TREDIS® 6 Technical Documentation:

Travel Cost Module

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1 Background: Travel Cost Accounting in the TREDIS Context

This technical document describes the calculations behind the Travel Cost Module, one of the core modules of TREDIS. This module takes as inputs travel characteristics and cost factors (defaults or provided by the user) to produce, as outputs, estimates of costs for both social and economic cost purposes. These outputs in turn key inputs for the Benefit-Cost and Dynamic Economic Impact Modules. All analyses in TREDIS will use this module unless the “Travel Cost Override” function is used to enter costs directly from out-of-model calculations.[1]

1.1 Defining the Concept of Travel Benefits

TREDIS does not measure transportation performance. It accepts transportation performance measures derived from travel demand models or planner/engineer estimates and uses that information to calculate the value of those changes – an input to the Benefit-Cost and Economic Empact Modules.

Definition. The benefits of transportation projects, programs or policies are normally defined in terms of improvement in (a) time, (b) expense, (c) reliability, (d) safety, and/or (e) accessibility, for at least some population or element of the economy. These are referred to as travel benefits and they drive both Benefit-Cost Analysis and Economic Impact Analysis. They are sometimes referred to as direct “traveler” or “user” benefits,[2] which means that they directly benefit people who travel. These factors also enable wider “non-traveler” benefits that accrue to wider populations of non-travelers, including environmental benefits, regional productivity benefits and social (quality of life) benefits.

Calculation of Direct Travel Benefits. In TREDIS, the Travel Cost Module calculates the direct money value of all travel-related benefits except accessibility (items “a” through “d” above). Accessibility (item “e” above) is addressed in the separate Market Access Module.

TREDIS calculates these travel cost values for the base case scenario and for each alternative scenario, and then calculates the difference between scenarios. An “improvement” in conditions is thus represented as a “savings in travel-related cost” —i.e., a reduction in the value of time expended, lives lost, and/or costs incurred for travel expenses, collision repair and medical injury care compared to the base case. The value of these costs and the associated cost reduction benefits of a proposed project, program or policy scenario is calculated separately for each specified region, year, mode and purpose class. The accounting can become complicated, as there may appear to be negative benefits for some classes of travel that are offset by positive benefits for other classes of travel.

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[1] The Travel Cost Override allows use of alternative calculation tools for economic valuation.

[2] Technically, “traveler benefits” refer to benefits accrued to travelers (drivers/operators and passengers), while “user benefits” add freight shippers since they are the true users of the freight system. However, common practice in engineering studies is to use the term “user benefit” to include mean traveler benefits (which does not include freight shippers). Recognizing this practice, this technical document discusses “travel benefits” separately from “other travel-related benefits.”

The process used for these calculations is compatible with the benefit valuation guidance of various countries (e.g., the United States, Canada, United Kingdom and Australia), though country-specific unit cost values must be entered or selected. Unit cost values are discussed in a separate document, *TREDIS Data Sources and Default Values*.

Uses in Economics Analysis. The direct user benefits calculated by TREDIS in this module provide inputs to two broader forms of economic analysis:

- Benefit-Cost Analysis (BCA) — Comparing the net present value of benefits and costs over time. This includes direct user benefits, and it can also include wider productivity benefits for the economy.
- Economic Impact Analysis (EIA) — Showing impact over time on regional economic growth, which occur as a wider economic consequence of direct user benefits.

The differences between these forms of economic analysis are discussed in a separate document, which explains their different uses in transportation planning and decision-making processes. (See TREDIS document on our website: *Application of Economic Analysis for Transportation Decision-making: A Guide to the Different Uses of Benefit-Cost Analysis, Economic Impact Analysis and Financial Impact Analysis*. http://www.tredis.com/images/pdf-docs/Application-of-Economic-Analysis%20for-Transportation-Decision-making.pdf)

See the Benefit-Cost Analysis and Dynamic Economic Model technical documents for more on TREDIS use for BCA and EIA.

1.2 The TREDIS Framework: A Modular Design

TREDIS is an integrated economic impact analysis system for transportation planning and project evaluation, designed to cover a wide range of applications including the assessment of benefits, costs, finance, and regional economic 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 accommodate this range of features, the TREDIS Framework operates as a set of four interconnected "core" modules: the Travel Cost, Market Access, Benefit-Cost, and the Dynamic Regional Economic Model.

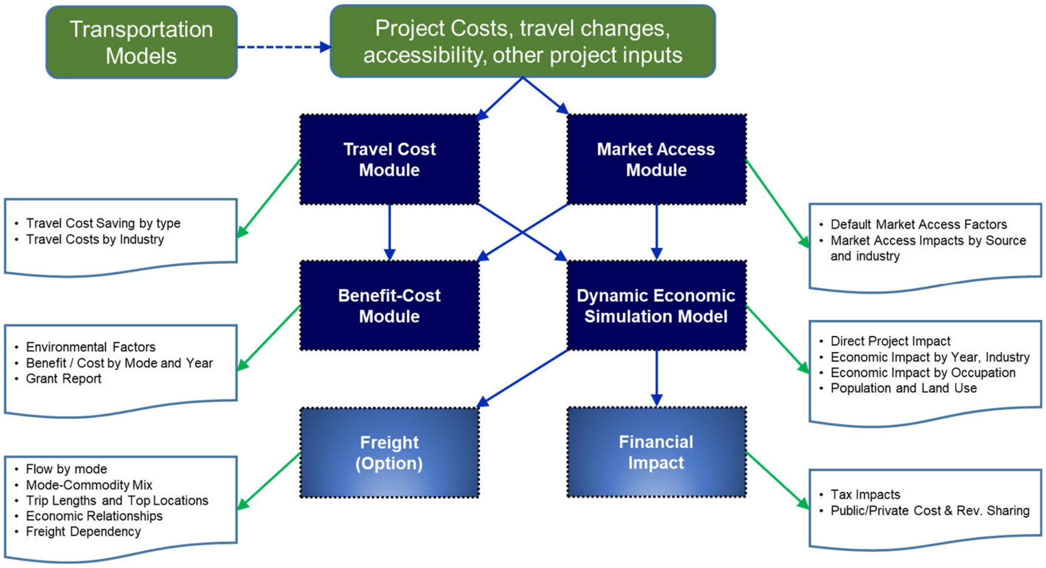

Figure 1. TREDIS Framework: Modular Design

The Travel Cost Module, which is the focus of this document, covers the process whereby changes in the quantity, type, and quality of travel translate into traveler and non-traveler benefits, as well as direct economic impacts. The Market Access Module covers the process whereby the network effects of travel affect access to wider markets and 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 Dynamic Regional Economic Model to estimate secondary (indirect and induced) economic effects, and also to the Benefit Cost Module, to itemize and discount costs, and the Financial Impacts module, which shows additional tax receipts associated with project impacts, and the freight module shows how commodity flows are affected. Not shown is the forecast module, which works in concert 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 with the economic adjustment, freight, and finance modules to forecast baseline economic conditions, freight flows, and tax receipts.

TREDIS is designed such that the modules can be used as a seamless system to analyze the effects of transportation projects "from scratch." However, elements of TREDIS can be separated so that modules may be used individually, in any combination with one another, or in conjunction with a user's in-house substitute. For example, a user may already have estimated the direct travel impacts of a transportation policy (for example, using HERS-ST) and is only interested in the market access effects and economic impacts. In this case, TREDIS's Travel Cost and Benefit-Cost Modules may be ignored in favor of independent analysis.

2 Travel Cost Module Overview

2.1 Modes and Purposes

The Travel Cost module translates changes in quantity, quality, and type of travel into cost changes for households and businesses (see Figure 2). Travel is defined by its mode and its purpose.

(a) Modes. TREDIS includes, but is not limited, to the following modes of travel:

TREDIS TRAVEL MODES

Car Modes: Passenger Car, TNC (Uber, Lyft), and Taxi

Public Transportation Modes: Passenger Bus, Bus Rapid Transit, Light Rail Transit, Heavy Rail, Commuter Rail, and Passenger Rail

Truck and Freight Modes: Light/Medium Duty Truck, Tractor Trailer Truck, Freight Rail, and Marine Freight

Active Transportation Modes: Bicycle and Pedestrian

Aviation Modes: Commercial Jet, Jumbo Jet, Regional Jet, Air Taxi, and General Aviation

Marine Modes: Cruise Ship, Marine Freight, and Passenger Ferry

Custom Modes (User Defined): e.g., Electric Car and Freight Truck Platoons

The defaults included in TREDIS are constantly being expanded and the user also has the ability to create custom modes to better suit their needs. So, 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 vs. natural gas bus or standard diesel bus) can be handled in this way.

(b) Purposes. Each of the modes is further specified by trip purposes.

TREDIS TRIP PURPOSE CLASSES

Business (on the clock) passenger travel – service delivery and business meetings

Commute travel – journey to/from work

Personal Travel – personal business, recreation, visiting friends and relatives

No Split / All purposes – composite of the above passenger purposes, averaged based on American Community Survey

Freight – cargo shipping and delivery

2.2 Travel Performance and Characteristics

The volume or quantity of vehicle travel is described by a range of transportation system use and performance metrics, shown in the box below.

TREDIS FACILITY USE AND PERFORMANCE (by mode and purpose)

Volume – person-trips and vehicle-trips, annual

Distance Traveled – vehicle-miles of travel (VMT) or vehicle-km of travel (VKM), person-miles of travel (PMT) or person-km of travel (PKM), annual

Time – vehicle-hours of travel (VHT) or person-hours of travel (PHT), annual

Vehicle Occupancy – average passengers per vehicle, average crew per vehicle, average freight tons/vehicle, and mix of freight commodities

Tolls or Fees – facility entry or use fees: per mile, per vehicle, per person, or per ton

Safety – rates of property damage, personal injury and death per vehicle-mile (or -km)

Use Conditions – congestion (reliability buffer time or share of VMT in congested conditions), also rating of road pavement condition

*Note that vehicle-based measures (including Vehicle Trips, VMT/VKT, VHT, and occupancy), are applicable for car, truck, rail, aviation and marine modes. For walking and bicycle modes, vehicle measures are entered. Note that person-based measures (including Person-Trips, PMT/PKM and PHT) are applicable for walking, biking and transportation services (including public transportation, aviation, marine and car-based mobility services).

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, TranPlan, Cube Voyager, and HERS.

Screen shots of TREDIS input tables are shown in Section 6.1. There are options for direct entry on these forms, or automated entry via corresponding spreadsheet tables.

2.3 Calculation of Valuations and Outputs

The Travel Cost Module uses formulas (shown in Section 3) along with default factors to translate these travel metrics into costs accruing to passengers, vehicle operators (“carriers”), freight shippers, and society. Project benefits are estimated by considering two alternatives side-by-side — i.e., travel costs under a no-build alternative versus costs after building a piece of infrastructure.

The U.S. defaults are provided in in the separate volume called *TREDIS Data Sources and Default Values*. However, the defaults may also be overwritten by the user as appropriate for use in their country or as desired by specific clients.

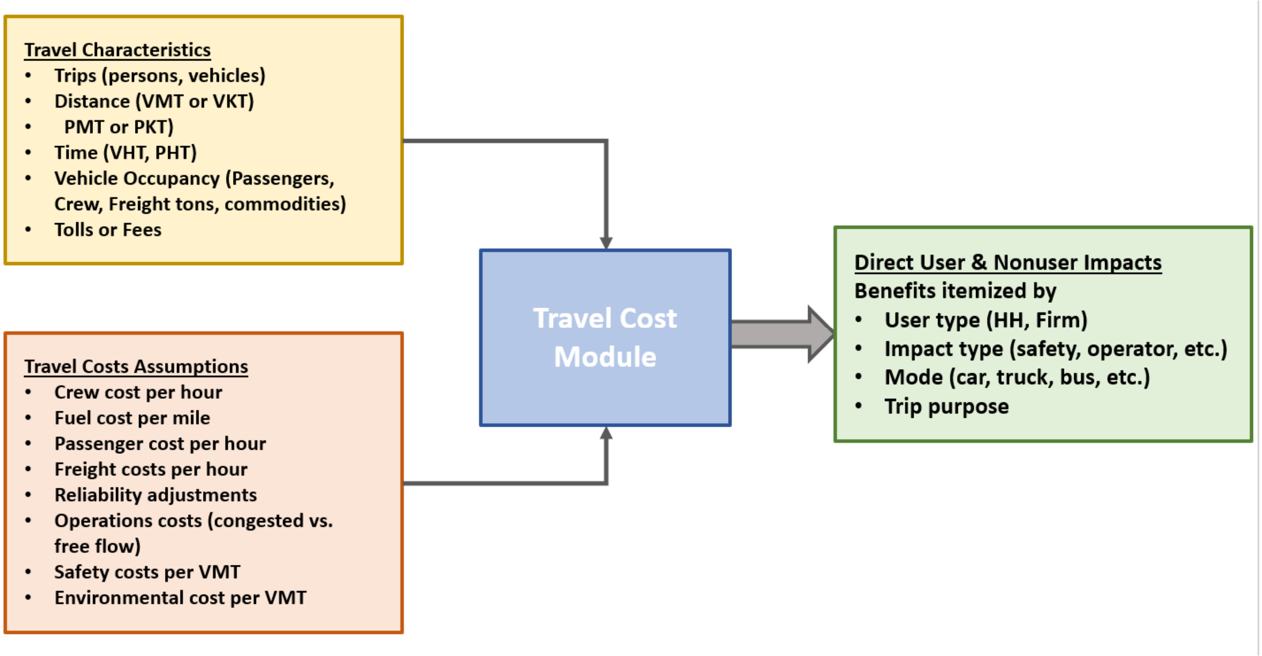

Figure 2. TREDIS Travel Cost Module Input and Output Factors

TREDIS generally performs more accurately when a minimum of two years of travel inputs are provided, though up to 50 years can be provided if desired. It takes these inputs and interpolates (and extrapolates if needed) travel inputs from Operation Start to Operation End years. If the user enters more than two years of travel inputs, then the model will more accurately reflect the user's intent for the project.

Screen shots of TREDIS output reports are shown in Section 6.2.

3 Calculation of Traveler Cost Savings

Transportation system improvements can be represented in economic terms as a savings in the time or money-related "costs" of travel. Travel costs fall into two primary categories: *traveler costs* and *other travel-related costs*. This section provides formulas for the calculation of traveler costs, which are those that accrue to vehicle owners, drivers, crew and passengers. The next section discusses the calculation of other travel-related costs — including freight system user costs (that accrue to shippers, receivers and truck fleet operators[3]) and wider social, economic and environmental costs (that are generated as a consequence of transportation system performance changes).

Traveler Costs

- Passenger time costs
- Crew time costs
- Freight time costs
- Reliability costs
- Vehicle operating costs
- Pavement condition effects
- Safety costs

Each traveler cost category is monetized based on levels of travel characteristics (trips, VMT, VHT, vehicle occupancy and loadings) and value factors determined by regulatory guidance

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[3] 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.

and a review of research literature. They are calculated as cost levels for each alternative. Project scenario impacts are then calculated as the difference in costs between two alternatives. More explicitly, for a project with two alternatives, *build* and *no-build*, the Travel Cost module calculates the costs for each alternative (using the same methodology) and then determine the cost savings as the difference between the project case and the base case.

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 spent 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.

In the formulas which follow, the superscript "s" is used to indicate a single alternative. For monetization valuation factors, see the document *TREDIS Data Sources and Default Values*.

Monetary Costs vs. Non-monetary Costs. In economics, we often refer to "costs," but these are not always "costs" as they are commonly understood outside economic analysis. "Monetary costs" represent those that are actual money transfers between parties, whereas "non-monetary costs" represent externalities that may be valued in money terms but which don't actually result in a money transfer.

For example, the costs of time for personal travel are non-monetary. If you take a long-distance car trip, saving an hour on the drive wouldn't actually save you money, even if you would have paid $20 to save that time. The time saved could be valued at $20 for analytic purposes, but it is non-monetary.[4]

On the other hand, reduced travel might save you monetary costs in the form of maintenance and fuel. If your daily drive to drop off your child at childcare each day is 10 miles shorter, you may avoid a car repair bill over the course of the year of $200 as well as potentially $500 in gas costs over the course of the year. These are examples of monetary costs imposed by car travel since they involve an actual transfer of money.

The Travel Cost Module considers both types of costs, including some value of time costs that are monetary costs when they are done for business or commute purposes. (For BCA analysis, both monetary and non-monetary costs are considered, but for Economic Impact or Financial Impact analysis, only actual money transfers are considered.)

Social Costs. The term "social costs" comprises any costs or benefits that are monetary or non-monetary. These are typically the domain of what may be considered a Benefit-Cost Analysis (BCA), which usually combines monetary and non-monetary costs (once the latter have been monetized). By contrast, Economic Impacts Analyses typically only consider monetary costs (although non-monetary costs are sometimes converted to productivity effects).

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[4] One's personal willingness-to-pay for time is just one way that economists use to estimate the value of non-monetary costs. The method used will vary based on what is being valued. For purposes of using TREDIS, the method used is not important, although the source of the estimate should be documented, as it is for all defaults provided in TREDIS.

BCA typically considers some monetary costs as transfers between sectors that cancel out and thus have no effect on the net benefit-cost calculation. However, because any two sectors will have differing economic effects when money is added or subtracted from it, transferring between sectors is not a zero-sum activity.

3.1 Value of Travel Time Savings for Drivers and Passengers

Travel time is defined to encompass several classes of travel: in-vehicle travel time and out-of-vehicle time (which includes both origin-destination access time and wait time). The valuation factors will differ by the class of travel, as well as mode and purpose. However, the same general formulas apply, as indicated below. In each case, the valuation factors are presented in *TREDIS Data Sources and Default Values*.

Passenger Time Cost (Delay Valuation). Passengers have an opportunity cost to time spent traveling, which can include both in-vehicle travel time and out-of-vehicle time (which includes any waiting plus time to actually access the vehicle). For any single alternative “s”, and for each combination of travel mode (m) and trip purpose (p), passenger time costs are the product of total VHT, passengers per vehicle (*PassPerVeh*), and the cost rate per hour of passengers.

Guide to Formulas

m = mode

p = purpose

s = scenario

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

TREDIS enables separate valuation of in-vehicle and out-of-vehicle time for each mode/purpose combination.

Crew Time Cost (Delay Valuation). For each mode/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.

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

TREDIS enables separate valuation of crew hourly costs and occupancy rates for each mode (*m*) and purpose (*p*): freight, business, commute, or personal. This distinguishes between driver and other crew costs for buses, trains, aircraft and marine transportation services. It also enables distinction between crew costs for passenger versus freight services. For car mode, the driver is most often also a passenger and hence is covered by passenger cost.

3.2 Value of Travel Time Reliability for Drivers and Passengers

Beyond creating delay and higher vehicle operating costs, congestion and traffic incidents also have the effect of increasing the *variability* of travel times. Travel time variability relates to the day-to-day variation in how long it takes to complete the same trip. 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 allow for possible delays and leave earlier to ensure an on-time arrival. This extra time is sometimes referred to as “schedule padding” or “buffer time.” Just like actual travel time, this added buffer time has an opportunity cost because it takes away from time that could otherwise be spent doing other activities. The valuation of this additional time is split between a traveler reliability time value (applying for driver and passengers) and a logistics cost value (applying for shippers and their agents).

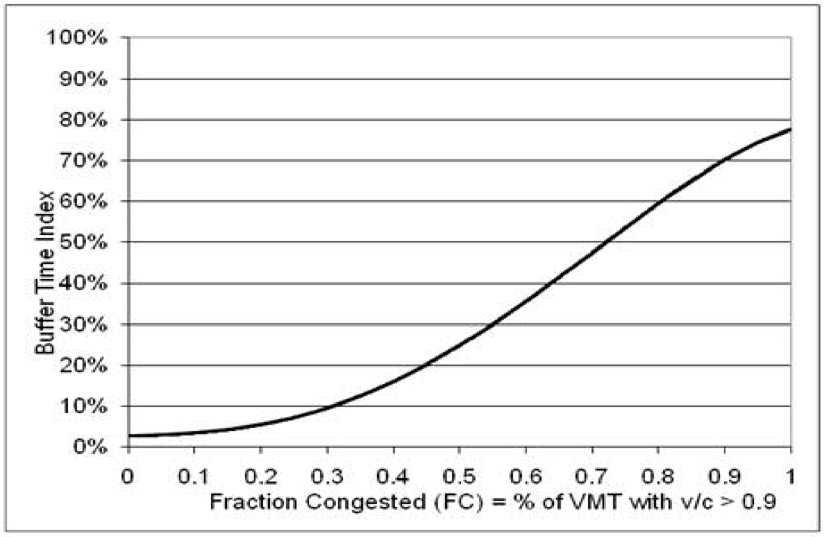
Buffer time in TREDIS is defined to be the added time allowed to ensure an on-time arrival 95% of the time, which is equivalent to 19 out of 20 workdays per week. Buffer time is most commonly considered to have a monetary cost for work travel, commuting and freight delivery trips. The Travel Cost module 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:

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

Typically, the "cost per buffer hour" is the same as the value of time for the driver and passengers. This formulation for valuing reliability has the benefit of being highly general, so costs for in-vehicle and "out of vehicle" time can all be included.

It is usually assumed that there is no added vehicle operating cost associated with scheduling extra time for a household vehicle or business car to be available. Technically, freight delivery fleets are optimized to avoid idle time so there *is* an added fleet cost associated with the addition of buffer time in scheduling time-sensitive, same-day deliveries. However, that is covered by logistics cost in TREDIS, which is discussed later in Section 4.1.

When buffer time is not known for car or truck travel, TREDIS provides an alternative option that automatically generates a rough estimate of aggregate buffer time for a network of highway links, based on the fraction of VMT on links that are "highly congested" (i.e., with volume/capacity ratio over 0.8%). This approach does not allow for the role of highway traffic and design or operations improvements in affecting reliability, which can be done with the direct buffer time impact metric. Rather, it draws on empirical relationships between buffer time and congestion for individual highway links,[5] and then extrapolates that relationship based on its inflection point around 0.8 v/c, as shown in Figure 3.



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[5] Figure 2.3 Relationship between Congestion Level and Reliability, in *Traffic Congestion and Reliability: Linking Solutions to Problems*, by Cambridge Systematics and Texas Transportation Institute, FHWA, 2004. https://ops.fhwa.dot.gov/congestion_report_04/chapter2.htm

Figure 3. Relationship between Buffer Time Index and Congestion for Road Modes

The Buffer Time Index shown in this graphic is the fraction of time cushion (i.e., extra time) that travelers must add to their average travel time when planning trips to ensure on-time arrival."[6] 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, TREDIS draws on a few other travel demand input variables. In the following equation, the BTI term is a function 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:

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

3.3 Vehicle Operation Cost (VOC)

TREDIS defines vehicle operating costs as the per-mile cost of vehicles (such as tires, maintenance, and depreciation) for travel in free-flow conditions. TREDIS accounts for fuel consumption separately from other vehicle operating costs that vary with vehicle use. (See Section 3.4). Fixed costs of ownership such as licensing and registration are not considered for household vehicles, but may be considered for commercial modes when fleet size can fluctuate over the long-run. For TNCs and Taxis, cleaning costs are included.

TREDIS uses three separate fixed factors that work in tandem to calculate the impacts of transportation system improvements on vehicle operating costs:

- *Vehicle Operating Cost ($/mile, free-flow)* — the average per-mile cost of vehicle operation for uncongested network travel. Note: changes in vehicle mileage affect all elements of operating cost.
- *Vehicle Operating Cost ($/mile, congested)* — the average per-mile cost of vehicle operation under congested conditions. For roads, congestion is defined as a travel on links with a volume/capacity ratio > 0.9. Note: In congested conditions, fuel consumption is higher. All other cost elements are the same.
- *Vehicle Operating Cost ($/hr, congested or idle)* — the average per-hour cost of a vehicle sitting at idle, in a queue, or traveling in highly congested conditions. Note: Longer vehicle operating times, including idling, increases fuel consumption. Other cost elements (e.g., insurance and depreciation, are not affected).

All three measures are used because quantifying operating costs is done differently by 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,

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[6] This definition is 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)

three separate equations may be used to calculate vehicle operating costs. In addition, there can be situations where a transportation system improvement reduces time delay but does not change vehicle-miles of travel.

For each mode-purpose combination, TREDIS determines whether to calculate costs using VMT or using VHT. For example, it is possible (though unlikely in practice) for Passenger Cars with a Commute purpose to use VMT but for Passenger Cars with a Personal purpose to use VHT.

VMT is used to calculate costs for a mode-purpose if any of the following are true:

- the scenarios have different levels of VMT
- the scenarios have different fractions of congestion
- the scenarios have different fractions of pavement designated “poor”

If none of these are true, then VHT is used to compute costs for the mode-purpose.

In the following equations, FF indicates “free-flow” travel conditions and “Cong” indicates congested travel conditions. The unit cost factors (per mile or per hour) are shown in the separate volume called *TREDIS Data Sources and Default Values*.

Time-based calculation

$$VOC_{mp}^{s} = VHT_{mp}^{s} * CostPerHour_{mp}$$

Distance-based calculation

$$VOC_{mp}^{s} = VMT_{mp}^{s} * CostPerMileFF_{mp}$$

$$C)\ VOC_{mp}^{s} = VMT_{mp}^{s}\Big[\big(CostPerMileCong_{mp} * FracCong_{mp}^{s}\big) + \big(CostPerMileFF_{mp} * (1 - FracCong_{mp}^{s})\big)\Big]$$

These equations assume all travel on roads is on 100% sufficient pavement, with no adjustment for poor pavement effects. See the section on pavement conditions for details on how this is adjusted.

3.4 Fuel Costs

TREDIS calculates fuel costs separately from other elements of vehicle operating cost to enable analysis of scenarios involving changes in types of fuel used, fuel prices and fuel consumption (average vehicle fuel efficiency).

The TREDIS default modes represent a single fuel type across the fleet (e.g., passenger cars are all gasoline, all heavy-duty trucks are diesel). Custom modes can be created to allow the addition of new mode-fuel combinations, such as electric passenger cars. Fuel prices and tax rates are modifiable by mode, year, and scenario. For free flow traffic, fuel consumption is measured by multiplying mode-specific fixed fuel efficiency factors, such as gallons of fuel (or kwh) consumed per vehicle mile traveled, by the VMT for each mode. However, not all travel happens in free flow conditions and therefore TREDIS can also model fuel use under congested conditions by using a ratio to scale fuel per mile used under free flow conditions to congested conditions.

Only car, tractor trailer truck, and light/medium duty truck are subject to changes in fuel consumption while congested. All other modes use the same consumption for congested and uncongested conditions as congestion is most relevant for the road-based modes. Buses’ regular operation is under stop and start conditions and are assumed to not be noticeably affected by congestion for most applications. Users should consider modifying defaults for projects such as dedicated bus lanes, which might significantly change drive cycles. Fuel consumption rates and congested mile to free flow mile ratios are available in the *TREDIS Data Sources and Default Values* document.

Additionally, as for vehicle operating costs, under certain circumstances TREDIS will use VHT to estimate fuel use. See the section on vehicle operating costs for details. Fuel use is estimated assuming sufficient pavement quality but might be adjusted for poor pavement conditions; see the section on pavement conditions for details.

Three factors are used:

$FuelPerMile^{s}_{mp}$ – gallons or GGE of fuel used per mile

$CongestedToFreeFlowRatio_{mp}$ – ratio of congested use to free flow use

$CongestedHourToCongestedMileRatio_{mp}$ – ratio of congested use per hour to congested use per mile

For VMT, the equation for gallons or GGE of fuel used is

$$Gallons^{s}_{mp} = VMT^{s}_{mp} * \left(1 - FracCong^{s}_{mp}\right) * FuelPerMile^{s}_{mp} + VMT^{s}_{mp} * FracCong^{s}_{mp} * FuelPerMile^{s}_{mp} * CongestedToFreeFlowRatio_{mp}$$

If using VHT, it is

$$Gallons^{s}_{mp} = VHT^{s}_{mp} * FuelPerMile^{s}_{mp} * CongestedToFreeFlowRatio_{mp} * CongestedHourToCongestedMileRatio_{mp}$$

The cost is then simply the unit cost multiplied by the gallons (or GGE) estimated.

$$FuelCost^{s}_{mp} = Gallons^{s}_{mp} * FuelCostPerUnit^{s}_{mp}$$

3.5 Pavement Condition Effects on VOC and Fuel Consumption

Road pavement conditions are an important factor consideration in transportation asset management. In the US, the Highway Performance Monitoring System (HPMS) data is used by FHWA to classify road links as having “good” or “poor” pavement condition, taking into consideration road roughness, cracking and rutting / faulting. TREDIS recognizes that “poor” pavement condition has the effect of increasing vehicle operating cost (VOC) as drivers seek to avoid large ruts and potholes. This leads to higher fuel consumption (due to rut or pothole avoidance deceleration and re-acceleration) and it also increases the rate of tire or vehicle parts replacement. TREDIS reflects this effect via a “poor pavement” multiplier factor applied to VOC and fuel consumption.

FHWA defines “poor” pavement as having an IRI (International Roughness Index) of over 170 inches / mile and either (a) asphalt rutting of over 0.40 inches or (b) concrete cracking rate of over 10%. See Grogg, Max: “Overview of Performance Measures: Pavement Condition to Assess the National Highway Performance Program,” Highway Information Seminar, November 2017, FHWA Office of Infrastructure. The pavement cost increase factor is shown in the separate document called *TREDIS Data Sources and Default Values*.

For vehicle operating costs, the adjustment is as follows:

$$VOC_{PoorPavement} = VOC_{GoodPavement} * VehOperCostPenaltyRatio$$

Three parameters are used:

- $VehOperCostPenaltyRatio_{mp}$ – the ratio of vehicle operating costs while driving on poor pavement to the vehicle operating cost while driving on sufficient pavement
- $PoorPavementFuelRatio_{mp}$ — the ratio of fuel consumption while driving on poor pavement to the fuel consumption while driving on sufficient pavement
- $PercentPoorPavement_{mp}^{s}$ — the percent of poor pavement in a scenario for the travelling done by the mode-purpose combination

These are taken to weight the amount of fuel consumed:

$$AdjustedGallons_{mp}^{s} = \left(1 - PercentPoorPavement_{mp}^{s}\right) * Gallons_{mp}^{s} + PercentPoorPavement_{mp}^{s} * Gallons_{mp}^{s} * PoorPavementFuelRatio_{mp}$$

which is algebraically equivalent to

$$AdjustedGallons_{mp}^{s} = Gallons_{mp}^{s} * \left(PercentPoorPavement_{mp}^{s} * \left(PoorPavementFuelRatio_{mp} - 1\right) + 1\right)$$

Similarly, the vehicle operating cost can be adjusted:

$$AdjustedVOC_{mp}^{s} = VOC_{mp}^{s} * \left(PercentPoorPavement_{mp}^{s} * \left(VehOperCostPenaltyRatio_{mp} - 1\right) + 1\right)$$

The adjusted fuel consumption or VOC are used as the final fuel consumption or vehicle operating costs where appropriate and in equations in this document.

3.6 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 $1 million 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:

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

3.7 Costs of Crashes

Calculating Numbers of Fatalities, Injuries, and Vehicles. TREDIS valuations of the cost of crashes are based on the value of different crash outcomes. There are multiple ways to provide TREDIS inputs related to the crash outcomes resulting from different alternatives. Regardless of the selected inputs, the numbers calculated always take the same form: numbers of KABCO-rated fatalities and injuries[7] as well as crash-involved vehicles. Optionally,

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[7] In the KABCO severity ratings of injuries and fatalities, K means a fatality, A-B-C-O refer to decreasing injury severity ratings, and U refers to "injury of unknown severity." U-level injuries are incorporated by assigning them proportionately to one of the severity ratings A-B-C-O based on crash outcome research.

you may input injuries as unknown severity (rather than one of the specific severities indicated by A-B-C-O) and you may enter total crashes in lieu of crash-involved vehicles. You can input this data at full detail by mode and purpose, without mode and purpose detail, or based on rates per 100 million vehicle miles traveled.

When calculating these numbers using rates, the number of fatalities, injuries, and vehicles is the product of the rate and the number of miles, where the crash outcome type (denoted by *t*) is one of the following: fatality; A injury; B injury; C injury; O injury; crash-involved vehicle.

$$Incidents_{mp}^{s,t} = (VMT_{mp}^{s}/100\text{M}) * Rate_{mp}^{s,t}$$

If "Crashes" are entered in TREDIS instead of "Crash-Involved Vehicles", these are converted to *Crash-Involved Vehicles* using the *Vehicles Per Crash* factor.

Total Social vs. Monetary Costs. The costs of crashes are calculated separately for the Benefit-Cost Module and the Dynamic Regional Economic Model, which means the total social costs of crashes are calculated separately from the monetary costs, even though monetary costs are usually included in total social costs.

This is because the source for the total societal costs of fatalities and injuries is value-of-statistical-life research cited by the USDOT BCA guidance, which includes in a single number both the dollar-denominated non-monetary value of avoiding crashes (in the form of willingness-to-pay indicators) and monetary costs (due to lost productivity and other considerations). This is an appropriate value for BCA analysis since it reflects total social costs, but would be incorrect to use for Economic Impact Analysis since it includes considerations such as willingness-to-pay for averting crashes. Moreover, the pure VSL-based valuation does not account for specific economic sectors affected by crash consequences and cannot support Economic Impact Analysis.

The primary source for the monetary costs associated with fatalities, injuries and crash-involved vehicles[8] (that is, the monetary costs used for Economic Impact Analysis) also provides detail on different components of the total costs, differentiating, for example, medical costs from workplace costs. The process for this is described in the *Dynamic Regional Economic Simulation Model* document.

Calculating Total Social Costs. When crashes occur, social costs result from property damage, personal injuries, and fatalities. While the number of each of these may vary between alternative, the cost for each fatality, injury, or crash-involved vehicle is fixed for all alternatives. Unit costs are shown in the separate document called *TREDIS Data Sources and Default Values*.

$$Social\ Cost_{mp}^{s,t} = Incidents_{mp}^{s,t} * Social\ Cost\ per\ Incident_{mp}^{t}$$

Calculating Costs for Economic Impact Analysis. The monetary costs to be used for the economic impact analysis are calculated in a similar manner to the social costs, but for each outcome (fatality, injury, or property damage), costs are estimated across several distinct

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[8] Blincoe, L., Miller, T. R., Zaloshnja, E., & Lawrence, B. A. (2015). The economic and societal impact of motor vehicle crashes, 2010 (Revised) (No. DOT HS 812 013).

components: medical care, patient transportation, household lifetime earnings, household productivity, insurance administration, workplace costs, legal costs; and property damage.[9]

The equation, using *c* to represent the appropriate component and *t* to represent the crash outcome (among fatalities, injuries by severity, and crash-involved vehicles), is

$$Economic\ Cost_{mp}^{s,t,c} = Incidents_{mp}^{s,t} * Economic\ Cost\ per\ Incident_{mp}^{t,c}$$

3.8 Social Costs and Benefits and Value of Time Adjustments

The net social cost represents a combination of two effects: a value of time adjustment for passengers, and a social cost adjustment for vehicles.

$$SocialNetCost = VOTAdjustment + OtherSocialNet$$

Value of Time Adjustments. The value of time represented elsewhere in TREDIS does not capture special circumstances for passengers on transit experiencing negative or even positive value of time adjustments. For example, crowding on a train will make passenger time more undesirable than it would be normally. These adjustments are expressed as a ratio in TREDIS as the adjusted value of time over the regular value of time, and then a percent of hours traveled is designated as “adjusted.”

$$ModelAdjustment_{mp}^{s} = InModelTripBalance_{mp}^{s} + \left(OutModelTripBalance_{mp}^{s} * 0.5\right)$$

$$\begin{aligned} VOTAdjustment_{mp}^{s} \\ &= ModelAdjustment_{mp}^{s} * PassengerHoursTraveled_{mp}^{s} \\ &* PercentVOTAdjusted_{mp}^{s} * CostPerPassengerHour_{mp} \\ &* \left(VOTPenaltyRatio_{mp} - 1\right) \end{aligned}$$

Other Societal Costs and Benefits. The second component of *SocialNetCost* represents other social costs and benefits that might be generated by VMT, such as noise, which in TREDIS are modeled using the fields *OtherSocialCosts* and *OtherSocialBenefits*, as characteristics of each mode.

$$OtherSocialNet_{mp}^{s} = VMT_{mp}^{s} * \left(OtherSocietalCosts_{mp} - OtherSocietalBenefits_{mp}\right)$$

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[9] Based on Harmon, T., Bahar, G. B., & Gross, F. B. (2018). Crash costs for highway safety analysis (No. FHWA-SA-17-071). United States. Federal Highway Administration. Office of Safety. While TREDIS uses ABCO injury levels directly for social cost estimation, ABCO injuries are first converted to the Maximum Abbreviated Injury Scale (MIAS) to better match the source material.

4 Calculation of Other Travel-Related Cost Savings

This section provides formulas for the calculation of costs arising from transportation movement that do not accrue specifically to travelers but are instead felt by others. This includes both (a) freight system user costs that accrue to shippers and receivers, and (b) broader environmental, economic and social costs that accrue to society at large. Non-travel benefits, like travel benefits, can be counted in benefit-cost analysis and can serve as a driver for broader regional economic benefits.

Other Travel-Related Costs

- Freight Logistics user costs
- Emissions costs
- Economic productivity
- Other Social costs

These "other travel-related costs" are also incurred as a function of of changes in trips, modes of travel, and VMT and VHT, and are assigned a specific monetary value defined by regulatory guidance and research. The formulas are discussed below. The dollar valuation factors are provided in the document *TREDIS Data Sources and Default Values*.

4.1 Freight Logistics Cost Savings

Definition. Besides traveler (passenger, crew and vehicle operating) costs represented by Traveler Cost Savings, freight shipments involve opportunity costs that directly accrue to non-travelers, specifically shippers and delivery vendors working on their behalf. Those freight costs are, in turn, typically passed on to receivers or consignees.

Today, many manufacturers and distributors operate their own in-house truck fleets to deliver products to customers. Others rely on logistics companies and consolidators as their agents to accomplish this outcome. Either way, shippers are the real "users" who bear costs of freight transportation even though they are not themselves traveling. More specifically, shippers are the ones who ultimately incur logistics-related costs as a consequence of delivery delays and systematic schedule uncertainty.[10] These costs include (a) inventory carrying costs, (b) fleet carrying costs, and (c) late delivery penalties. Shippers with time sensitive deliveries typically pad their schedules to minimize late deliveries – an action which incurs additional indirect costs for which we use the late delivery penalty variable as a proxy. In TREDIS, freight logistics cost are valued separately for predictable delays and for unreliability based on the following two equations:

$$LogisticsDelayCost_{m,r}^{a} = InventoryCarryingCost_{m,r} * VehicleHoursTraveled_{m,r}^{a}$$

Guide to Formulas

m = mode

a = alternative

c = commodity

r = region

sen = sensitivity group of commodities

For this section, purpose is always freight so no *p* subscripts are noted.

Unlike other travel cost factors, by default, certain valuations vary by geography. Fuel price behaves similarly in calculations.

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[10] For a further discussion of this issue, see FHWA's website on incorporating freight in benefit-cost analysis, http://ops.fhwa.dot.gov/freight/freight_analysis/cba/index.htm.

$$LogisticsReliabilityCost^{a}_{m,r} = \left(InventoryCarryingCost_{m,r} * InventoryCostMultiplier_{sen} + FleetCarryingCost_{m} + LateDeliveryPenalty_{m}\right) * BufferHours^{a}_{m,r}$$

This cost varies by the commodity mix and mode use of the affected transportation facilities. For each region, a basic TREDIS subscription uses Freight Analysis Framework (FAF) data to provide information on the commodity mix associated with each mode type. This commodity mix varies depending on whether freight flows are internal to the region, incoming, outgoing, or traveling through the region. The FAF data is based on regions defined by USDOT. Users of the vFreight data product for TREDIS have access to county-level detail on internal-inbound-outbound-through flows of freight. TREDIS fueled by Transearch allows corridor-specific freight flow data to be applied when valuing logistics costs for delay and reliability.

Derivation of Behavioral Impacts. Additional logistics costs occur as a consequence of recurring delay caused by congestion slowdowns as well as delivery schedule padding that is done in advance to ensure on-time deliveries. These elements of logistics costs are applicable for time-sensitive deliveries. Table 1 summarizes the behavioral processes whereby these costs are incurred. Table 2 shows the commodity classification used in TREDIS to define time-sensitive deliveries (these classifications can be modified by the user).

Table 1. Elements of Total Logistics Cost and How They are Incurred

Effect	Recurring Freight Delay Impact	Freight Schedule Buffering Impact
Inventory Carrying Cost (varies by mode depending on regional commodity data)	Capital cost of inventory increases while inventory is tied up in transit.	Carrying cost of inventory increases if greater inventory must be held at destination to avoid shortfalls due to late deliveries.
Fleet Carrying Cost (varies by mode)	*Not included as it is already considered in vehicle operating costs.*	Vehicle cannot be scheduled for other uses since schedules need to be buffered. Additional vehicles and drivers are thus required.
Late Delivery Dock Cost (only applies for time-sensitive deliveries)	*Not included because logistics providers are able to make reasonable plans to avoid late deliveries from recurring delay.*	Deliveries are not scheduled for the end of the shift to avoid arriving late; or more workers are scheduled for the end of shifts than would otherwise be needed.

Table 2. Classification of Time-Sensitivity by Commodity

High Time Sensitivity	Medium Time Sensitivity	Not Time Sensitive	
Pharmaceuticals	Chemical products	Tobacco products	Fertilizers
Precision instruments	Plastics/rubber	Newsprint/paper	Building stone
Electronics	Printed products	Gasoline	Nonmetal mineral
Transport equipment	Base metal articles	Basic chemicals	Cereal grains
Textile Products	Alcoholic beverages	Metallic ores	Waste/scrap
Machinery	Base metals	Other agricultural	Nonmetallic minerals
Motorized vehicles	Milled grain products	Fuel oils	Logs/timber
Meat/seafood	Furniture	Wood products	Coal
Live animals/fish	Other Foodstuffs	Crude petroleum	Sand and Gravel
Mixed Freight		Animal feed	All Other Commodities

Definitions for the Components of Total Logistics Cost

The currently applicable factor values for these cost elements or their components are provided in the document *TREDIS Data Sources and Default Values*.

$InventoryCarryingCost_{m,r}$ is the excess cost of capital tied up by "rolling inventory" (products on trucks) due to recurring or sporadic delivery delays.

$$InventoryCarryingCost_{m,r} = TonsPerVeh_{m,r} * \sum_{c} \left(ValuePerTon_{c,r} * HourlyInterestRate \right)$$

When valuing reliability, a cost multiplier is applied to better capture interactions within the supply chain related to non-recurring delay leading to mismatch between on-hand inventory and in-transit inventory. This multiplier varies across the time sensitivity groups (and is zero by default for the low sensitivity group.)

$FleetCarryingCost_m$ is the additional cost of acquiring, storing, and maintaining additional vehicles in a fleet to allow for schedule padding as required to ensure on-time customer deliveries in the face of sporadic cargo movement delays. For example, a schedule padding of one hour per vehicle/day would have the effect of reducing the number of deliveries that a truck can make in an 8-hour day to be the equivalent of 7 effective hours, thus requiring a proportionally larger fleet size. This effect applies for schedule-sensitive shipments, as defined above. This concept of *fleet carrying cost* is different from (an additional to) the *freight vehicle operating cost (VOC)* that was covered in Section 3.3. There is no overlap because freight VOC was defined to include incremental costs of operating a vehicle for more miles or longer periods of time, but it does not include the hourly (depreciated acquisition) cost of enlarging a fleet to address inefficient allocation of resources due to unreliability.

$LateDeliveryPenalty_m$ applies only for commodities where same-day delivery is commonly required. These are typically commodities classified as either perishable (e.g., fresh food), high-value (e.g., computer chips) or inputs for just-in-time lean manufacturing processes (e.g., automotive assembly parts). In these cases, there is typically a late arrival penalty cost for loading dock handling outside of normal working hours. The late arrival penalty covers staff time for overtime dock handling (unloading and warehouse restocking) and/or consignee staff rescheduling. It applies only for delays occurring late in the day that extend delivery times later than the normal delivery window.

$$LateDeliveryDockCost_{m,r} = \sum_{c} \left(LateRiskFactor_{sen} * RawPenaltyCost_m \right)$$

Where regional variation depends on what share of the regional commodity mix falls in each sensitivity category

4.2 Environmental Cost Savings

Types of Environmental Cost. TREDIS estimates the production and costs of the following pollutants and greenhouse gases:

- VOC — volatile organic compounds
- SO_2 — sulfur dioxide
- NO_x — nitrogen oxides
- PM 2.5 — particulate matter 2.5 microns or less in diameter
- CO_2 — carbon (dioxide) emissions

TREDIS incorporates two sets of equations distinct mechanisms for calculating environmental costs, one for VOC, NOx, SO_2 and PM 2.5, and one for CO_2.

TREDIS reports both projected quantity of emissions and valuation. Other costs that may not be considered environmental, such as noise or odor, are not calculated, though TREDIS provides an alternative input table that can be used to enter broader social or environmental non-user impacts (via the mode-purpose factors for *Other Social Costs* and *Other Social Benefits*).

For all of the equations in this section (and generally), unless otherwise specified, the *s* subscript, which stands for *scenario*, refers to a scenario (otherwise called an alternative), but also a year, period, and region as a sub calculation. The mode-purpose subscript, *mp*, is shown as a separate subscript because many fixed factors are determined at the mode-purpose level.

For both CO2 and other pollutants, TREDIS determines for each mode-purpose combination, whether to calculate environmental costs using VMT or using VHT, using the same rules as it does for Vehicle Operation Cost; see the appropriate section for details.

VOC, NOx, SO2, and PM 2.5. For each of the pollutants VOC, NOx, SO_2 and PM 2.5, TREDIS assigns a value for each mode-purpose, where *s* is the scenario alternative, *pol* is the pollutant, and *mp* is the mode-purpose:

$GramsPerVMT_{pol,mp}$ — tonnage produced per mile traveled in what is considered free flow traffic

$CostPerMetricTon_{pol}^{year}$ — cost in dollars per metric ton of the emission, determined by the year

$FracCong_{mp}^{s}$ — fraction of traffic congested

If using the VMT-based calculations, the total emissions for each combination of scenario, mode-purpose and pollutant is as follows:

$$Emissions_{pol,mp}^{s,year} = VMT_{mp}^{s,year} * GramsPerVMT_{pol,mp}$$

The environmental cost for each of the pollutants is calculated using the emissions:

$$EnvironmentalCost_{pol,mp}^{s,year} = Emissions_{pol,mp}^{s,year} * CostPerMetricTon_{pol}^{year}$$

Estimating to CO_2 Tonnage and Costs. CO_2 estimates require an estimate of the fuel used. See the section on fuel costs to see equations for the calculation of fuel use, and the section on poor pavement adjustments if applicable. Conversion ratios are generally fixed over time and are given in the *TREDIS Data Sources and Default Values* document. Emissions for each year are converted from pounds to metric tons using the conversion of 1.1015 US tons per metric ton.

$$Emissions_{mp}^{s} = Gallons_{mp}^{s} * ConversionRatio_{fuel} * 0.0005/1.1015$$

Cost estimates for CO2 and other emissions are determined by a cost schedule that assigns a (cost-year dollar) value to each year of emissions for a number of decades.

The final equation for CO_2 environmental cost is as follows:

$$EnvironmentalCost_{CO2,mp}^{s} = Emissions_{mp}^{s,year} * CostPerMetricTon_{CO2}^{year}$$

4.3 Economic Productivity

Types of Wider Economic Productivity Impact. When a transportation investment enables access to wider markets for workforce, customers or regional freight deliveries, businesses can gain “economies of scale” that save cost and increase productivity. Transportation investments can also enable more reliable deliveries to support just-in-time supply chain processes, which further increase the value of wider delivery market access improvements.

The value of these productivity benefits depends critically on the economic (industry) mix of businesses affected by a transportation improvement. For instance, wider labor market access is most important for businesses that require access to a large pool of highly educated workers to maximize job-skill matching. Supply chain access and reliability is most critical for high-value and perishable cargo. Since information on local industry mix is required, these productivity impacts are calculated within the TREDIS dynamic economic impact model. Please consult the technical documentation of the economic model for further information on the calculation of these benefits.

4.4 Social Benefit and Land Value Impacts

Types of Social Benefits. There is a nascent body of research on the costs on the valuation of improved neighborhood quality of life, including improved access to education, health care and recreation. TREDIS does not currently calculate these costs or benefits.

Interpretation of Land Value Impacts. Transportation projects and system improvements can have measurable impacts on nearby land values. There is a broad literature on “bid-rent” models and on “hedonic price” models that all show how land values rise around transportation system access points (largely defined as transit or rail stations and highway interchanges). Hedonic models show how this land value effect is a reflection of (a) increased modal choice, (b) reduced travel time, and (c) expanded market access in affected areas. These localized effects can be important considerations for planners, as they supports higher land use density, joint development and value capture financing.

From the regional analysis perspective of TREDIS, there are two reasons why land value impacts are considered duplications of already-captured effects:

(1) Regional effects on mode switching, reduced highway VMT and reduced emissions are already TREDIS scenario inputs. Their direct valuation and their wider regional impacts in terms of net regional income (GDP) are already calculated by TREDIS.

(2) With regional productivity and income effects already recognized, the localized effect on land values is considered to be a “spatial transfer,” in which local areas benefitting from improved transportation system access gain land value by shifting demand away from other areas in the region that do not get those transportation benefits. That localized spatial transfer effect represents a zero-sum impact for benefit-cost analysis and for regional economic impact.

For these two reasons, effects on land value impacts are generally viewed as double counting traveler benefits. However, land values can also potentially capture additional social benefits not otherwise measured in TREDIS, such as effects on neighborhood quality of life, as noted in Section 4.4. If further land value analysis is done outside of TREDIS to isolate these additional social benefits from effect of traveler benefits, then those findings can be entered into the TREDIS input table for broader social impacts.

5 Accounting for Transportation Benefits

5.1 Total vs. Local Travel Costs

For each cost type described in Sections 3 and 4, some portion of the cost may accrue to households and/or businesses within the specified study region, while the rest may accrue outside of 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.

There are two ways that users can enter travel data. The facility-based method has users enter data by fractional flows, indicating the percentage of trips in a region that are internal, incoming, outgoing, or through. Alternatively, the origin-destination (O-D) method has users enter data by regional pairs, indicating the “from” and “to” region, where sometimes the “from” and “to” are the same region. In this case, TREDIS has no information about the relative size of regions and location of trip ends within regions, so 50% of the costs from any pair of O-D movements are assigned to each involved region.

Whichever method is used, from the perspective of any region, there are the four types of flows, with “through” or “external to external” costs being excluded from the model results. The remaining costs are accounted for with this equation:

$$\begin{aligned} RegionalCost_{mp}^{s} &= TotalCost_{mp}^{s} \\ &* \left(FractionInternal_{mp}^{s} + \frac{1}{2} FractionIncoming_{mp}^{s} + \frac{1}{2} FractionOutgoing_{mp}^{s} \right) \end{aligned}$$

5.2 Accounting for Induced Travel

As described above, travel costs correspond to levels for a specific scenario alternative, and benefits are estimated by differencing two alternatives (for example, “build” vs. “no-build”). For projects with no induced travel, the change in direct travel impacts between two alternatives can simply be calculated as the difference between two alternatives. However, for projects with induced travel, this “simple” difference must be adjusted to account for travelers’ and shippers’ economic response to travel cost changes.[11]

A transportation project or improvement program may reduce travel costs through any of the traveler cost categories discussed in Section 3 or freight categories discussed in Section 4.1. 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 alternatives, then overall benefit can 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 4 demonstrates graphically the standard economic interpretation of induced travel.

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[11] 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.

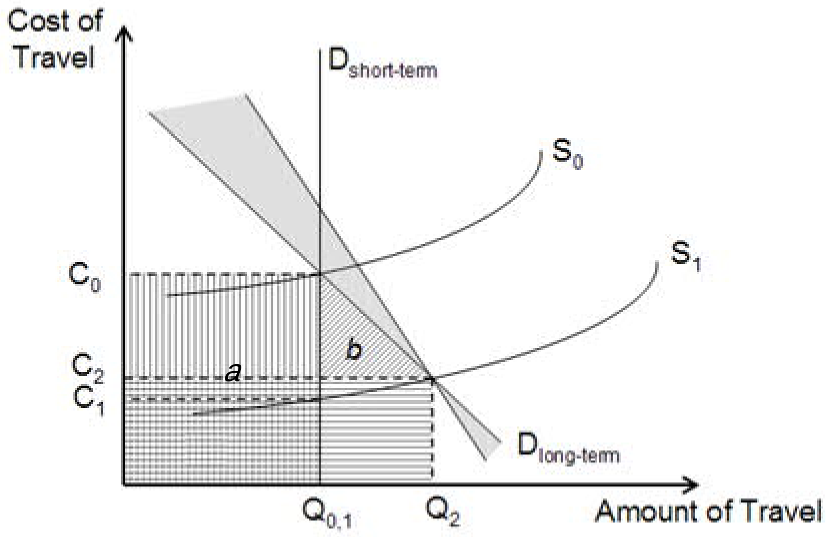

Figure 4. A Graphical Representation of Induced Travel

Over the short-term, travel demand has limited sensitivity to cost changes, though this might vary 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 above as the area bounded by C_0, C_1 and $Q_{0,1}$ 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” alternatives, then area *b* is the induced benefit — the increase in consumer surplus accruing to induced travelers. 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. In the following equations, indexes are s = alternative, t = travel period, m = travel mode, p = trip purpose.

$$\text{(1a)}\quad PassVol_{mp}^{st} = \left(VehicleTrips_{mp}^{st}\right)\left(PassPerVeh_{mp}^{st}\right)$$
$$\text{(1b)}\quad FreightVol_{mp}^{st} = \left(VehicleTrips_{mp}^{st}\right)\left(TonsPerVeh_{mp}^{st}\right)$$

These measures of travel volume are calculated for each of the two alternatives and differences are generated for each mode and trip purpose combination. For 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):

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

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 alternative are calculated as:

$$(3)\quad C_{mp}^{st} = \frac{UserCost_{mp}^{st}}{Q_{mp}^{st}}$$

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

$$(4)\quad InducedBenefit_{mp}^{t} = {}^{1}\!/_{2}\, InducedQ_{mp}^{t}\left(C_{mp}^{base,t} - C_{mp}^{alternative,t}\right)$$

5.3 Distribution of Benefits to Economic Categories

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, cost savings beneficiaries are grouped into five categories:

(1) household benefits that affect out-of-pocket expenditures
(2) household travel time benefits (that have a value but 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 many modes, five trip purposes, and seven user cost types, there are unlimited 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 of how benefits are allocated to the study area's economy.

Table 3. How Travel Benefits are Allocated to Economic Beneficiaries

Mode	Trip Purpose	Cost Type	Beneficiary Category:
Air	Personal/recreational	Passenger	Household time value (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. 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 business 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 trips that have at least one end in a modeled region, 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.