied) are documented in Appendix IA: *Default Values and Assumptions* and Appendix IB: *Travel Cost Module*.

Economic costs, benefits and impacts are derived from vehicle miles and vehicle hours of travel by trip purpose and facility type, with reliability effects derived based on the percentage of VMT and VHT occurring under congested conditions reported from the Portland Metro Travel Demand Model. The reliability methodology is further described in section (3) of this technical memorandum. The value of time and vehicle operating costs are based on the vehicle type (car or truck), the trip purpose (commuting, personal travel or on-the-clock travel). Technical derivation of the value of travel time, operating cost, reliability and safety impacts from national sources is documented in Appendix IA: *Default Values and Assumptions* and Appendix IB: *Travel Cost Module* .

(2) SCENARIOS AND CONCEPTUAL STRUCTURE

The economic analysis is primarily focused on economic and societal costs of collecting revenue through tolling. The economic analysis compares the societal costs of a "base-case" transportation system without any toll facilities to a system that includes tolling designed to generate revenue, either on OR 217 or Cornelius Pass Road. The relative cost impacts of tolling each is considered separately, across a range of toll levels. The analysis focuses on two issues: (1) how tolling redistributes money through the regional economy and (2) the net result of tolling on user costs (or savings) due to toll-related diversion. A full economic analysis of the tolling program (including benefit/cost ratios, net present value and internal rates of return) would only be possible if the uses and benefits of investing toll revenues were known. However, because the highest levels of net revenue for any toll rate considered in the current study yield only approximately $1 Million for OR 217 and $6 Million for Cornelius Pass over the time horizon to 2035, and this is not assumed to fund a robust transportation improvement service packages. Therefore, it is assumed here that toll proceeds would not be used to generate any new performance or economic benefits to the system.[1]

2.1 Key Assumptions Regarding Tolling Scenarios

All toll collection will be made electronically. Vehicles without transponder tags will not be permitted. Toll rates vary by time of day (e.g., higher during peak periods, and lower during off-peak hours) on a fixed schedule. OR 217 Tolls would be located at all on-ramps for Wilshire, Walker and Denny interchanges. Cornelius Pass Road toll would be located south of the US 30 intersection (both directions).

For the purposes of the economic analysis, toll levels are characterized as either low, medium or high. Tables 2-1 and 2-2 show the assumed peak and off-peak toll rates for the facilities studied in this analysis.

Table 2-1: Toll Rates Analyzed for OR 217

Scenario	OR 217 Ramp Pricing	Toll Rate (peak/off-peak)
1	No-Toll	NA
2	Low Toll	$0.25 / $0.15
3	Medium Toll	$0.50 / $0.25
4	High Toll	$2.00 / $1.00

[1] While this analysis does not consider the impacts of constructed projects, new projects could result in improved transportation system performance and therefore impact the results identified in this analysis.

Table 2-2: Toll Rates Analyzed for Cornelius Pass

Scenario	Cornelius Pass Pricing	Toll Rate (peak/off-peak)
1	No-Toll	NA
2	Low Toll	$1.00 / $0.50
3	Medium Toll	$2.00 / $1.00
4	High Toll	$4.00 / $2.00

For the purposes of the economic analysis, the discrete regional economic effects of tolling OR 217 are modeled separately from the effects of tolling Cornelius Pass. Modeling these proposed projects separately allows for a clear comparison of the nature of societal costs associated with the traffic patterns suggested by tolling at each location.

2.2 Conceptual Structure of Economic Analysis

Overall, it is expected that as tolls increase, two counteracting effects will occur:

(1) The tolls will lead to increasing diversion of passenger car traffic off of the tolled facility onto supporting arterial and/or local roadway systems. This may lead to longer trips and travel time due to congestion and lower design speeds on alternative routes.

(2) The tolls will reduce travel time and cost for remaining traffic on the tolled facility (due to reduced congestion) and improve the reliability of travel for drivers choosing to pay the tolls; especially trucks who will enjoy the less congested roadway without paying the toll. This is also likely to result in some reassignment of truck traffic onto the tolled facility and away from other routes. This induced-demand effect may even result in some trucks traveling longer distances to save time. This pattern is evident in the Cornelius Pass Road toll scenarios, where, travel time (truck VHT) eases but distance traveled (truck VMT) increases.

The methodology is based on the Transportation Regional Economic Development Information System (TREDIS).

2.3 Scope of Economic Costs and Benefits Considered

This economic analysis focuses on the regional effects of toll-related diversion at levels consistent with the given revenue analysis. Available traffic models provide relevant estimates of the change in vehicle miles and hours likely to result from toll-related diversion (due to users re-routing to avoid toll costs) at the given toll levels. The economic modeling monetizes changes in travel time, safety, reliability, environmental and vehicle operating costs directly attributable to toll-related diversion to assess how these changes affect regional earnings, output and employment[2].

[2] While some localized speed and capacity impacts are documented in localized traffic analysis of tolling scenarios, regional measures of aggregate congestion effects do not support a level of resolution on speed and capacity relationships to support conclusions about system-wide changes in operating costs due to congested speeds on particular diversion routes. Therefore, this economic analysis emphasizes the regional effects of diversion itself (as measured primarily by changes in VMT and VHT.) If more detailed traffic operation modeling were to find significant differences in congested operating speeds and that can be aggregated to the regional level, the economic findings presented in this Technical Memorandum could then be updated to reflect the user-costs of these congested operating speeds and their associated operating costs.

The Economic Development Research Group (EDR Group) TREDIS input-output methodology was used to derive these benefits. Earnings, output and employment are computed in the TREDIS methodology using input-output analysis applying ratios and multipliers from the Minnesota Implan Group (MIIG).

(3) ECONOMIC EFFECTS OF TOLLING

3.1 Vehicle Miles and Vehicle Hours of Travel

The effects of tolling are represented in the economic model by changes in vehicle miles and vehicle hours of travel (VMT and VHT). These two transportation performance indicators play a significant role as cost factors in the modeling of economic effects for different scenarios. Understanding the relative changes in VMT and VHT provides the foundation for understanding how different tolling scenarios provide relative economic savings in comparison to a "no-toll" baseline. Changes in VMT and VHT are the basis for estimating operating, time, reliability, safety, and other benefits (or dis-benefits) resulting from the tolling effects on traffic. Table 3-1 below compares the relative change in VMT and VHT of the three different tolling scenarios for OR 217 when compared to the "no-toll" baseline. Each tolling scenario represents a specific toll cost and the resulting changes in VMT and VHT for both autos and trucks within the region due to the toll. In general as toll rates increase, auto VMT and VHT also increase due to passenger car traffic departing from OR 217 to utilize slower, and potentially more congested arterial routes in avoidance of the toll. In the same way, truck VMT and VHT decrease as toll rates increase, because trucks exempt from the toll are able to enjoy less congestion on OR 217 due to autos diverting to avoid the toll. However, because so many more cars than trucks are affected by the tolling policy, the VMT and VHT increases for passenger cars far outweigh the VMT and VHT decreases for trucks.

Table 3-1: Total Annual VMT and VHT changes compared to No build scenario (OR 217)

Cost Factor	2035 VMT and VHT Estimates forOR 217 (increase or decrease "toll" vs. "no-toll")		
	Δ Low Toll	ΔMedium Toll	Δ High Toll
Auto VMT	2,752,124	3,126,563	3,550,763
Truck VMT	-142,540	-163,224	-188,031
Auto VHT	190,904	255,535	335,096
Truck VHT	-5,872	-6,865	-8,007

Figures 3-1 and 3-2 compare the VMT and VHT effects of tolling (relative to a no-build), respectively and indicate the relative changes for both autos and trucks. Figure 3-1, demonstrates how the effect of tolling leads to increases in Auto VMT and associated reductions in Truck VMT.

Figure 3-1 Auto and Truck Changes in VMT with Tolling OR 217

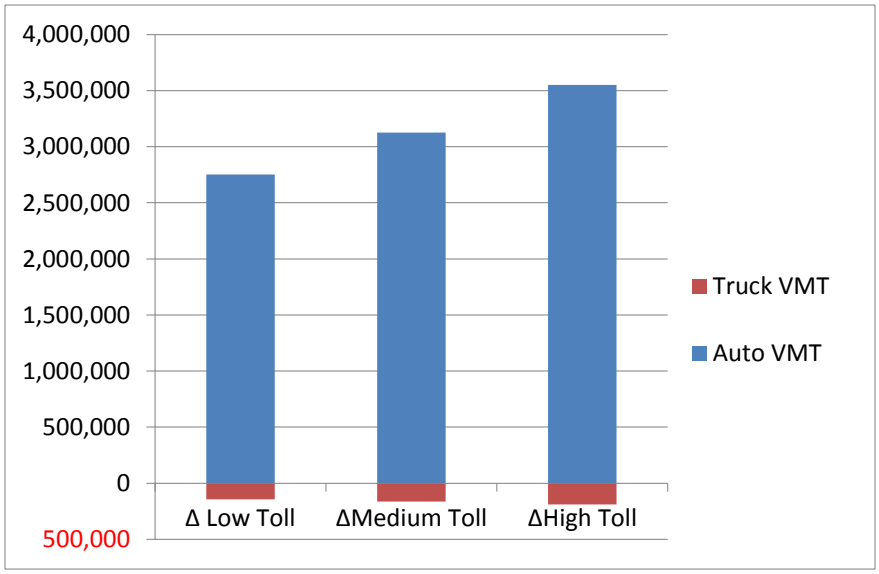


Figure 3-2 shows the changes in VHT for all the OR 217 tolling scenarios to be similar to the changes in VMT. Both Figure 3-1 and Figure 3-2 show how the magnitude of overall VMT and VHT increase for passenger cars significantly overtakes VMT and VHT savings which accrue to trucks.

Figure 3-2 Auto and Truck Changes in VHT with Tolling OR 217

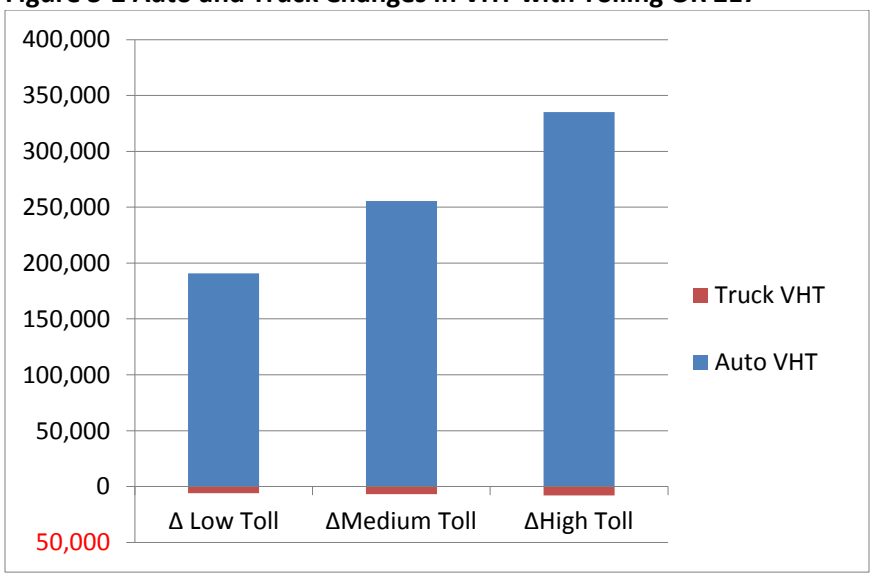


Table 3-2 shows the modeled change in VMT and VHT for cars and trucks with different toll levels on Cornelius Pass Road. The analysis shows a similar toll-to-VMT relationship as the tolling on OR 217 for passenger cars, with VMT increasing with higher toll levels. However, in the case of Cornelius Pass Road, truck VMT also increases, as the passenger car toll gets higher, although truck VHT decrease. This shows the induced demand effect of truck traffic re-routing and driving additional miles to save time by using the less congested Cornelius Pass Road (for which trucks are toll-exempt).

Table 3-2: Total Annual VMT and VHT changes compared to No build scenario (Cornelius Pass Road Road)

Cost Driver	2035 - (increase or decrease vs. "no-toll")		
	Δ Low Toll	ΔMedium Toll	Δ High Toll
Auto VMT	2,280,503	2,908,722	3,395,608
Truck VMT	278,601	352,687	416,382
Auto VHT	33,907	51,720	70,944
Truck VHT	-1,757	-1,656	-1,519

Figures 3-3 and 3-4 compare the VMT and VHT effects of tolling Cornelius Pass Road (relative to a no-toll), respectively and indicate the relative changes for both autos and trucks. Figure 3-3, demonstrates how the effect of tolling leads to increases in Auto and Truck VMT, but a reduction in Truck VHT.

Figure 3-3 Auto and Truck Changes in VMT with Tolling Cornelius Pass Road

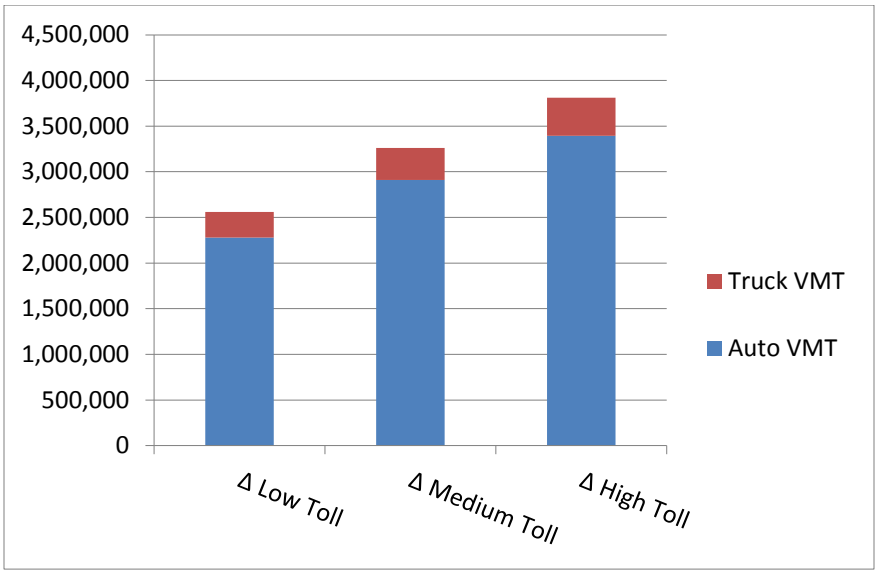
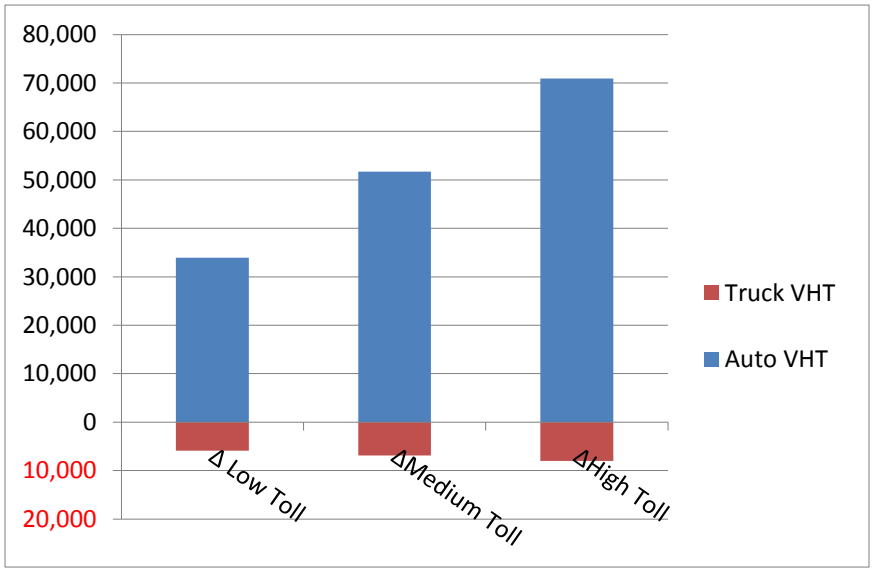


Figure 3-4 shows the changes in VHT for all the Cornelius Pass Road tolling scenarios to be similar to the changes in VMT. Both Figure 3-3 and Figure 3-4 show how the magnitude of overall VMT and VHT increase for passenger cars significantly overtakes VMT and VHT savings which accrue to trucks.

Figure 3-4 Auto and Truck Changes in VHT with Tolling Cornelius Pass Road



3.2 Percent Congested and Reliability

As a result of tolling, traffic may shift away from congested roadways , making additional capacity available and affecting travel time reliability. For the scenarios in this analysis, some facilities become more congested whereas others become less congested, and the effects differ between cars and trucks. For example, because of their toll-exempt status, trucks overall enjoy less congested conditions (and greater reliability benefit) as the toll rises. The effects for passenger cars are less consistent, and vary depending on the location within the overall study area, and the toll level analyzed, but overall passenger car traffic is more subject to reliability cost than truck traffic under all tolling scenarios.

The economic model places a monetary value on "buffer time" which can best be understood as the "window" around an expected travel time during which a trip may arrive at its destination, or a truck may arrive at its terminus. When there is more "buffer time", households and businesses have to allow for more uncertainty in the timing of activities and business operations. For this reason "buffer time" imposes greater costs on society than recurring travel time or delay, because regular travel time or delay can be built into household and business schedules minimizing time lost due to waiting to see how severe the traffic will be.

Research from the Center for Transportation Research (CTR) at the University of Texas, and the Texas Transportation Institute (TTI) along with research conducted for the US DOT Highway Economic Requirements System (HERS) informs methods for estimating buffer times based on overall system congestion levels. The methods are based on empirical research which has found that buffer times for cars and trucks increase with the share of the system that is operating at or above its capacity. The

economic model uses formulas from this research to determine buffer times based on the volume to capacity relationships estimated in the Metro model. Appendix II includes a detailed description of the basis for buffer time and reliability analysis and its role in the findings of the economic model.

3.3 Safety Effects of Re-assigning Freeway to Arterial

There are different safety impacts associated with re-assigning traffic from freeways to arterial roads and from arterial roads onto surface streets. While crash severity on higher speed roadways tends to be more severe crash rates (per vehicle) are much lower on freeways than on other roadways. The diversion of traffic onto lower speed surface streets therefore would be expected to result in more overall crashes, but a lower rate of severe crashes. Further safety analysis undertaken by DKS Associates has found that safety effects are likely to be concentrated within the areas of influence for the different tolls, but will not be of a magnitude likely to change the region-wide general fatality and severity rates assumed in the economic modeling. For this reason crash/safety related costs of tolling in this analysis are based on a fixed set of regional crash rates that are applied to the VMT and VHT changes found by the traffic model for all tolling scenarios.

3.4 Overall Economic Effects

Overall the findings show that tolling leads to traffic diversion that increases VMT and VHT for passenger cars on OR 217 and Cornelius Pass Road. The findings furthermore show that toll-exempt trucks enjoy reduced VMT and VHT on OR 217 and reduced VHT on Cornelius Pass Road. These increases in passenger car hours and mileage, and reductions in truck hours and mileage translate into overall economic costs and savings at the regional level, which affect the regional economy.

Tables 3.3 and 3.4 illustrate a summary of different economic costs or savings which are expected to be associated with the affected roadway systems when the different tolling scenarios are compared to the no-build (zero-toll) baseline on OR 217 and Cornelius Pass Road -- respectively. It should be noted that the operation and maintenance costs for the facility itself, as well as toll collection costs are included as "costs" (as it is assumed the operation and maintenance of the tolled facility as well as the toll collection costs would both have to be covered by the toll before any other revenue could be made available to offset the other societal costs).

Table 3.3: Cumulative Economic Effects of OR 217 Tolling Scenarios to 2035

Present Value of Cumulative Economic Effects of OR 217 Tolling Scenarios to 2035 Economic Effects of Tolling (In $2010 Million)			
Toll Levels	**Low**	**Medium**	**High**
Annual Direct Effects (Including Freeway O&M + Toll Collection)	-$12.00	-$7.60	-$2.90
Vehicle Operating Cost (Car)	-$21.30	-$24.20	-$27.50
Vehicle Operating Cost Savings (Truck)	$2.30	$2.70	$3.10
Business Time & Reliability Cost (Car)	-$23.70	-$31.70	-$41.70
Business Time & Reliability Savings (Truck)	$2.70	$3.20	$3.80
Personal Time & Reliability Cost (Car)	-$37.30	-$49.90	-$65.50
Safety Cost (Car)	-$6.20	-$7.00	-$7.90
Safety Savings (Truck)	$0.30	$0.40	$0.40
Shipper/Logistics Savings (Truck)	$0.90	$1.00	$1.20
Social/Environmental Costs (Overall)	-$0.90	-$1.00	-$1.20
TOTAL SOCIETAL ECONOMIC EFFECTS OF TOLLING	***-$95.20***	***-$114.10***	***-$138.20***

Table 3.4: Cumulative Economic Effects of Cornelius Pass Road Tolling Scenarios to 2035

Present Value of Cumulative Economic Effects of Cornelius Pass Road Tolling Scenarios to 2035 Economic Effects of Tolling (In $2010 Million)			
Toll Levels	**Low**	**Medium**	**High**
Annual Direct Effects (Including Freeway O&M + Toll Collection)	-$2.70	-$2.00	-$1.30
Vehicle Operating Cost or Benefit (Car)	-$17.60	-$22.50	-$26.20
Vehicle Operating Cost or Benefit (Truck)	-$4.50	-$5.70	-$6.80
Business Time & Reliability Cost or Benefit (Car)	-$4.20	-$6.40	-$8.80
Business Time & Reliability Cost or Benefit (Truck)	$0.80	$0.80	$0.80
Personal Time & Reliability Cost or Benefit (Car)	-$6.60	-$10.10	-$13.80
Safety Cost or Benefit (Car)	-$5.10	-$6.50	-$7.60
Safety Cost or Benefit (Truck)	-$0.10	-$0.20	-$0.20
Shipper/Logistics Cost or Benefit (Truck)	$0.30	$0.20	$0.20
Social/Environmental	-$1.10	-$1.40	-$1.60
TOTAL SOCIETAL ECONOMIC EFFECTS OF TOLLING	***-$40.80***	***-$53.80***	***-$65.30***

Overall, the analysis shows that the total societal dis-benefit (or societal cost) of the tolling program on OR 217 ranges from $95.2 Million with a low toll to $138.2 Million with a high toll. The largest source of societal cost in tolling OR 217 is from the personal and business time and reliability costs to diverted passenger car traffic. The second major source of societal economic cost is the vehicle operating costs for passenger car traffic, and associated safety and environmental costs of diversion. These economic costs accruing to passenger car traffic equate to more than 14 times the benefits accruing to toll-exempt truck traffic with a low toll and nearly 17 times the benefits accruing to toll exempt truck traffic with a high toll. When these effects are fully analyzed though the input-output (buyer-supplier) relationships in the economic model, it is found that the societal costs of tolling OR 217 are found to yield job loss to Portland's regional economy ranging from 308 with a low toll to 835 jobs lost with a high toll. Other adverse impacts include losses in output ranging from $28 Million to $89 Million and losses of personal income ranging from $8 Million to $30 Million.

For Cornelius Pass Road, the findings are similar, with the total costs accruing to passenger car traffic more than six times the benefits accruing to toll-exempt truck traffic with a low toll rate, and more than seven times the benefits accruing to toll-exempt truck traffic with a high toll rate. Overall, tolling Cornelius Pass Road is expected to yield an overall societal dis-benefit to the regional economy on the magnitude of $40.8 Million for a low toll, and $65.3 Million for a high toll rate. The societal costs of tolling Cornelius Pass Road are found to yield job loss to the regional economy ranging from 254 with a low toll rate to 517 jobs lost with a high toll rate. Other adverse impacts of the Cornelius Pass Road tolling scenarios include losses in output ranging from $33 Million to $65 Million and losses of personal income ranging from $8 Million to $20 Million.

3.5 Implications of Findings

The economic analysis finds the proposed toll levels are likely to result in significant losses to the regional economy even when it is assumed that all the proceeds of tolling are re-invested into Portland's government and business sectors (mostly by expenditures for collection costs and operation and maintenance of tolled facilities). Given the anticipated net revenues with a present value of only $1 Million for OR 217 and $9 Million for Cornelius Pass Road, it appears unlikely investment of toll revenue will generate sufficient transportation performance benefits to overtake these costs. It is furthermore assumed that in the absence of alternative toll-scenarios designed with rates and locations specifically targeted to reduce congestion and is associated costs, any congestion-pricing/mitigation effects cannot be assumed to offset the above mentioned societal costs at the given toll rates.

(4) CONCLUSIONS

From the above analysis, conclusions and recommendations are offered regarding the evaluation of tolling for OR 217 and Cornelius Pass Road in the Portland Metro Area. These conclusions are:

- Tolling at levels proposed for OR 217 and Cornelius Pass Road imposes economic costs on users significantly beyond any benefits expected to accrue from revenues raised.

- These costs are experienced in terms of transportation related costs on alternative facilities, as well as induced and indirect costs passed through the economy.

Appendix IA
TREDIS® Data Sources and Default Values
Version 3.6.4

www.tredis.net

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1 TREDIS v3.6.4 Documentation

This document is part of a suite that describes and supports TREDIS v3.6.4. It has two purposes. First, it indicates where TREDIS draws on default factors, providing source and reference information and information as to when to overwrite defaults. Second, for the broader set of background data contributing to final results, it discusses how this is incorporated into various modules and provides references to further information. Other documents in the suite include:

- *TREDIS Overview* – this explains some of the theoretical background and architecture at the executive level, putting its functionality in the context of economic modeling and objectives.

- *TREDIS User's Manual* – the user manual provides technical assistance with the model's online interface, including how to create a project, add, modify, and delete scenario data, and navigate through the results

- *TREDIS Case Studies* – these documents assist the user in modeling particular types of situations, addressing which input values to use for different impact type, potential data sources for their inputs, and how to interpret results in the context of the projects' overall goals.

- *TREDIS Technical Documentation* – this group of documents provides technical detail as to how inputs and background data are processed into final results, including a discussion of some of the underlying economic theory.

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2 Why Default Values?

TREDIS is a fully multi-modal analysis system, designed to allow users maximum flexibility in defining transportation investment and policy scenarios, with the ultimate purpose of estimating how these scenarios affect transportation and economic outcomes. This flexibility across passenger and freight modes requires that users have the ability to model detailed transport characteristics such as operating performance, unit cost factors, freight and passenger loadings, safety, or emissions factors (among many others). But with this flexibility also comes a need to ensure that reasonable values are adopted to generate believable results.

Moreover, final results – economic impacts or benefit/cost ratios – can be sensitive to specific default factors. As such, it is critical to make such factors fully transparent to users (with references) and provide guidelines as to appropriate ranges and when to deviate from those ranges. This need for transparency extends further, to cover all data sources used to generate final results – even those that cannot be changed as part of an investment or policy scenario. As will be discussed, these include baseline economic data and relationships, market access and connectivity factors, economic forecasts, and freight flows. This document describes TREDIS default data with precisely these goals in mind.

2.1 When to Use or Override Default Values

Analysts may rely on the default values for fixed factors unless they have reason to override them. However, they should understand that it is fully appropriate to override the defaults when:

- the study involves types of vehicles (and associated operating cost factors) that are different from the default average (e.g., transit system using mini-buses instead of standard buses; airport with general aviation rather than commercial aircraft); or
- the study area has vehicle passenger occupancy rates and/or freight loads that are different from the assumed defaults; or
- the study is being done in Canada, using Canadian rather than US dollars; or
- the study is being done in a state or province that has wage and income levels significantly different from the assumed national average, and the applicable government agency prefers to use values of time that reflect local wage rates; or
- the sponsoring agency dictates that different assumptions to be used

However, even when these situations apply, the new factors should remain within a reasonable range. In this document, where appropriate, upper and lower bounds are suggested to define the reasonable range based on: (a) the range of commonly available vehicle sizes and types, and (b) the range of operating cost and time valuation factors observed in published literature. Analysts are warned to be careful about using values outside of these ranges.

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3 TREDIS Default Data

TREDIS comes pre-loaded with an extensive database of information on the current characteristics of your study area(s) and modes. Broad categories, each of which is described below, are listed in the following table.

Default Database	Changes By	Fixed or Adjustable
Current Economic Patterns	Study Region	Fixed
Economic Forecasts	Study Region	Adjustable
Freight Flows	Study Region	Fixed[1]
Regional Accessibility and Connectivity Factors	Study Region	Adjustable
Unit Transportation Cost Factors	Mode, Trip Purpose	Adjustable
Modal Characteristics	Mode, Trip Purpose	Adjustable[2]

[1] *Average commodity mix and loading (tons/veh) can be modified as part of scenario design*

[2] *Modal characteristics are not automatically populated into scenario tables; factors are provided here for general guidance*

3.1 Current Economic Patterns

For U.S. applications, economic patterns are typically supplied by IMPLAN[1]. For each study region defined in TREDIS, this source describes industry production for each of the 55 sectors listed in Appendix A. Production is measured by four variables:

- *Output* – these are final sales, or total revenues, by industry. Depending on the industry, sales can be to any combination of other businesses, households, or the federal/state/local government.

- *Value Added* – this metric describes the value of goods sold by an industry over and above the value of goods purchased by it. It is generally used as a broad measure of value creation by an industry, including wage income, employee benefits, profits, and tax payments. Summed across all industries, total regional value added is precisely "Gross Regional Product".

- *Income* – this is total compensation (including benefits) to all employees of an industry, including business owners (proprietors).

- *Employment* – this is the total head count of workers in an industry, including self-employed, railroad workers, and agriculture workers. Because employment is measured as employee head count, it is important to note that a single individual with two part-time jobs is counted twice, regardless of which industries those jobs are in. Therefore, the job count is typically higher than "full-time-equivalent" employment.

[1] IMPLAN is a registered trademark of Minnesota IMPLAN Group.

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Beyond these industry metrics, IMPLAN data is used in a number of other places in TREDIS. This default data includes:

- *Economic Multipliers* – these are region-specific factors that translate a direct economic change into total economic impacts, including indirect (inter-industry supply-chain) effects, and induced (wage spending) effects. In IMPLAN, multiplier impacts are applied with source and target industry detail, meaning that it is possible to determine the effect of direct spending in one sector (say, construction) on another (say, retail).

- *Industry Make/Use Tables* – these are region-specific factors that indicate which commodities a single industry uses to produce its final goods, as well as which commodities are made by the industry. As such, they translate industry activity to commodity activity, which is used in TREDIS' Freight Module, as well as in determining which industries are affected by projects affecting freight modes.

- *Tax Receipts* – for Tax Module subscribers, IMPLAN is used to determine how changes in economic activity lead to changes in federal and state/local tax revenues. These are based on the current pattern of transfer payments in IMPLAN's social accounting structure.

Detailed descriptions and source information for all IMPLAN data is provided in the "Knowledge Base" section of IMPLAN's website (https://implan.com/V4/Index.php).

3.2 Economic Forecasts

The TREDIS forecasting module is typically supplied with Moody's Economy Dot Com (MEDC) projections, which include employment and value added forecasts for each TREDIS industry (see Appendix A for a list). For simplicity, economic projections are shown in TREDIS as indexes from the base year for each region. As with many other defaults, forecasts can be overwritten by users.

Moody's state and county forecasts are ultimately based on their U.S. National economic model (http://www.economy.com/store/samples/macromodel.pdf). This national forecast is combined with state, metro, and county data to allocate growth forecasts down to sub-national regions. The benefit to this approach is geographic consistency – that is, employment and value added always aggregates up (from counties to states and from states to national) without double-counting.

Allocations of employment and value added to states and counties are made based on the same government data sources used by IMPLAN to develop current economic characteristics. These sources include Bureau of Labor Statistics (BLS), Current Employment Survey (CES), and the Quarterly Census of Employment and Wages (QCEW), and Bureau of Economic Analysis (BEA).

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3.3 Freight Flows

The TREDIS Freight Module is typically supplied with data from Freight Analysis Framework (FAF), published by Federal Highway Administration (FHWA). The FAF database describes commodity flows for an entire year in terms of total tonnage and the value. This broad picture of commodity flows is indexed by a number of attributes. These include:

- *Origin and Destination* – FAF divides the United States into 114 regions. These may be states, metro areas, or "rest of state" areas. In addition, FAF defines 7 international regions. All commodity flows have an explicit origin and destination.

- *Commodity Description* – flows are indexed as one of 42 commodity types. These correspond to two-digit Standard Classification of Transported Goods (SCTG) groupings.

- *Transportation Mode* – all FAF flows are indexed as one of 7 transportation modes. These are truck, rail, marine, air, truck-rail intermodal, other intermodal, and pipeline/unknown.

Detailed definitions and descriptions of these indices are available in the following link (http://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2userguide/index.htm).

The current TREDIS version (v3.6.4) uses FAF^2 data. Thus, flows were calibrated using the 2002 Commodity Flow Survey (CFS) and the 2002 Vehicle Inventory and Use Survey (VIUS). However, all flows reflect 2008 economic activity. Since the initial calibration, FAF has published updated annual flow tables reflecting the growth in economic activity since the initial calibration year. The entire 2008 commodity flow database can be downloaded at (http://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2_pro.htm). The following link describes how the FAF gets updated for each year's data: (http://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2provisional_2008/rpt/index.htm)

Since the release of TREDIS v3.6.4, FHWA released FAF^3, which was calibrated using the 2007 Commodity Flow Survey. This data will be incorporated into future TREDIS versions.

3.4 Market Access and Connectivity Factors

The TREDIS Market Access module estimates how transportation system changes affect the region's economic geography – i.e., how the region's economy improves if businesses have better access to labor, customers, suppliers, and international markets (see separate documentation for further description). The statistical relationships applied by this module were estimated using a database of accessibility and connectivity factors for each US county. These factors are shown in Report 3a, and are also the default values used to populate the Market Access Input table which is used to define Scenarios. The sources and methodology behind each default value used in this module are described below.

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Population accessible within a 40 minute drive time – this variable is used as a proxy for labor market and consumer market access. TREDIS uses ESRI's Business Analyst Online service to calculate this factor and produce the corresponding map shown on Report 3a. For each individual county, the drive time is calculated from the population-weighted centroid of the county. Using population as a weight to determine the county's center better reflects the true center of economic activity in the county. From this point, ESRI calculates the area that can be reached within a 40 minute drive-time (with "average" network congestion), and sums total population within the area. Population estimates are based on census block-group and zip code data, with estimates adjusted to current (2010) levels. The following link discusses ESRI's population-location methodology (http://www.esri.com/library/whitepapers/pdfs/esri-data-tapestry-segmentation.pdf).

Employment accessible within a 3-hour drive time – this variable is used as a proxy for access to industrial supply chains. The three hour threshold is based on industry surveys indicating that this is about as far apart as two businesses can be and still have same-day truck delivery cycles. This default factor and corresponding map are estimated from the population-weighted centroid using ESRI's Business Analyst Online service. The following ESRI article describes how the database of business activity is maintained and located on maps (http://www.esri.com/library/whitepapers/pdfs/esri-data-business-locations.pdf)

Airport activity level (annual operations) – this variable reflects the total number of takeoffs plus landings per year at the nearest facility with domestic air-carrier traffic. This database is updated using the AirNav website (http://airnav.com/).

Average drive time to rail intermodal facility (minutes) – Oak Ridge National Laboratory's Center for Transportation Analysis gathered and published a list of U.S. intermodal rail facilities (these are available at http://cta.ornl.gov/transnet/Intermodal_Network.html; see http://cta.ornl.gov/transnet/terminal_doc/index.htm for methodology). For each county, drive-time was calculated by ESRI between the population-weighted centroid and the nearest rail facility.

Average drive time to domestic airport (minutes) – the list of airports with commercial service is from FAA (http://www.faa.gov/airports/airport_safety/airportdata_5010/). For each county, drive-time was calculated by ESRI between the population-weighted centroid and the nearest airport with domestic air-carrier traffic.

Average drive time to marine port facility (minutes) – Marine facilities were available from the same source as for rail facilities (see above).). For each county, drive-time was calculated by ESRI between the population-weighted centroid and the nearest rail facility.

Average drive time to international land border (minutes) – WISER Trade (http://www.wisertrade.org/home/index.jsp) was used to identify the 25 most active U.S. land border gateways in terms of commodity movements (by $). These were each given latitude/longitude coordinates. Drive-times were then calculated by ESRI from each U.S. County's population-weighted centroid to the nearest facility.

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Average drive time to international airport (minutes) – WISER Trade was used to identify the 25 most active airports for international import/export activity (by $ value of commodity movements). These were each given latitude/longitude coordinates. Drive times were then calculated by ESRI from each U.S. County's population-weighted centroid to the nearest facility.

3.5 Unit Transportation Cost Factors

Transportation cost factors are used to determine how changes in the volume and quality of trips translate to cost savings to households and businesses. These fall into four basic groups, all of which vary by mode and trip purpose:

Type	Can be Modified by	Default Factor
Time Cost Factors	Project, mode, trip purpose	Crew Time Cost ($/crewmember-hour)
		Passenger Time Cost ($/passenger-hour)
		Freight Time Cost ($/ton-hour)
		Buffer Time Cost ($/hr per vehicle trip)
Vehicle Cost Factors	Project, mode, trip purpose	Vehicle Mileage-based Operating ($/mile)
		Vehicle Time-based Operating Cost ($/hr.)
		Cost per Collision ($/occurrence)
		Cost per Personal Injury ($/occurrence)
		Cost per Fatality ($/occurrence)
		Environmental/Emissions Cost ($/mi)
Accident Rates	Scenario, mode, trip purpose	Collision Rate (occurrence/VMT)
		Injury Rate (occurrence/VMT)
		Fatality Rate (occurrence/VMT)
Vehicle Loadings*	Scenario, mode, trip purpose	Average Crew Size
		Average Passenger Occupancy
		Average Freight Cargo (tons)

** Vehicle loading factors are provided for guidance, but are not automatically populated into the corresponding fields in the Travel Demand Characteristics input table (Scenario Page). All other factors automatically load into the appropriate TREDIS table.*

Interpreting Default Values for Economic Concepts

TREDIS, because it uses the same basic transportation cost factors for both benefit/cost analysis and economic impact analysis, has to carefully distinguish social benefits from business impacts for all modes. This affects the way that default values are expressed in the table that follows. This includes the following effects:

- Values may appear higher than those used in some previous studies due to updating. While the system typically calculates benefits and impacts over a long time horizon (e.g., 25-30 years), all analysis is done in constant dollars. Currently, default values and ranges are expressed in constant 2009 or 2010 dollars, and findings on default

values from earlier studies have been adjusted upward to reflect those constant year values.

- Values are sometimes different for traveler benefit valuation and total economic impact. Different trip purposes are assigned to different benefit and impact classes. Time savings for personal travel is classified as a social benefit value that affects benefit/cost ratios but does not have any impact on the flow of income in the economy. Time savings for business travel is classified as a business operating cost change affecting both benefit/cost ratios and economic impacts. Time savings for commuting has elements of both of these classifications (a social benefit for affected households, but also an element of wage rate impact for businesses), as explained in the footnotes.

- Some but not all values are increased by the role of fringe benefits in long-term impacts. Fringe benefits come into play in different ways for different trip classes. For economic impact studies, the valuation of business travel time is measured as the long-term business cost. While delay in the short-term may cause workers to put in more hours to complete deliveries, continued delays over a long-term period will require affected businesses to hire more workers to complete a given set of deliveries. Hence the need to add fringe benefit costs in the long-term business travel time value. Other classes of travel also have time valuations pegged to wage rates, but they do not lead to additional worker hiring so their values do not incorporate fringe benefits.

The table which follows shows default values for each factor, along with the normally acceptable range. These ranges were set on the basis of actual variation observed in vehicle sizes (affecting occupancy and operating costs) and the observed range of time valuation factors used in studies over the past decade. The table also denotes whether the various factors are normally used in (1) traditional benefit/cost studies focusing on traveler benefits and/or (2) economic impact analysis.

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Economic Impact Modeling Factor	Default Value		Acceptable Range	Factor in traveler benefits	Factor in economic impacts
Crew Time Cost ($/hr per crew member) – the business cost of labor for professional drivers and paid crew (including cost of wages plus fringe benefits). <See note A>	Car: Truck: Bus: Rail-transit: Rail-freight: Aircraft: Ship:	$21.60 $25.02 $22.31 $30.84 $33.42 $77.84 $42.33	18 – 25 18 – 40 15 – 30 20 – 45 20 – 45 50 – 99 25 – 50	X X X X X X X	X X X X X X X
Average Crew Size (number) – including professional driver/ pilot and supporting paid crew. (This should be customized for the applicable location and type of vehicles.) <See note B>	Car: Truck: Bus: Rail-transit: Rail-freight: Aircraft: Ship:	0.0 1.2 1.0 2.0 2.0 4.7 (no default)	0 – 1 1 – 2 1 – 2 1 – 4 1 – 4 1 – 12 1 – 1,000	N.A.	N.A.
Passenger Time Cost ($/hr per occupant) – the business opportunity cost, or user valuation, of the average passenger's time. This is in addition to the passenger vehicle operating cost per hour. The same values apply for in-vehicle and out-of-vehicle time (except for transit OVTT = out-of-vehicle). <See note C>	<u>Ground Transport:</u> *(car-truck-bus-rail)* On-the-Clock: Commute *=user benefit* *+wage premium* Personal: *(transit OVTT* <u>Air Transport:</u> Business Commute Personal	 $27.50 $21.20 *$10.60* *$10.60* $10.60 *$21.20)* $40.10 $33.30 $33.30	*( ) = public transit* 20 (10) – 40 16 (8) – 35 10 (5) – 16 *(10 – 16)* 25 – 50 20 – 40 20 – 40	 X X - X X X X X	 X X X -- -- X X --

Economic Impact Modeling Factor	Default Value		Acceptable Range	Factor in traveler benefits	Factor in economic impacts
Buffer Time Cost ($/hr) – the business opportunity cost, or user valuation, of lost scheduling time due to unreliable travel conditions (i.e., effect of "schedule padding"). <See note D>	Passenger Modes: *Same as above* Truck Freight: non-mfg goods Non-dur. mfg: Durable mfg.:	 $0.75 $2.25 $5.00	 0 - 2 0 - 5 0 - 15	 X X X	 X X X
Average Passenger Occupancy (number) – the total number of occupants excluding professional driver and supporting paid crew. (Note: in most cases, the car driver is counted as an occupant and not a crew member.) <See note E>	Car: Truck: Bus: Rail-pass: Rail-freight: Aircraft: Ship:	1.5 0 10.5 120 0 105 (no default)	0 – 5 0 – 4 1 – 60 1 – 600 0 – 4 0 – 400 0 – 1,000	N.A.	N.A.
Freight Logistics Time Cost ($/hr. per ton) – business opportunity cost of freight delay, including shipper inventory, dock handling & consignee schedule disruption. <See note F>	Truck & Air only non-mfg goods: Non-dur. mfg: Durable mfg.:	 $0.75 $1.50 $2.50	 0 - 2 0 - 4 0 - 8	 -- -- --	 X X X
Average Freight Cargo (tons) – the total number of tons of freight per vehicle <See note G>	Truck: non-mfg: Truck: mfg goods: Rail-freight: Aircraft: Ship:	1.0 17.5 3,024 4.6 14,000	0 – 10 8 – 25 25 – 5,000 0 – 6 0 – 30,000	N.A.	N.A.
Vehicle Mileage-based Operating Cost: Free Flow ($/mile) – the average per-mile cost of vehicles' fuel, tires, maintenance, and depreciation for travel in free-flow conditions. <See note H>	Car: Truck: Bus: Train: Air: Ship:	$ 0.58 $ 1.18 $ 1.45 $ 8.21 $16.45 $25.00	0.30 – 0.90 0.9 – 1.5 1 – 2 5 – 12 5 – 25 1 – 100	X X X X X X	X X X X X X

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Economic Impact Modeling Factor	Default Value	Acceptable Range	Factor in traveler benefits	Factor in economic impacts
Vehicle Mileage-based Operating Cost: Congested ($/mile) – the per-mile costs of roadway vehicles operating under congested roadway conditions. <See note I>	Car: $0.64 Truck: $1.46 Bus: $1.55	0.35 – 1.2 1.15 – 1.75 1 – 2	X X X	X X X
Vehicle Time-based Operating Cost: ($/hour) – the average per-hour cost of vehicles' fuel, tires, maintenance, and depreciation for travel. <See note J>	Air: $3,650.00 Ship: $260.00	3,000 – 4,000 200 – 1,000	X X	X X
$ per Accident <See note K>	<u>Cars and Trucks:</u> Prop Damage $ 3,160 Pers. Injury $ 83,520 Fatality $ 6,000,000 • *Econ cost* *$1,221,500* • *Social adder* *$4,778,500*	1,000 – 5,000 80,000 – 250,000 $ 2.6m – 8.5m	X X X X	X X X --
***Accident Rates*:** All rates shown are per 100m Vehicle Miles Traveled <See note L>	<u>Passenger Car /Truck:</u> Prop Damage 206 /198 Pers. Injury 90 /12 Fatality 1.5 /0.4 <u>Public Transit:</u> Pers. Injury 585 Fatality 7.6 <u>Air Travel:</u> Pers. Injury 0.184 Fatality 0.012	100 – 300 50 – 150 0 – 5 400 – 800 0 – 20 0 – 1 0 – 1	N.A.	N.A.

Economic Impact Modeling Factor	Default Value	Acceptable Range	Factor in traveler benefits	Factor in economic impacts
Environmental Cost: Mileage-Based ($/vmt) — cost of air pollution and greenhouse gases per vehicle-mile of travel <See note M>	Car: $0.028 Truck: $0.05	0 – 1 0 – 1	X X	-- --

Notes:

- **Crew wages** are drawn from the BLS National Compensation Survey (issued June 2007) for applicable transport occupations, with 40% added for fringe benefits (national average in those occupations). Values for truck drivers, bus drivers and train engineers are published BLS values for those occupations, plus fringe benefits. Values for aviation are based on weighted average of $34.11/hr. for flight attendants and $94.47/hr. for pilots, plus fringe. Values for marine (ferry or freighter) are based on weighted average of $13.11 for sailors and $30.04 for ship engineers, plus fringe. Source: http://www.bls.gov/ncs/ocs/sp/ncbl0910.pdf

- **Default crew size** for all modes are drawn from typical values for New York City, San Francisco and Chicago, as reported in Chester, Mikhail, Institute of Transportation Studies, UC Berkeley, 2008.

- **Values of time** shown here are generally consistent with methods for valuing *user travel time benefits* as followed by HERS and BCA.Net software, as well as CUTR and USDOT guidance. However, values have also been updated to reflect 2007 wage rates (average of all occupations, not just transport occupations), based on BLS wage data. Also, additional long-term business costs (beyond the user value of travel time) have been added in the form of fringe benefit costs for "on-the-clock travel" and wage premiums paid by employers for commuting in higher-cost congested areas. As a result, car/light truck "on-the-clock" travel time is calculated as a business cost valued at 100% of the national average wage rate plus 30% fringe. Both commuting and personal travel time are treated as a non-money user benefit with a value set at 50% of the wage rate (no fringe added). For economic impact analysis only, there is an additional allowance for the effect of higher commuting cost on employer cost in the form of a wage rate premium valued at another 50% of the wage rate per hour without fringe (per research by Zax et al.). For public transit, the wider range reflects possible variation in riding conditions, as noted by CUTR: "*Transit travel time should be valued at 25 - 35 percent of prevailing wage under comfortable conditions (when sitting), but can be significantly higher for crowded transit vehicles (100% of wage rate) or for waiting under unpleasant conditions (up to175% of wage rate).*" For out-of-vehicle transit time, TREDIS uses 100% of the wage rate, but allows for a wider range of values.

- **The costs of travel time variability** (non-recurring delay) is calculated using the concept of "buffer time", which is defined as the additional schedule time needed to ensure an on-time arrival 95% of the time (19 out of every 20 trips) versus the average travel time. For example, If a weekday commute normally (i.e., on average) takes 30 minutes to complete, but unplanned congestion causes 5% of trips (about 1 per month) to take 45 minutes, then the commuter must schedule 45 minutes for the trip on the average day to ensure an on-time arrival (even though it is likely to only to take 30 minutes). This trip therefore requires 15 minutes of "buffer time". For passenger travel, buffer time has been shown to be valued similarly to travel time unless a schedule constraint exists (see CUTR). For Freight Trucks, the value of buffer time

can vary widely for carrier types and commodity, but is generally higher than passenger travel (relative to travel time). USDOT reports that the value of reliability can vary from 20% to 250% of "standard" delay (http://ops.fhwa.dot.gov/freight/documents/improve_econ.pdf).

- **Typical passenger loadings** for all modes are drawn from typical values for New York City, San Francisco and Chicago, as reported in Chester, Mikhail, Institute of Transportation Studies, UC Berkeley, 2008.

- **Freight logistics cost** is estimated on the basis of values assigned for recurring travel time delay from HEAT documentation, based on literature review and additional research by Cambridge Systematics and EDR Group. These logistics cost values, added to crew cost and vehicle operating cost, yield total freight costs per hour in line with TTI congestion studies.

- **Typical Cargo loadings** for trucks come from the USDOT Comprehensive Truck Size and Weight Study; data for rail is from the Association of American Railroads www.aar.org/PubCommon/Documents/AboutTheIndustry/Statistics.pdf ; data for water transport is based on 1000 TEUs per ship at 14 tons per TEU from InfoMare and NY/NJ port; data for air transport from Bureau of Transportation Statistics.

- **Vehicle operating cost per mile: for free flow conditions is defined for cars as an average** of small, medium and large cars and SUV; source AAA. Truck cost is based on FHWA Truck Size and Weight Study, with cost/mile ranging from $1.03 - $1.38 depending on speed.

- **Vehicle operating cost per mile: for congested road conditions** is based on auto fuel consumption estimates from US EPA and truck fuel consumption estimates from Berwick and Farooq (2003), using an assumptions of stop-and-go travel conditions (as defined by US EPA at www.fueleconomy.gov and with a long-term (30-year) fuel cost of $4.00 per gallon.

- **Per hour operating cost** is to be used for modes where vehicle operating cost is most easily measurable on a time-basis (air and marine). The operating cost/hour for water freight cost/mile ranges from $242/hour for 11,000 ton vessel to $491/hour for 265,000 ton vessel; default represents a 90,000 ton vessel. 2008. Airline costs are from www.airlines.org/economics/cost+of+delays/

- **Accident costs** are derived from the following sources: total fatality cost including both money costs and social value of lost life (lifetime earnings) is from "Treatment of the Economic Value of a Statistical Life in Departmental Analysis – 2009 Annual Revision," USDOT, Memorandum to Modal Administrators, March 18, 2009. http://ostpxweb.dot.gov/policy/reports/VSL%20Guidance%20031809%20a.pdf.

- Detailed values for injury and property damage are drawn from Blincoe, L. et al. (2002). *The Economic Cost of Motor Vehicle Crashes, 2000* (Table 2) and then

updated from 2000 dollars to 2008 dollars by the CPI change (25%). http://thedesignstate.com/wp-content/uploads/2009/04/economicimpact2000.pdf The difference between total fatality valuation and fatality cost is attributed to social valuation of lost life.

- **Accident rates** are from Bureau of Transportation Statistics: http://www.bts.gov/publications/national_transportation_statistics/#chapter_2.

- **Environmental costs** per VMT can include a wide variety of air pollution, water pollution, noise pollution and land quality/use impacts. However, the default values shown here include only costs associated with air pollutants defined by the Clean Air Act (NOx - nitrogen oxides, SO_2 - sulfur dioxide, PM - particulate matter and VOC - volatile organic compounds) plus greenhouse gases.

- For the Clean Air Act pollutants, the total cost per VMT is estimated to be 1.1c for cars and 3.9c for large trucks (source: FHWA: *1997 Federal Highway Cost Allocation Study Final Report Addendum*, Federal Highway Administration, USDOT, 2000, Table 12. For greenhouse gases, the total cost per VMT is estimated to be 1.7c for cars and 2.4c for trucks based on Littman (Todd Littman: "Climate Change Emission Valuation for Transportation Economic Analysis," VTPI, 2009 and drawing from *Transportation Energy Data Book*, Oak Ridge National Laboratory, 2008). Also shown in Table 5.10.7-2 of Littman: Transportation Cost and Benefit Analysis II – Air Pollution Costs, Victoria Transport Policy Institute, updated 2009. Note that there are also some studies that have derived values based on changing market values for emission credits; these sources have been used to derive estimates as high as 5c per VMT for cars and 26c/vmt for trucks.

4 USER INPUTS

The following list shows available user inputs. See TREDIS User Guide and appropriate Case Studies for more explicit guidance on sources for these inputs.

Available Modes - sub-modes may be defined as desired (examples in parentheses)

- Cars (may split by trip purpose: work, commute or personal):
- Trucks (may split delivery vans, light trucks, heavy trucks, multiple trailer, etc.)
- Transit (may split by trip purpose or sub-mode: van, regular bus, BRT, light rail, etc.)
- Rail (may split freight, commuter rail, inter-city passenger, high speed rail, etc.)
- Marine (may split passenger ferry, car ferry, barge, freighter, cruise ship, etc.)
- Air (may split general aviation, air taxi/charter, freight, prop, regional jets, full size commercial airliners, jumbo jets, etc.),

Modal Characteristics

- Avg. Vehicle occupancy (passengers)
- Avg. Driver/crew size (commercial services)
- Avg. Cargo carried (tons)
- Avg. fare, toll, road user fee or freight fee
- Cargo mix (default or user-selected commodity mix)
- Operating costs/mile (or per km)
- Fuel economy (miles/gallon or per liter)
- Emission rates (various pollutants and CO, per mile or per km)

Traffic Characteristics

- Volume, speed or average trip distance
- Baseline traffic growth rate (annual rate)
- VMT vehicle miles traveled (or VKT vehicle kilometers traveled)
- VHT vehicle hours traveled
- Congestion levels (volume/capacity ratio, or percent of major routes congested)
- Reliability (time variability or buffer time)
- Safety (accident rates: mortality, injury, property damage)
- Induced travel

Origin/Destination Patterns

- Fraction of trips internal to study area (local origin and destination)
- Fraction of trips with coming into the study area (outside origin, local destination)
- Fraction of trips leaving the study area (local origin, outside destination)
- Fraction of trips passing through the study area (outside origin and destination)

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Access Characteristics

- Size of labor and shopper markets (population within 40 minute travel time)
- Size of same day truck delivery market (employment within 3-hour travel time)
- Average road access time to commercial airports (and activity scale of the airport)
- Average road access time to marine port
- Average road access time to an intermodal rail terminal
- Average road access time to international gateway airport

Policy, Program or Project Attributes

- Regulation or Restrictions on Use of Facility or Equipment (e.g., truck lanes, carpool lanes, bridge weight limits, airport runway limits, port vessel size limits)
- Charges for Use of Facility or Equipment: Tolls, Taxes, Fees (per vehicle, per trip, per mile, or per fuel unit; for specific facilities or areas)
- Cost of Constructing or Reconstructing Facility & Purchasing Equipment (total, over time, by type)
- Cost of Operating Facility & Equipment (total, allocation over time, budget elements)
- Public/private partnership roles (finance, operation, revenue collection)
- Contingent development (dependent on transport access investment)

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Appendix A: TREDIS Sectoring Scheme

NAICs Sector(s)	Description
111	Crop Production
112	Animal Production
113	Forestry & Logging
114	Fishing, Hunting & Trapping
115	Support for Agriculture & Forestry
211	Oil & Gas Extraction
212-213	Mining & Support Activities
221	Utilities
230	Construction
311	Food Products
312	Beverage & Tobacco Products
313	Textile Mills
314	Textile Product Mills
315	Apparel Manufacturing
316	Leather & Allied Products
321	Wood Products
322	Paper Manufacturing
323	Printing & Related Support Activities
324	Petroleum & Coal Products
325	Chemical Manufacturing
326	Plastics & Rubber Products
327	Nonmetallic Mineral Products
331	Primary Metal Manufacturing
332	Fabricated Metal Products
333	Machinery Manufacturing
334	Computer & Electronic Products
335	Electric Equipment, Appliances, etc.
336	Transportation Equipment
337	Furniture & Related Products
339	Miscellaneous Manufacturing

NAICs Sector(s) Cont'd	Description
420	Wholesale Trade
441-454	Retail Trade
481-487	Transportation
491-493	Mail, package delivery & warehousing
511	Publishing Industries (except Internet)
512	Motion Picture & Sound Recording
513	Broadcasting
514	Internet & data process svcs
521-523	Monetary, Financial, & Credit Activity
524	Insurance Carriers & Related Activities
525	Funds, Trusts, & Other Financial Vehicles
531	Real Estate
532	Rental & Leasing Services
533	Lessors of Nonfinancial Intangible Assets
541-551	Professional Scientific, Technical, Services
561	Administrative & Support Services
562	Waste Management & Remediation
611	Educational Services
621-624	Health Care & Social Services
711-713	Amusement & Recreation
721-722	Accommodations, Eating & Drinking
811-812	Repair, Maintenance, & Personal Services
813	Religious, Civic, Professional, Organizations
814	Private Households
920	Government & non NAICs

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Appendix IB:
TREDIS® Technical Document:
Travel Cost Module
Version 3.6.4

www.tredis.net

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1 Introduction

This technical document describes the Travel Cost Module which is one of the core modules within TREDIS, the Transportation Development Impact System. This document looks at how changes in the amount, type, and quality of travel translate into user and nonuser benefits, as well as direct economic impacts.

1.1 The TREDIS Modular Structure

TREDIS is an integrated economic impact model and analysis system for transportation planning and project evaluation, designed to cover a wide range of applications including the assessment of benefits, costs, finance and macroeconomic impacts of alternative projects, plans and programs. It covers all passenger and freight modes, and it assesses costs, benefits, and impacts across a range of economic responses and societal perspectives. To integrate this range of features, TREDIS operates as a set of interconnected "core" modules as shown in Figure 1:

- *Travel Cost*
- *Market Access*
- *Economic Adjustment*
- *Benefit/Cost*

In addition to the four listed above, TREDIS has two optional modules that can be used to gain further insight and analytical power. These are the *Finance and Freight Modules.*

The Travel Cost module, the focus of this document, looks at how changes in the amount, type, and quality of travel translate into user and nonuser benefits, as well as direct economic impacts. The Market Access module, considers the network effects of travel – how changes in access to markets improve conditions for business growth and productivity. Together, these two modules constitute the direct impacts of a transportation project or policy. These direct impacts are then sent to the Economic Adjustment module to estimate secondary (indirect and induced) economic effects, and also to the Benefit-Cost module, to itemize and discount costs, benefits, and impacts for the project's life. Along the way, the freight and tax modules draw on additional data sources and inputs to indicate a project's impacts relative to the concept – for example, the tax module shows additional tax receipts associated with project impacts, and the freight module shows how commodity flows are affected.

If enabled, the freight, finance and tax modules draw on additional data sources and inputs to indicate a project's impact on freight flows, project cash flows finance and tax revenues.

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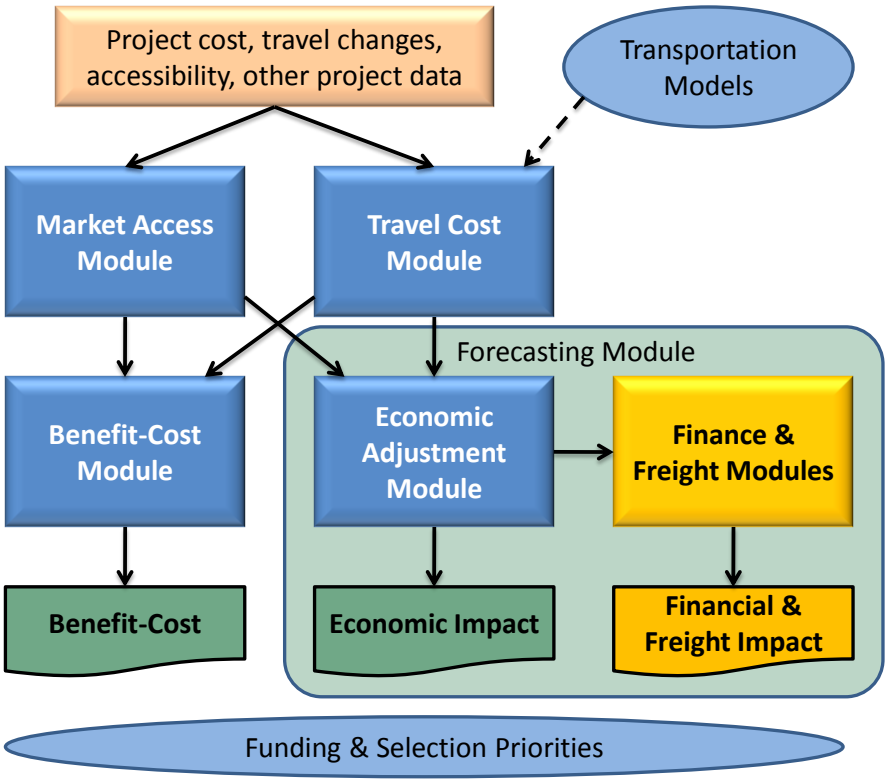

Figure 1 - TREDIS Modules

1.2 A Comprehensive Suite of Documents

This technical document is part of a suite that describes and supports TREDIS v3.6.4. The current document provides a technical explanation of the Market Access module, including underlying economic theory, data, and methodology. The entire suite of documents consists of:

- *TREDIS User's Manual*
- *Data Sources and Default Values for Multimodal Transportation Studies*
- *TREDIS Overview*
- *TREDIS Case Studies*
- *TREDIS Technical Documentation*

2 Module Overview

The Travel Cost module translates changes in the quantity, quality, and type of travel into cost changes for households and businesses (see Figure 2, next page). The type of travel is defined by the modes chosen, the trip purposes, and additional information such as passenger or freight occupancy. TREDIS offers the following passenger and freight modes:

- *Passenger Car*
- *Passenger Bus*
- *Passenger Rail*
- *Passenger Air*
- *Passenger Ferry*
- *Truck Freight*
- *Rail Freight*
- *Air Freight*
- *Marine Freight*

Each of the passenger modes is further specified by trip purpose (*on-the-clock*, *commute*, or *personal*) to combine for 19 possible mode-trip purpose combinations. Beyond this list, any mode or trip purpose may be customized according to the user's needs. For example, if a project requires two vehicle classifications for Freight Truck (perhaps separating delivery trucks from tractor-trailers), then a standing set of customizable modes may be used for this purpose. Variants on transit modes (for example, articulated electric bus versus standard diesel bus) as well as non-motorized modes can be handled in this way as well.

Generally, the quantity of travel is described by data such as Trips, Vehicle Miles Traveled (VMT), Vehicle Hours Traveled (VHT), and passenger and freight occupancy, while travel quality is reflected in terms of congestion, safety, and tolls. The Travel Cost Module uses default factors to translate these travel metrics into costs accruing to passengers, vehicle operators ("carriers"), freight shippers, and society. The defaults are fully referenced in the document *Data Sources and Default Values for Multimodal Transportation Studies*, but may also be overwritten by the user. Project benefits are estimated by considering two scenarios side-by side – i.e., travel costs under a no-build scenario versus costs after building a piece of infrastructure.

Inputs to the Travel Cost Module can be generated by sketch planning methods, spreadsheets, capacity databases (such as HPMS), surveys, or travel demand models. Because the inputs are general to the quantity and quality of travel, there are no restrictions as to the type of model generating them. For example, TREDIS has been used with a variety of travel models and data sources, including EMM2, TRANUS, TRIPS, TransCAD®[1], TranPlan, Cube Voyager, and HERS.

[1] TransCAD is the registered trademark of Caliper, Corporation. All other trademarks are the property of their respective owners.

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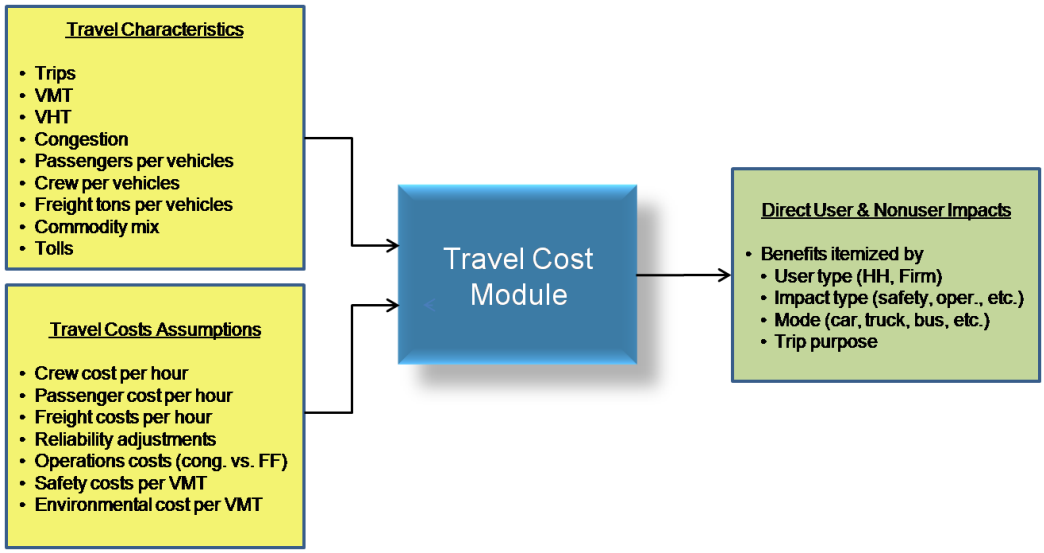

Figure 2 - TREDIS Travel Cost Module Input and Output Factors

3 Estimating Travel Costs

This section provides detailed descriptions of how all travel costs are calculated by TREDIS. Travel costs fall into two categories: user costs and non-user costs. User costs are those that accrue to the traveler (broadly defined), which may be the passenger, the driver or crew, or the shipper/receiver of freight travel[2]. Non-user costs are those arising from transportation that do not accrue to users, but are rather felt by society at large.

User Costs

- *Passenger time costs*
- *Crew time costs*
- *Freight time costs*
- *Reliability costs*
- *Vehicle operating costs*
- *Accident costs*
- *Toll/fare costs*

Non-User Costs

- *Emissions*

Each cost category is monetized based on levels of travel characteristics (Trips, VMT, VHT, vehicle occupancy and loadings, etc), and value factors suggested by regulatory guidance and a literature review about the value of the concept to traveler (See Figure 2). For a full discussion of monetization rates, see separate document: *Data Sources and Default Values for Multimodal Transportation Studies*.

Before proceeding, it should be noted that travel costs are calculated as cost levels for each scenario separately. Project impacts are then estimated as the difference in costs between the two scenarios (in TREDIS this is called a *Case*). More explicitly, for a project with two scenarios, *build* and *no-build*, the Travel Cost module estimates the costs for each scenario independently (using the same methodology) before differencing the two scenarios to find the cost savings. In all the following equations, the superscript s is used to indicate a single scenario.

The Travel Cost module also itemizes travel costs by mode and trip purpose (denoted as the subscripts m and p in the following equations). This is important for two reasons. First, unit cost factors used to monetize each cost type vary with mode and trip purpose. As a simple example, time spend making a personal trip typically has a lower opportunity cost than on-the-clock travel. Second, in order to estimate economic impacts (see separate documentation of the *Economic Adjustment* module), transportation cost savings must be allocated to households and industries. This allocation is made based on which modes and trip purposes are affected.

[2] For a further discussion, see FHWA's website on incorporating freight in benefit/cost analysis, which has some excellent technical and non-technical reviews: http://ops.fhwa.dot.gov/freight/freight_analysis/cba/index.htm.

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3.1 User Costs

3.1.1 Passenger Time Cost

Passengers have an opportunity cost to time spent traveling. For a single scenario *s*, and for each mode/trip purpose combination *mp*, passenger time costs are the product of total *VHT*, passengers per vehicle (*PassPerVeh*), and the cost rate per hour of passengers.

$$PassengerCost_{mp}^{s} = VHT_{mp}^{s} * PassPerVeh_{mp} * PassengerCostPerHr_{mp}$$

3.1.2 Crew Time Cost

For each mode/trip purpose combination, crew time costs are calculated as total vehicle hours traveled (*VHT*) times crew cost hour (*CrewCostPerHr*), multiplied by the number of crew (*CrewPerVeh*) needed to operate the vehicle.

$$CrewCost_{mp}^{s} = VHT_{mp}^{s} * CrewPerVeh_{mp} * CrewCostPerHr_{mp}$$

3.1.3 Freight Time Cost

As with passengers and crew, freight travel time has an opportunity cost, which is related to handling or storage costs, lost sales or late delivery penalties, or production costs associated with holding extra inventory or raw materials. The following equation is used to calculate freight time costs for a single scenario and mode/trip purpose:

$$FreightCost_{mp}^{s} = VHT_{mp}^{s} * \sum_{c}\left[\left(AvgTonsPerVeh_{mp}^{s} * CommodityMix_{mp,c}^{s}\right)\left(AvgCostPerTonHr_{mp} * CommodityValueFactor_{c}\right)\right]$$

This is total vehicle travel time *VHT* times a weighted average of cost per vehicle-hour, where the weighting is based on the commodity mix (commodity is denoted by the subscript *c*) and the relative cost per hour of each commodity.

3.1.4 Reliability Costs

Beyond creating delay and higher vehicle operating costs, congestion has the effect of increasing the variability of travel times. Travel time variability relates to how long it takes to complete the same trip on different days. Consider a morning commute, where a driver makes the same trip roughly 20 times per month. If he or she can make the trip in about 30 minutes almost every day, then that trip is very reliable. If, on the other hand, the same trip sometimes takes 35, 45, or 60 minutes, then the travel time is highly variable, and the driver must budget extra time into his or her commute. As with in-vehicle travel time, this extra “schedule”, “float”, or “buffer” time has an opportunity cost because it infringes on work and leisure activities.

The Travel Cost module estimates the costs of buffer time by multiplying the total number of trips by the average buffer hours per trip and the average cost per hour of buffer time:

$$ReliabilityCost_{mp}^{s} = VehTrips_{mp}^{s} * BufferTimePerVehTrip_{mp}^{s} * CostPerBufferHr_{mp}$$

This formulation has the benefit of being highly general, so that costs for any type of "out of vehicle" time can be calculated. For example, transit travel time is frequently split between in-vehicle and access/wait/transfer time. In TREDIS, the latter can be accounted for separately by simply entering the average out-of-vehicle time per trip.

For cars and trucks, TREDIS provides an auto-fill option that automatically estimates the amount of buffer time needed for the given congestion characteristics entered by the user. The buffer time estimate is based on empirical relationships between buffer time and congestion. This relationship is summarized in Figure 3.

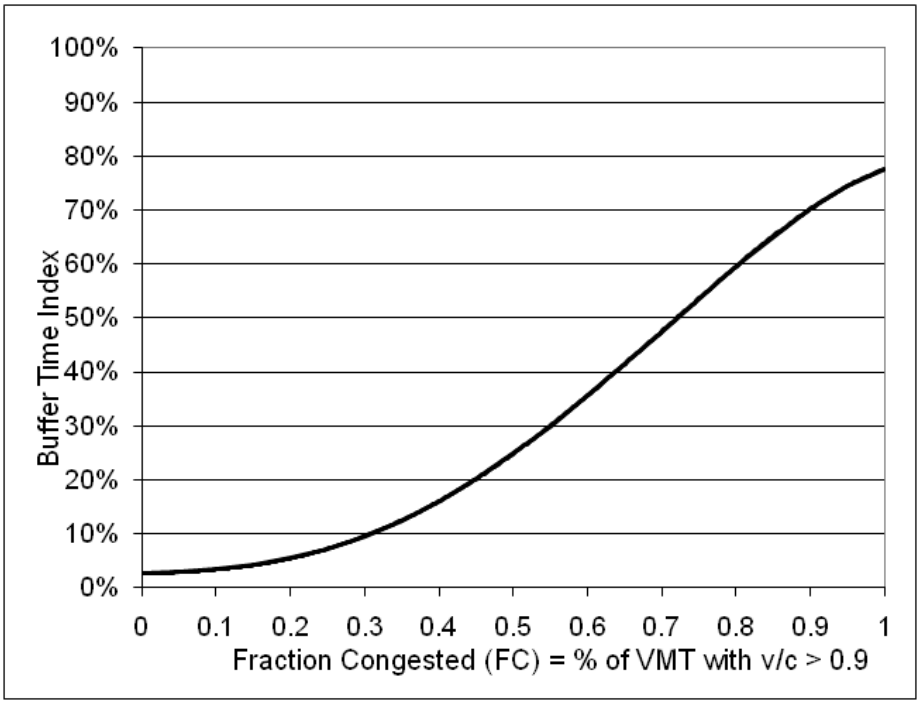

Figure 3 - Relationship between Buffer Time and Congestion for Road Modes

In Figure 3, Buffer Time Index is defined as the "extra time (or time cushion) that travelers must add to their average travel time when planning trips to ensure on-time arrival."[3] To generalize the concept, BTI is shown as a percent of the total trip time. So if a particular trip on average takes 20 minutes but has a BTI of 20%, a traveler must budget 4 extra minutes to ensure an on-time arrival. Note that the relationship is non-linear, so that reducing low levels of congestion has little effect on buffer time. But as congestion worsens, travel time becomes more and more unreliable, and so the incremental reduction in congestion has a more pronounced benefit in improving reliability.

To operationalize the relationship shown in Figure 3, TREDIS draws on a few other Travel Demand Characteristic input variables. In the following equation, the *BTI* term is a function

[3] definition taken from "Travel Time Reliability: Making It There On Time, All The Time", *USDOT/FHWA website* (http://ops.fhwa.dot.gov/publications/tt_reliability/brochure)

of the fraction congested variable for that specific mode/purpose combination [that is, it should be read "*BTI* as a function of fraction congested"]. For example, if fraction congested is 0.3, the *BTI* used to estimate average buffer time per trip is about 10%. The average buffer time per trip follows as a straightforward calculation of *BTI* times the average time per trip, where the latter is simply *VHT* divided by the vehicle trips:

$$BufferTimePerVehTrip_{mp}^{s} = BTI\left(FractCong_{mp}^{s}\right) * \left(\frac{VHT_{mp}^{s}}{VehTrips_{mp}^{s}}\right)$$

3.1.5 Vehicle Operation Costs

TREDIS uses three separate fixed factors (that work in tandem) to estimate total vehicle operating costs, including fuel and oil consumption, tire wear, maintenance, and depreciation:

- *Vehicle Operating Cost ($/mile, free-flow)* – the average per-mile cost of vehicle operation for uncongested network travel.

- *Vehicle Operating Cost ($/mile, congested)* – the average per-mile cost of vehicle operation under congested conditions. For highway travel, congestion is defined as a volume/capacity ratio greater than 0.9.

- *Vehicle Operating Cost ($/hr, congested or idle)* – the per-hour cost of a vehicle sitting at idle, in a queue, or traveling in highly congested conditions (for road modes, volume/capacity ratio greater than 0.9).

All three measures are used because quantifying operating costs is done differently mode-to-mode. As a simple example, the cost of most road modes is easily estimated on a per-mile basis, while air and marine modes are typically estimated on a per-hour basis. Ultimately, three separate equations may be used to calculate vehicle operating costs. In the following equations, FF indicates "free-flow" travel conditions and "Cong" indicates congested travel conditions:

<u>Time-based</u>

$A)\ VHT_{mp}^{s} * CostPerHour_{mp}$

<u>Distance-based</u>

$B)\ VMT_{mp}^{s} * CostPerMileFF_{mp}$

$C)\ VMT_{mp}^{s}\left[\left(CostPerMileCong_{mp} * FractCong_{mp}^{s}\right) + \left(CostPerMileCong_{mp} * (1 - FractCong_{mp}^{s})\right)\right]$

The following rules explain which method is used and how that decision rule relates to how input data is filled in:

- If you set both *$/mi (Free-Flow)* and *$/mi (Congested)* to zero then TREDIS will use *VHT only* to estimate vehicle operating costs (Method A). This is the default setting for all air and marine modes.

- If you set *$/mi (Congested)* to zero, then TREDIS will calculate vehicle operating costs using *both VMT and VHT* (but not fraction congested) and return the greater of the two (Max of Method A or B). This is the default setting for passenger and freight rail modes.

- If you set *$/hr (Congested or Idle)* to zero, then TREDIS will use *VMT and fraction congested* variable to estimate costs (Method C)

- If you enter values for all three factors, then TREDIS uses a decision rule[4], where if VMT is nonzero, then that is used, with fraction congested, to estimate costs (Method C); if VMT is set to zero but VHT is positive, then VHT is used to estimate costs (Method A). This is the default option for passenger car and freight truck modes.

3.1.6 Toll/Fare Costs

Many transportation modes have direct user fees such as tolls or fares. For passenger cars and trucks, this is interpreted as an out-of-pocket user fee, and it might include fixed tolls, congestion pricing, or weight-based fees (for trucks). For other modes, tolls are interpreted as fares to passengers (or freight for freight-only modes). Because TREDIS is vehicle-based, these fares should correspond to estimated vehicle occupancy. For example, a bus system with average annual fare-box revenues of $1million and 10,000 annual vehicle-trips should use an average toll figure of $100/vehicle-trip. Total toll costs are simply the product of total vehicle trips times the average toll per vehicle trip:

$$TollCost_{mp}^{s} = VehTrips_{mp}^{s} * AvgTollPerVehTrip_{mp}^{s}$$

3.1.7 Safety Costs

Driving or riding in a vehicle carries risk. When crashes occur, costs result from property damage, personal injuries, and fatalities. TREDIS estimates safety costs by allowing users to enter average crash rates (per 100 million *VMT*) for all modes, and average costs incurred for each crash type ($/accident). Note that average crash rates may differ by scenario, but that the average cost per crash is fixed for all scenarios.

$$SafetyCost_{mp}^{s} =$$

$$VMT_{mp}^{s} * AvgCrashRateFatality_{mp}^{s} * AvgCostPerFatality_{mp}$$

$$+ VMT_{mp}^{s} * AvgCrashRatePersInjury_{mp}^{s} * AvgCostPerPersInjury_{mp}$$

$$+ VMT_{mp}^{s} * AvgCrashRatePropDamage_{mp}^{s} * AvgCostPerPropDamage_{mp}$$

[4] This decision rule was introduced so that, for sketch planning purposes, it is possible to estimate vehicle operating cost savings based on VHT savings alone for highway modes.

3.2 Non-User Costs

3.2.1 Environmental Cost

The operation of vehicles can produce various types of pollution. The Travel Cost module estimates the environmental costs of emissions only[5]. These are accounted for in the same way as for vehicle operating costs. That is, three variables work in tandem to estimate total emissions costs:

- *Emissions Cost ($/mile, free-flow)* – the average per-mile social cost of vehicle emissions operating in uncongested network travel conditions.
- *Emissions Cost ($/mile, congested)* – the average per-mile social cost of vehicle emissions operating in congested travel conditions. For highway travel, congestion is defined as a volume/capacity ratio greater than 0.9.
- *Emissions Cost ($/hr, congested or idle)* – the per-hour social cost of vehicle emissions while sitting at idle, in a queue, or traveling in highly congested conditions (for road modes, volume/capacity ratio greater than 0.9).

In the following equations, FF indicates "free-flow" travel conditions and "Cong" indicates congested travel conditions:

<u>Time-based emissions costs</u>

$A)\ VHT_{mp}^{s} * CostPerHour_{mp}$

<u>Distance-based emissions costs</u>

$B)\ VMT_{mp}^{s} * CostPerMileFF_{mp}$

$C)\ VMT_{mp}^{s}\left[\left(CostPerMileCong_{mp} * FractCong_{mp}^{s}\right) + \left(CostPerMileCong_{mp} * (1 - FractCong_{mp}^{s})\right)\right]$

The following rules explain which method is used and how that decision rule relates to how input data is filled in:

- If you set both *$/mi (Free-Flow)* and *$/mi (Congested)* to zero then TREDIS will use *VHT only* to estimate emission costs (Method A). This is the default setting for all air and marine modes.
- If you set *$/mi (Congested)* to zero, then TREDIS will calculate emission costs using *both VMT and VHT* (but not fraction congested) and return the greater of the two (Max of Method A or B). This is the default setting for passenger and freight rail modes.

[5] Note that there is a separate scenario input table that can be used to enter broader social or environmental non-user impacts

- If you set *$/hr (Congested or Idle)* to zero, then TREDIS will use *VMT and fraction congested* variable to estimate emission costs (Method C)

- If you enter values for all three factors, then TREDIS uses a decision rule, where if VMT is nonzero, then that is used, with fraction congested, to estimate emission costs (Method C); if VMT is set to zero but VHT is positive, then VHT is used to estimate costs (Method A). This is the default option for passenger car and freight truck modes.

3.3 Total vs. Local Travel Costs

For each cost type described above, some portion of the cost accrues within the study region in question (to households, businesses, or society), while rest accrues outside the study region. Accounting for the spatial distribution of costs is extremely important because only the local portion of user costs actually trigger local economic impacts.

TREDIS uses four variables describing travel origin/destination patterns to allocate these costs[6] (note that these can vary by scenario):

- *Fraction of Trips: Internal*

- *Fraction of Trips: Incoming*

- *Fraction of Trips: Outgoing*

- *Fraction of Trips: Through*

For each cost type, local costs are calculated as:

$$LocalCost_{mp}^{s} = TotalCost_{mp}^{s} * \left(FractionInternal_{mp}^{s} + \frac{1}{2}FractionIncoming_{mp}^{s} + \frac{1}{2}FractionOutgoing_{mp}^{s}\right)$$

3.4 Travel Cost Savings (Benefits)

Sections 3.1 and 3.2 describe how cost levels are calculated for each individual scenario (both total and local), across all cost types. For each TREDIS *Case*, cost savings are the simple difference between scenario costs:

$$TotalCostSavings_{mp}^{Case} = TotalCost_{mp}^{Base\ Scenario} - TotalCost_{mp}^{Project\ Scenario}$$

$$LocalCostSavings_{mp}^{Case} = LocalCost_{mp}^{Base\ Scenario} - LocalCost_{mp}^{Project\ Scenario}$$

[6] For freight modes, these are also used to match commodity costs to industries based on whether the commodities are being imported or exported. Incoming freight trips are matched to industries that *use* the commodity being shipped. Outgoing trips are matched to industries that *produce* the on-board commodity. Internal trips are split between users and producers.

This equation is applied separately for each cost type and mode/trip purpose combination. Note that it yields savings as a *positive* amount, so if an investment lowers costs, that lower cost will be a positive savings. Negative results indicate higher costs, or dis-savings.

3.5 Accounting for Induced Travel[7]

As described above, travel costs correspond to levels for a scenario, and benefits are estimated by differencing two scenarios (for example, *build* vs. *no-build*). For projects with no induced travel, the change in direct travel impacts between two scenarios can simply be calculated as the difference between two scenarios. However, for projects with induced travel, this "simple" difference must be adjusted to account for travelers' and shippers' economic response to travel cost changes.

A new piece of infrastructure or policy may reduce travel costs through any of the user cost types discussed above. Over time, firms and households recognize this lower price as an opportunity to decrease production costs or satisfy new trips. In both cases, the total number of trips (or miles traveled) may increase in the long-term. If direct impacts are calculated as the "simple" user cost difference between scenarios, then overall benefit might be underestimated because the new (induced) trips are tallied as having costs but no benefits. In reality, induced trips are made *precisely because they have value*, which outweighs the cost of making the trip. Figure 3-2 demonstrates graphically the standard economic interpretation of induced travel.

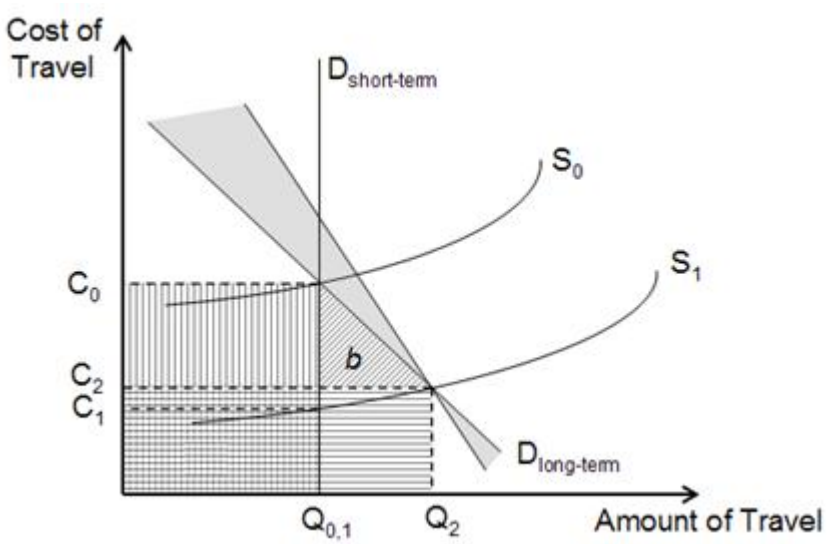

Figure 4 - A Graphical Representation of Induced Travel

[7] For more information, see Brian Alstadt and Glen Weisbrod, "A generalized approach for assessing the direct user impacts of transport projects", Transportation *Research Record No. 2079*, National Academies Press, Washington D.C.

Over the short-term, travel demand has limited sensitivity to cost changes. (This differs by trip purpose.) The relative insensitivity is reflected by a nearly vertical (inelastic) short-term demand curve. Thus, following an investment that increases supply, travelers initially consume the same amount of travel ($Q_0 = Q_1$) and simply enjoy the lower costs. Over time, however, households and firms decide to purchase or pay for more travel, which may again increase the unit cost of travel (from C_1 to C_2) due to congestion. This is reflected in a long-term demand curve that has pivoted or shifted (or both, as indicated by the grey shaded line), such that it crosses the new supply curve at a lower cost (C_2) but higher travel volume (Q_2). The short-term benefit is shown as area *a*, and the induced benefit as area *b*; together, they comprise the net increase in consumer and/or producer surplus from the change in supply.

The TREDIS Benefit Cost module accounts for induced travel based on the theory shown in Figure 3-2. If S_0 and S_1 reflect the respective supply curves for *no-build* and *build* scenarios, then area *b* is the induced benefit – the increase in consumer surplus accruing to induced travelers. Note that the benefit to the existing pool of travelers (to the left of $Q_{0,1}$) are already accounted for in TREDIS.

To estimate the induced benefit, total travel volume is calculated and reconciled across all modes. This step is important because increases in demand for one mode may simply reflect a switch from another. If this occurs (and if both modes are included in the model), then including mode-shift as induced would be double-counting, because the benefits of mode-switching are already captured by the net changes in user costs across both modes (however, if only one of the modes is included, then the induced benefit may be used to proxy the consumer surplus gain in the mode switch). TREDIS measures the quantity of travel consumed (Q) as either *passenger*trips* or *ton*trips*, depending on whether the mode is passenger-focused or freight-focused. Note that these measures normalize demand among all competing modes, and the benefits of more trips and increased ridership are captured. In the following equations, indexes are s = scenario, t = travel period, m = travel mode, p = trip purpose.

$$PassVol_{mp}^{st} = \left(VehicleTrips_{mp}^{st}\right)\left(PassPerVeh_{mp}^{st}\right) \tag{1a}$$

$$FreightVol_{mp}^{st} = \left(VehicleTrips_{mp}^{st}\right)\left(TonsPerVeh_{mp}^{st}\right) \tag{1b}$$

These measures of travel volume are calculated for each of the two scenarios and differences are generated for each mode/trip purpose combination. For any instances where total volume increases, the modeler then determines the fraction of increased volume that resulted from mode switching, and enters that value in the appropriate input table. Any remaining increase (not captured by mode shifting) is assumed to be induced, as shown in the following equation, where Q may be either of the measures (1a) or (1b):

$$InducedQ_{mp}^{t} = \left(Q_{mp}^{build,t} - Q_{mp}^{no-build,t}\right)\left(1 - ModeShift_{mp}^{t}\right). \tag{2}$$

In practice, equation (1a) is used for all passenger-focused modes, and equation (1b) is used for freight-focused modes. Unit travel costs for each scenario are calculated as

$$C_{mp}^{st} = \frac{UserCost_{mp}^{st}}{Q_{mp}^{st}}, \tag{3}$$

The induced benefit (area *b*) is therefore calculated as

$$InducedBenefit_{mp}^{t} = \tfrac{1}{2} InducedQ_{mp}^{t}\left(C_{mp}^{base,t} - C_{mp}^{alternative,t}\right). \tag{4}$$

3.6 Economic Distribution of Benefits

Once TREDIS has estimated user benefits based on the modeler's inputs, the local portion of cost savings are categorized by how they impact the economy (within the study area). Generally, the costs are grouped into five categories:

(1) household benefits that affect out-of-pocket expenditures

(2) household travel time benefits (that do not affect out-of-pocket expenditures)

(3) cost savings to transportation providers (for example, air carriers, transit operators, or for-hire trucking

(4) cost savings to industry (as transportation users) by NAICS sector

(5) societal environmental costs.

How benefits are allocated to the five categories described above depends on the cost type, the travel mode, and the trip purpose. Note that, because TREDIS recognizes 7 modes, 3 trip purposes, and 7 cost types (according to the boxes on Page 3), there are a total of 147 different combinations to allocate to one of the five categories. TREDIS processes each combination separately based on the unique economic interpretation of each. The table below shows six examples (out of 147) of how benefits are allocated to the study area's economy.

Mode	**Trip Purpose**	**Cost Type**	**Benefit goes to:**
Air	Personal/recreational	Passenger	Household – time (2)
Passenger Car/ Lt. Truck	On-the-clock	Toll	Industry (4)*
Passenger Rail	Commute	Crew	Vehicle Operator (3)
Water	On-the-clock	Freight	Industry (4)*
Passenger Car/ Lt. Truck	Personal/recreational	Veh. Oper	Household – out of pocket (1)
All modes	All trip purposes	Environ.	Social/ Environmental (5)

** Further allocated to NAICS sector*

It should be noted that in some cases, not all costs may accrue to a single category. For example, there is evidence that commuter cost savings benefit both households and industries. As another example, certain types of cost savings may be split between the carrier and shipper for certain freight modes. In these cases, the cost savings are allocated across user groups according to the propensity of that group to ultimately receive the cost savings (based on empirical or theoretical research).

Once cost savings are allocated to the five categories described above, one final step is needed before they can be used by the Economic Adjustment module (see separate documentation of that module). All cost savings to industries (category 4) must be further allocated across the NAICS sectors listed in Appendix A. This process is different for passenger and freight modes. For passenger modes, costs are allocated according to two factors: (1) how intensively an industry depends on a particular transportation mode/trip purpose combination, and (2) how much of that industry exists in the study area in question. For example, Health Care and Social Services (NAICS 621-624) requires a lot of on-the-clock travel. Therefore, cost savings for on-the-clock passenger modes will accrue to this sector – particularly if this industry has a large share of the total amount of employment in the study region.

For freight modes, the process of allocating cost savings to industries is explicitly tied to the average commodity mix on the mode in question. For non-through trips, the commodities on board are either produced by or consumed by a local industry. For outgoing freight trips, cost savings accrue to the producers of the commodities on board. For incoming freight trips, cost savings accrue to consumers of the commodities on board. For internal trips, cost savings are split between producers and consumers.

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4 Travel Cost Module Results

Travel Cost module results are displayed in Reports 2a and 2b. Report 2a (sample shown in Figure 5) shows Cost savings by cost type. The upper portion of the table summarizes some Travel Demand Characteristics inputs as well as showing intermediate calculations for passenger and freight volumes, crashes, and local portion of trip ends.

REPORT 2a: TRAVEL COST SAVINGS - BY COST TYPE

Project: Reducing Highway Congestion
Base Scenario: Baseline Scenario
Project Scenario: Freeway Expansion Project
Analysis Year: 2030
Constant $ Year: 2010
Region: All Regions
Period: All Periods

Reduction/ Savings in:	Passenger Car On-the-Clock	Passenger Car Commute	Passenger Car Personal/ Rec	Truck Freight Freight	Total
Gross Vehicle Trips	0	0	0	0	0
Gross VMT	0	0	0	0	0
Gross VHT	625,000	2,380,953	1,785,714	892,857	5,684,524
Gross Buffer Time (hrs)	82,842	994,390	452,941	59,350	1,589,522
Passenger Trips	0	0	0	0	0
...diverted from in-model source	0	0	0	0	0
...diverted from other source	0	0	0	0	0
...induced from latent demand	0	0	0	0	0
Passenger Miles	0	0	0	0	0
Freight Ton Trips	0	0	0	0	0
...diverted from in-model source	0	0	0	0	0
...diverted from other source	0	0	0	0	0
...induced from latent demand	0	0	0	0	0
Freight Ton Miles	0	0	0	0	0
Fatalities	0.00	0.00	0.00	0.00	0.00
Personal Injuries	0.00	0.00	0.00	0.00	0.00
Property Damage	0.00	0.00	0.00	0.00	0.00
Local Portion of Trip Ends	80%	90%	90%	60%	
Total Value of Travel Impacts:					
Passenger Cost - Net Total	18,906,250	65,619,065	34,071,423	0	118,596,738
Crew Cost - Net Total	0	0	0	22,339,282	22,339,282
Freight Cost - Net Total	0	0	0	16,176,816	16,176,816
Reliability Cost - Net Total	2,278,149	21,081,066	4,801,173	3,487,993	31,648,381
Veh Oper Cost - Net Total	1,050,000	4,500,000	2,250,000	3,500,000	11,300,000
Toll Cost - Net Total	0	0	0	0	0
Safety Cost - Net Total	0	0	0	0	0
Environmental Cost - Net Total	52,500	225,000	112,500	162,500	552,500
Induced Benefit - Total	0	0	0	0	0
Total Value of Travel Impacts:	**22,286,899**	**91,425,131**	**41,235,096**	**45,666,591**	**200,613,718**
Local Value of Travel Impacts:					
Passenger Cost - Net Local	15,125,000	59,057,158	30,664,281	0	104,846,439
Crew Cost - Net Local	0	0	0	13,403,569	13,403,569
Freight Cost - Net Local	0	0	0	9,706,090	9,706,090
Reliability Cost - Net Local	1,822,520	18,972,960	4,321,056	2,092,796	27,209,330
Veh Oper Cost - Net Local	840,000	4,050,000	2,025,000	2,100,000	9,015,000
Toll Cost - Net Local	0	0	0	0	0
Safety Cost - Net Local	0	0	0	0	0
Environmental Cost - Net Local	42,000	202,500	101,250	97,500	443,250
Induced Benefit - Local	0	0	0	0	0
Local Value of Travel Impacts:	**17,829,520**	**82,282,618**	**37,111,586**	**27,399,955**	**164,623,679**

Figure 5 - Sample of Report 2a: Travel Cost Savings by Cost Type

The middle part of the table, "Total Value of Travel Impacts", displays the monetized value of cost savings to all network users, itemized by cost type and mode/trip purpose. The bottom portion of the table shows the portion of travel cost savings accruing only to the study area.

Report 2b (sample shown in Figure 6, next page) shows local travel cost savings by recipient, which is the result of the process discussed in Section 3.6. Note that the Report 2b total is the same as the local cost savings total from Report 2a. Both figures are in the lower-right corner. The upper portion of Report 2b shows how travel cost savings accrue to industries. Note that the column for personal travel is all zeroes because this does not apply to industries. Conversely, the on-the-clock and commute industry savings accrue disproportionally to service sectors, whereas Truck Freight savings accrue primarily to manufacturing sectors. The bottom portion of Report 2b shows the sum of cost savings to industries as well as cost savings to the other four possible groups: vehicle operators, households (either out-of-pocket or personal value), or society at large.

REPORT 2b:TRAVEL COST SAVINGS - BY INDUSTRY

Project: Reducing Highway Congestion
Base Scenario: Baseline Scenario
Project Scenario: Freeway Expansion Project
Analysis Year: 2030
Constant $ Year: 2010
Region: All Regions
Period: All Periods

NAICS	Industry	Pass Car On-the-Clock	Pass Car Commute	Pass Car Personal/ Rec	Truck Freight Freight	Total
111	Crop Production	0	176,755	0	1,421,020	1,597,774
112	Animal Production	0	80,428	0	372,572	453,001
113	Forestry & Logging	0	2,014	0	202,454	204,468
114	Fishing, Hunting & Trapping	0	1,093	0	68,636	69,729
115	Support for Agriculture & Forestry	7,357	53,009	0	8,641	69,006
211	Oil & Gas Extraction	0	194	0	24,102	24,296
212-213	Mining & Support Activities	3,066	7,068	0	466,605	476,740
221	Utilities	0	35,295	0	6,706	42,000
230	Construction	412,289	1,180,454	0	261,928	1,854,670
311	Food Products	3,523	94,510	0	2,454,395	2,552,428
312	Beverage & Tobacco Products	2,166	11,216	0	242,961	256,344
313	Textile Mills	532	4,723	0	50,164	55,419
314	Textile Product Mills	366	11,222	0	25,897	37,485
315	Apparel Manufacturing	190	16,936	0	25,413	42,539
316	Leather & Allied Products	363	2,347	0	26,989	29,699
321	Wood Products	9,894	85,717	0	362,439	458,051
322	Paper Manufacturing	7,014	71,576	0	248,946	327,535
323	Printing & Related Support Activities	6,398	413,249	0	68,385	488,032
324	Petroleum & Coal Products	3,118	9,483	0	401,406	414,008
325	Chemical Manufacturing	12,558	92,096	0	582,732	687,386
326	Plastics & Rubber Products	18,210	191,822	0	124,831	334,863
327	Nonmetallic Mineral Products	5,047	53,006	0	2,318,234	2,376,286
331	Primary Metal Manufacturing	10,254	58,211	0	473,961	542,427
332	Fabricated Metal Products	55,856	490,236	0	314,446	860,538
333	Machinery Manufacturing	30,576	389,601	0	823,422	1,243,599
334	Computer & Electronic Products	5,601	650,504	0	185,436	841,541
335	Electric Equipment, Appliances, etc.	9,216	75,798	0	236,083	321,096
336	Transportation Equipment	8,299	61,985	0	407,727	478,011
337	Furniture & Related Products	6,402	115,343	0	111,439	233,184
339	Miscellaneous Manufacturing	12,618	415,935	0	140,325	568,879
420	Wholesale Trade	138,761	2,269,596	0	55,666	2,464,022
441-454	Retail Trade	3,291,206	5,172,431	0	167,687	8,631,325
481-487	Transportation	8,755	1,034,945	0	12,252	1,055,952
491-493	Mail, package delivery & warehousing	44,729	358,974	0	15,709	419,413
511	Publishing Industries (except Internet)	73,953	450,467	0	24,664	549,084
512	Motion Picture & Sound Recording	42,546	94,054	0	1,207	137,807
513	Broadcasting	43,970	140,023	0	2,541	186,534
514	Internet & data process svcs	147,805	253,471	0	2,649	403,926
521-523	Monetary, Financial, & Credit Activity	694,929	1,601,128	0	1,182	2,297,239
524	Insurance Carriers & Related Activities	303,244	1,537,811	0	262	1,841,318
525	Funds, Trusts, & Other Financial Vehicles	8,111	131,375	0	66	139,552
531	Real Estate	126,478	567,213	0	3,409	697,101
532	Rental & Leasing Services	99,424	180,462	0	9,499	289,386
533	Lessors of Nonfinancial Intangible Assets	1,310	73,113	0	308	74,731
541-551	Professional Scientific, Technical, Services	2,905,376	5,507,035	0	48,641	8,461,053
561	Administrative & Support Services	1,612,763	3,107,596	0	23,142	4,743,501
562	Waste Management & Remediation	2,998	46,586	0	344,137	393,721
611	Educational Services	765,295	1,358,292	0	5,583	2,129,170
621-624	Health Care & Social Services	3,058,004	6,338,280	0	29,892	9,426,175
711-713	Amusement & Recreation	722,892	1,078,046	0	14,495	1,815,433
721-722	Accommodations, Eating & Drinking	1,808,994	2,837,744	0	30,140	4,676,879
811-812	Repair, Maintenance, & Personal Services	695,357	1,020,490	0	66,356	1,782,203
813	Religious, Civic, Professional, Organizations	559,703	1,029,100	0	6,461	1,595,264
920	Government & non NAICs	0	0	0	49,641	49,641
	Total Savings to Industry (sum of above)	17,787,520	41,040,059	0	13,373,885	72,201,464
	Cost Savings to Vehicle Operator	0	0	0	13,928,569	13,928,569
	Household Out-of-Pocket Cost Savings	0	2,025,000	2,025,000	0	4,050,000
	Household Value of Time Benefit	0	39,015,059	34,985,336	0	74,000,395
	Societal Environmental Benefit	42,000	202,500	101,250	97,500	443,250
	Total Benefits	17,829,520	82,282,618	37,111,586	27,399,955	164,623,679

Figure 6 - Sample of Report 2b: Travel Cost Savings by Recipient

Appendix A: TREDIS Sectoring Scheme

NAICs Sector(s)	Description
111	Crop Production
112	Animal Production
113	Forestry & Logging
114	Fishing, Hunting & Trapping
115	Support for Agriculture & Forestry
211	Oil & Gas Extraction
212-213	Mining & Support Activities
221	Utilities
230	Construction
311	Food Products
312	Beverage & Tobacco Products
313	Textile Mills
314	Textile Product Mills
315	Apparel Manufacturing
316	Leather & Allied Products
321	Wood Products
322	Paper Manufacturing
323	Printing & Related Support Activities
324	Petroleum & Coal Products
325	Chemical Manufacturing
326	Plastics & Rubber Products
327	Nonmetallic Mineral Products
331	Primary Metal Manufacturing
332	Fabricated Metal Products
333	Machinery Manufacturing
334	Computer & Electronic Products
335	Electric Equipment, Appliances, etc.
336	Transportation Equipment
337	Furniture & Related Products
339	Miscellaneous Manufacturing

NAICs Sector(s) Cont'd	Description
420	Wholesale Trade
441-454	Retail Trade
481-487	Transportation
491-493	Mail, package delivery & warehousing
511	Publishing Industries (except Internet)
512	Motion Picture & Sound Recording
513	Broadcasting
514	Internet & data process svcs
521-523	Monetary, Financial, & Credit Activity
524	Insurance Carriers & Related Activities
525	Funds, Trusts, & Other Financial Vehicles
531	Real Estate
532	Rental & Leasing Services
533	Lessors of Nonfinancial Intangible Assets
541-551	Professional Scientific, Technical, Services
561	Administrative & Support Services
562	Waste Management & Remediation
611	Educational Services
621-624	Health Care & Social Services
711-713	Amusement & Recreation
721-722	Accommodations, Eating & Drinking
811-812	Repair, Maintenance, & Personal Services
813	Religious, Civic, Professional, Organizations
814	Private Households
920	Government & non NAICs

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APPENDIX II:
TECHNICAL DOCUMENTATION OF METHODS AND ASSUMPTIONS FOR BUFFER TIME AND RELIABLITY

The percentage of diverted traffic expected to occur under congested conditions is a key determinant of the comparative reliability costs and benefits of different scenarios. It is assumed that as VMT and VHT increase (due to diversion to roadways with lower functional class), the share of traffic occurring under congested conditions increases incrementally with the diversion-related VMT and VHT.

Congestion creates delay and higher vehicle operating costs, and it also has the effect of increasing the variability of travel times. Travel time variability relates to how long it takes to complete the same trip on different days. Consider a morning commute, where a driver makes the same trip roughly 20 times per month. If he or she can make the trip in about 30 minutes almost every day, then that trip is very reliable. If, on the other hand, the same trip regularly takes 45 or even 60 minutes, then the travel time is highly variable, and the driver must budget extra time into his or her commute so that this unpredictability is accounted for. As with in-vehicle travel time, this extra "schedule", "float", or "buffer" time has value because it infringes on time that can be planned for both work and leisure activities.

Note that congestion and travel time variability are related but separate concepts. Congestion may be experienced on a single day, whereas variability must be measured over many days or weeks. Both congestion and variability can be caused by predictable factors such as weather or special events (concerts or sporting events, for example), and they can both be caused by unpredictable factors such as crashes or road closures (rail crossings, for example). However, variability can be a problem even on mildly congested corridors if crashes or special events are common, or if these incidents are not managed well. Conversely, congested corridors can operate reliably if incidents are minimized and managed well. Moreover, the relationship between congestion and variability is non-linear (see Figure 3.5, below). Above a certain threshold, variability worsens much faster than congestion, but then tends to be relatively constant for the most congested corridors. In other words, alleviating moderate congestion can have a disproportionately beneficial impact on reliability.

Figure 3-5: Relationship between congestion and travel time variability[i]

Estimating Travel Time Variability

The economic impact assessment methodology uses the concept of buffer time to estimate the impacts of travel time variability.[ii] Buffer time is defined as the "extra time (or time cushion) that travelers must add to their average travel time when planning trips to ensure on-time arrival."[iii] In practice, this can be estimated by comparing the worst travel time in a month versus the average over that month (using a month as the basis for this estimate is appropriate because there are about 20 work days in a month, and therefore the worst day approximates the 95th percentile travel time). The difference in travel time between the worst and average day is the buffer time. In the economic methodology, this is treated as buffer-hours per vehicle-trip.

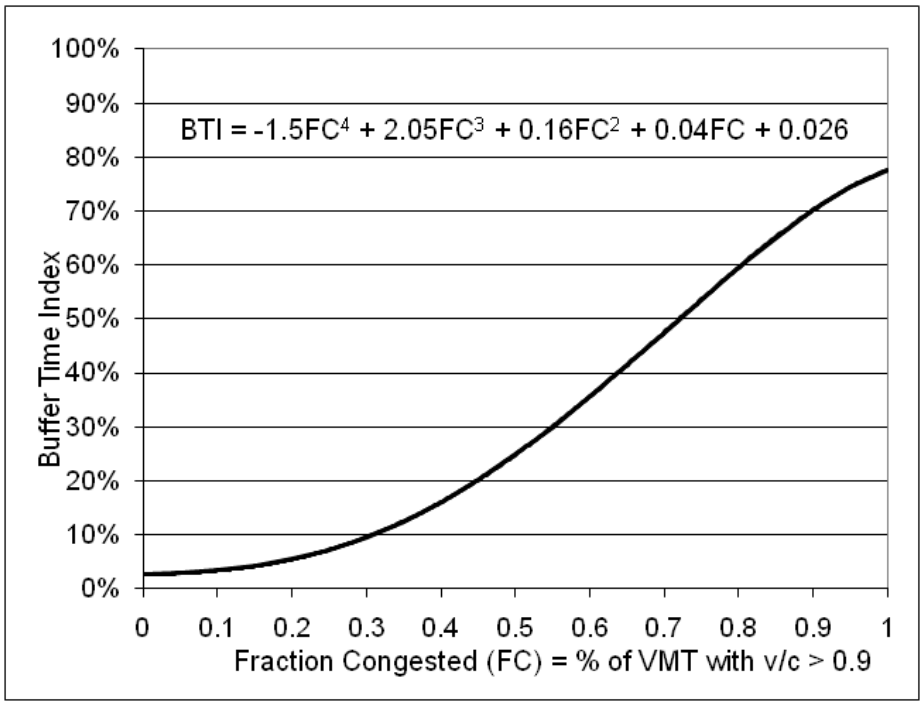
For cars and trucks, the economic methodology uses measures of the buffer time per trip based on previous research. **Figure 3.6** shows the relationship between congestion (as reflected by the travel time index) and reliability (as reflected by the buffer index[iv]) for a large sample of corridors across the country. The economic methodology estimates buffer time based on this relationship by first estimating the travel time index using the Bureau of Public Roads equation:

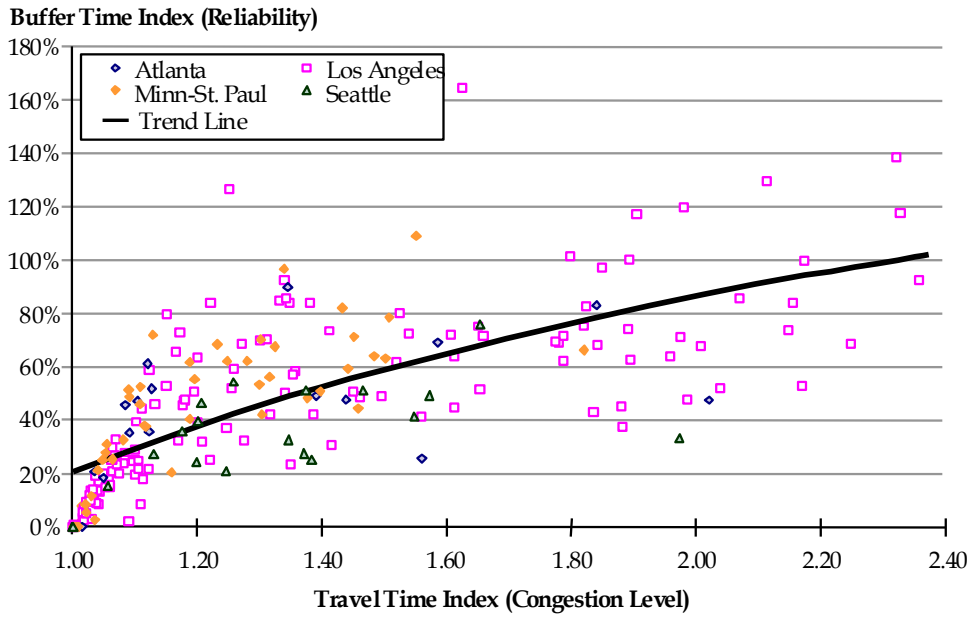
$$Travel\ Time\ Index = 1 + 0.15 * \left(\frac{road\ volume}{road\ capacity}\right)^4$$

In this equation, the volume to capacity ratio is estimated from the Portland Metro Travel Demand Model, which describes the fraction of VMT subject to a volume/capacity ratio greater than 0.9. Based on this research, the following relationship is observed between *Fraction Congested* and Buffer Index:

Fraction Congested	Buffer Time Index
0.00	2.6%
0.05	2.9%
0.10	3.4%
0.15	4.2%
0.20	5.4%
0.25	7.2%
0.30	9.6%
0.35	12.5%
0.40	16.0%
0.45	20.2%
0.50	24.9%
0.55	30.0%
0.60	35.6%
0.65	41.5%
0.70	47.5%
0.75	53.6%
0.80	59.6%
0.85	65.2%
0.90	70.2%
0.95	74.4%
1.00	77.6%

Figure 3-6: Buffer Time Index





Recall that the buffer index is the buffer time as a percentage of the average trip time. Therefore, in this analysis, the average buffer time per vehicle trip is estimated as the Buffer Time Index (BTI, as calculated above) times the average time per trip, where the latter is derived using the inputs *Vehicle Trips* and *VHT*:

$$Buffer\ Time\ per\ Vehicle\ Trip = BTI * \left(\frac{VHT}{Vehicle \cdot Trips}\right)$$

Valuing Travel Time Variability

A considerable amount of research has been done to determine how travelers value delay and reliability. For passenger modes, time is valued differently for different trip purposes[v]. For trucks, the value of time depends on the quantity of freight on board as well as its value (per ton) [1] and the effects of delays on other logistics costs associated with businesses using the congested portions of the highway system. The economic analysis uses the following default valuation factors.

- Ground transport in-vehicle travel time (including car, light truck, bus, and rail)
  - On-the-Clock: $27.50 per passenger-hour
  - Commute: $21.20 per passenger-hour (=user benefit $10.60 +wage premium of $10.60)
  - Personal: $10.60 per passenger-hour

- Car and Light truck buffer time
  - On-the-Clock: $27.50 per passenger-hour
  - Commute: $10.60 per passenger-hour (does not include wage premium)
  - Personal: $10.60 per passenger-hour

- Heavy Truck buffer time
    - varies by commodities – average of $58.77 per vehicle-hour

- Transit transfer and/or wait time
    - All trip purposes: $21.20 per passenger-hour

Values of time shown here are generally consistent with methods for valuing user travel time benefits as followed by HERS and BCA.Net software, as well as CUTR and USDOT guidance. However, values have also been updated to reflect 2007 wage rates (average of all occupations, not just transport occupations), based on BLS wage data. Also, additional long-term business costs (beyond the user value of travel time) have been added in the form of fringe benefit costs for "on-the clock travel" and wage premiums paid by employers for commuting in higher-cost congested areas.

As a result, car/light truck "on-the-clock" travel time is calculated as a business cost valued at 100% of the national average wage rate plus 30% fringe. Both commuting and personal travel time are treated as a non-money user benefit with a value set at 50% of the wage rate (no fringe added). For economic impact analysis only, there is an additional allowance for the effect of higher commuting cost on employer cost in the form of a wage rate premium valued at another 50% of the wage rate per hour without fringe (per research by Zax et al.). For public transit, the wider range reflects possible variation in riding conditions, as noted by CUTR: "Transit travel time should be valued at 25 - 35 percent of prevailing wage under comfortable conditions (when sitting), but can be significantly higher for crowded transit vehicles (100% of wage rate) or for waiting under unpleasant conditions (up to175% of wage rate)." For out-of-vehicle transit time, the economic methodology uses 100% of the wage rate, but allows for a wider range of values.

For passenger travel, buffer time has been shown to be valued similarly to travel time unless a schedule constraint exists (see endnote 5). For commute travel, only the passenger value is used. For Freight Trucks, the value of buffer time can vary widely for carrier types and commodity, but is generally higher than passenger travel (relative to travel time). USDOT reports that the value of reliability can vary from 20% to 250% of "standard" delay (http://ops.fhwa.dot.gov/freight/documents/improve_econ.pdf).

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[i] source: "Uses of Travel Time", PowerPoint Presentation by Richard Margiotta, Cambridge Systematics to *Talking Operations* Webinar, June 28, 2006. Available on National Transportation Operations Coalition website (http://www.ntoctalks.com/webcast_archive/to_jun_28_06/to_jun_28_06_rm.ppt)

[ii] The buffer time concept is applied to all modes as a general "out of vehicle" time which is monetized separately from in-vehicle time. Note that for other passenger modes (transit, rail, air), buffer time may be used to capture wait and/or transfer times.

[iii] definition taken from "Travel Time Reliability: Making It There On Time, All The Time", *USDOT/FHWA website* (http://ops.fhwa.dot.gov/publications/tt_reliability/brochure)

[iv] The buffer index is the buffer time as a percentage of the average time, so a buffer of 5 minutes on a 25 minute average trip time translates to a buffer index of 20%

[v] See Concas, Sisinnio, Kolpakov, and Alexander (2009). "Synthesis of Research on Value of Time and Value of Reliability", Report No. BD549-46, Florida Department of Transportation, Center for Urban Transportation Research. Available online: http://www.nctr.usf.edu/pdf/77806.pdf