Appendix B

Economic Concepts

Valuing Travel Time Benefits

The value of travel time (VTT) refers to the cost of time spent on transport. To calculate travel time benefits, average travel times must be estimated in both the with- and without-project contexts. In the rest of this appendix, these contexts will be referenced as the Build (with project) and No Build (without project) scenarios. The travel times should be estimated for both scenarios for a base year and a forecast year.

Travel times are based on average travel speed and the distance traveled. These estimates should calculate average travel times for different time periods, such as peak and off-peak and for different days of the week. If travel is diverted from other roads the VTT should be estimated for these roads as well. From there, an appropriate travel time unit cost ("value of time") should be determined. This is measured in dollars per hour and is typically based on the median wage in the state where the project is located. The value of time for truck traffic typically differs from passenger vehicles.

Average passenger vehicle occupancy should be estimated to account for the VTT of all occupants in a vehicle. This should account for the time value of all travelers and for carpooling. The unit cost for truck VTT uses a vehicle occupancy of 1.0 because drivers are assumed to drive alone. The unit costs should be adjusted for vehicle occupancy, multiplied by vehicle travel times, miles traveled, and traffic. This includes traffic for the base year (typically current year) and a forecast year (after project implementation). Traffic for interim years should be interpolated.

The basic equations to calculate undiscounted VTT benefits should be completed for every year of the analysis period:

Automobile VTT Benefits =

[No-Build Travel Time (hrs/mile) × No-Build Trip Length (miles) × No-Build Auto Traffic (veh)] –

[Build Travel Time (hrs/mile) × Build Trip Length (miles) × Build Auto Traffic (veh)] ×

Auto Vehicle Occupancy (persons/veh) × Auto Value of Time ($/hr)

Truck VTT Benefits =

[No-Build Travel Time (hrs/mile) × No-Build Trip Length (miles) × No-Build Truck Traffic (veh)] –

[Build Travel Time (hrs/mile) × Build Trip Length (miles) × Build Truck Traffic (veh)] ×

Truck Vehicle Occupancy (persons/veh) × Truck Value of Time ($/hr)

Valuing Vehicle Use and Ownership

Changes in the costs of ***owning and operating vehicles*** (trucks and cars) resulting from a transportation improvement project are counted as benefits or disbenefits depending on whether post-project implementation conditions increase or decrease costs of owning and operating a vehicle. The two primary subcategories of vehicle cost are fuel and non-fuel related. Projects affect vehicle costs by changing vehicle-miles traveled (VMT), traffic speeds and delay, and the condition of roadway surfaces. To calculate the benefit of reduced operating costs, you need to estimate changes in VMT, by vehicle type, and changes in travel speeds, with and without the project improvement.

Current and historic fuel prices can be collected from a few different sources. The Energy Information Administration (EIA) of the U.S. Department of Energy publishes fuel prices nationally, regionally and at the state level. The American Automobile Association (AAA) publishes daily average gasoline prices at the national and state level. Each of these sources are typically equally appropriate to for these calculations.

Fuel consumption rates can be gathered directly from the U.S. Environmental Protection Agency (EPA) MOVES model or calculated using a consumption-by-speed relationship model. The rates should include consumption at different speeds and for both passenger and truck vehicle types. The fuel consumption rates can be multiplied by the number of vehicles, the vehicle trip length, and the price of fuel to capture fuel-related operating costs. Fuel-cost savings tend to be the largest component of vehicle cost savings.

Non-fuel related costs include oil, tires, maintenance and repairs, and vehicle depreciation. FHWA developed a model as a framework for state and regional agencies to assess investments in multi-modal transportation infrastructure called the Surface Transportation Efficiency Analysis Model (STEAM). This model estimates tire and maintenance costs using a cost-per-mile for automobiles and trucks.

The simplest option for calculating the value per mile of vehicle cost savings is to use information from the AAA ***Your Driving Costs*** report for automobiles and the American Transportation Research Institute (ATRI) ***An Analysis of the Operational***

Cost of Trucking report for trucks. These reports provide estimates to develop cost per mile of vehicle operating and maintenance that includes both fuel and non-fuel subcategories.

The basic equation for undiscounted vehicle cost savings is shown below:

Auto Fuel Cost Savings = [(No-Build Fuel Consumption Rate (gal/mi) × No-Build Auto VMT)- (Build Fuel Consumption Rate (gal/mi) × Build Auto VMT)] × Auto Fuel Cost ($/gal)

Where fuel consumption rates are based on speed

Auto Non-Fuel Cost Savings = (No-Build Auto VMT – Build Auto VMT) × Auto Non-Fuel Unit Cost ($/mi)

Total Auto Vehicle Cost Savings = Auto Fuel Cost Savings + Auto Non-Fuel Cost Savings

Complete same calculations above for trucks

Valuing Safety Benefits

A project that changes traffic crash rates, severity or total VMT creates safety benefits that can be calculated and valued. There are three general steps to calculating safety benefits. The first is to determine how the project changes crash frequency, severity, or total VMT. The second is to choose appropriate unit crash costs for crashes by severity. The third is to estimate the total economic value of the changes in crash rates.

The first step of determining how a project will affect the number of crashes is to identify if certain project design components will affect safety. Examples of safety-focused design features include rumble strips, elimination of sharp curves in roads, or pedestrian bridges that eliminate dangerous crossings. Each of these features can be assigned a crash modification factor (CMF).

A CMF is a factor that represents the proportion of crashes expected to be remaining after implementing a safety measure. The crash reduction factor (CRF) is the percent reduction in crashes expected from implementing a safety measure. The CMF = 1- CRF. As an example, if an improvement is expected to reduce crashes by 45%, this indicates that the CRF is 45% and the CMF is 0.55. CMFs can be obtained for most safety improvements from FHWA CMF Clearinghouse (http://www.cmfclearinghouse.org/).

Often safety improvements will help avoid only certain types of crashes. For instance, improving sight distance through enhanced geometric design of a turn lane may not help avoid rear-end crashes. If detailed crash data is available that specifies the cause of the crash, this helps to determine if certain crashes can be avoided due to particular design components. Then, the CMF should only be applied to reduce the relevant crashes.

If more than one improvement is being implemented, often multiple CMFs can be identified and combined through multiplication. Alternatively, if one design feature is considered to be most significant, the CMF for that improvement can be used. Ultimately, the way CMFs are applied to a particular project should be based on the context and goals of its implementation. Once this has been determined the CMFs can be applied to expected baseline incidents to determine how many incidents are expected to be avoided.

Another way to avoid crashes is to reduce the overall VMT. If the project reduces trip length or traffic, then even without a change to the crash rate, the total number of expected crashes will decrease as well.

The value of incidents by severity can be a controversial determination because an important component is the value of a human life. Most transportation agencies maintain values for incident types and severities, but guidance is provided by USDOT when location specific values are not maintained. USDOT values can be found in **Table B-1**.

Table B-1. USDOT Values for Crash Incidents

KABCO Level	Monetized Value ($2018)
O - No Injury	$3,700
C - Possible Injury	$72,500
B - Non-Incapacitating	$142,000
A - Incapacitating	$521,300
K - Killed	$10,900,000
U - Injured (Severity Unknown)	$197,600
# Crashes Reported (Unknown if Injured)	$150,200

Source: USDOT *(48)*

The value of reduced crashes is found by multiplying the estimated value per crash type by the change in the number of crashes of each type. If available, site-specific data should be used for the number of incidents that involve fatalities, injuries, and property damage.

The basic equations to calculate undiscounted safety benefits should be completed for every year of the analysis period:

Build Expected Crashes, by severity = (No-Build Expected Crashes, by severity) × (CMF, by severity)

Safety Benefits = (No-Build Expected Crashes, by severity – Build Expected Crashes, by severity) × Monetary Value of Crash, by severity

Valuing Emissions Benefits

Projects that reduce emissions ***(including greenhouse gases and other pollutants)*** help avoid negative externalities. These emission reductions can be quantified and monetized as project benefits. A project may help avoid emissions by reducing vehicles on the road, diverting traffic to other routes or modes, reducing congestion, or changing the average travel speed.

The method for calculating emission reduction benefits can be broken into three steps. The first step is to estimate the VMT and average speed in the No-Build and Build scenarios. Once these are estimated a model is needed to produce average emission rates for each pollutant type, by speed bin and vehicle type. The second step is to apply an appropriate dollar value per unit of emission, by type of pollutant. The third step is to monetize the costs of emissions in the No-Build and Build scenarios and take the difference to estimate emission cost savings.

Typical pollutants considered for monetizing emission costs include carbon dioxide (CO_2), nitrogen oxide (NOx), sulfur dioxide (SO2), volatile organic compound (VOC), and particulate matter (PM2.5). Emissions can impose negative effects on human health, and create environmental damages leading to climate change. The EPA MOVES model provides emissions rates (grams/mile) for each pollutant type by speed bin and vehicle type at the county and national level. Specifically, this model includes rates for passenger vehicles and both long-haul and short-haul trucks. The model accounts for differences in operating conditions that can vary from location to location. Also, the MOVES model provides projections for future year emissions rates, which account for expected changes in technologies that improve fuel efficiency.

Studies done on carbon tax pricing are a resource in estimating unit costs for each pollutant type. A summary of these findings can be found in **Table B-2**. Note that this table shows amounts in 2007 U.S. dollars. These values need to be converted to the base year used in the BCA, which can be done using an inflation series from the Bureau of Economic Analysis (BEA) ***(55)***.

Using the table shown above as a reference the value of undiscounted emissions reductions can be calculated two different ways. Note that the emission reduction benefit has to be calculated for each pollutant type being considered. Benefits should be calculated for every year of the benefit analysis period.

Auto Emissions Reduction Benefit = [(No-Build Auto VMT × Auto Emission Rate, by pollutant (g/mi)) – (No-Build Auto VMT × Auto Emission Rate, by pollutant (g/mi))] × Unit Conversion (tons/g) × Unit cost ($/ton)

- Where emission rates vary by speed bin and vehicle type

Complete same calculations above for trucks

Considering Induced Travel

Projects that change user travel costs (i.e., travel time or out-of-pocket costs) can motivate users to change their routes, modes of transportation, or times of travel. Users may also be motivated to make additional new trips given a reduction in travel costs. These new trips generate additional traffic with impacts to other users and the roadway. Induced travel refers to increased vehicle trips brought about by a project improvement.

Table B-2. Regional Pollution Studies Summary Table – Selected Studies

Publication	Costs	Cost Value	2007 USD
Costs per Ton (Tonne if noted)			
AEA Technology (2005)	NH3 / tonne Europe	2005 Euro - € 19,750	$ 26,061
	NOx	€ 7,800	$ 10,293
	PM2.5	€ 48,000	$ 63,339
	SO2	€ 10,325	$ 13,624
	VOCs	€ 1,1813	$ 2,392
RWDI (2006)	PM2.5 / tonne	2005 Canadian $ 317,000	*$ 277,359*
	O3 Total	$ 1,739	$ 2,392
Wang, Santini & Warinner (1994), U.S. cities	NOx	1989 $ / ton $ 4,826	$ 8,059
	ROG	$ 2,419	$ 4,040
	PM10	$ 6,508	$ 10,868
	SOx	$ 2,906	$ 4,853
Costs per Vehicle Mile			
CE Delt (2008)	Urban Car	0.0018 – 0.0024 €/km (2000)	$ 0.003 – 0.004
	Urban Truck	0.106 – 0.234 €/km	0.189 – 0.417
Delucchi et al (1996)	Light Gasoline Vehicle	$ 1990 / VMT 0.008 – 0.129	0.013 – 0.205
	Heavy Diesel Truck	0.054 – 1.233	0.086 – 1.960
Eyre et al. (1997)	Gasoline Urban	$ / VMT 1996 0.030	0.040
	Diesel Urban	0.074	0.098
FHWA (1997)	Automobiles	$ / VMT 0.011	0.015
	Pickups/Vans	0.026	0.034
	Diesel Trucks	0.039	0.051

Source: Litman ***(56)***

Additional vehicle travel tends to increase external costs due to downstream congestion, crash risk, emissions, and noise. Incorporating induced travel into an economic evaluation can be difficult. The elasticity of demand for travel in relation to total travel costs determines the degree to which induced travel is generated. The elasticity measures how much demand is generated for every percent decrease in travel costs or trave time. DeCorla-Souza ***(57)*** uses a travel demand elasticity with respect to travel time of -0.5 and an extreme value of -1.0 in their example highway evaluation. The moderate elasticity of -0.5 is based on Goodwin ***(58)***.

The Highway Economic Requirements System-State version (HERS-ST) model is a program developed by FHWA to help state DOTs evaluation evaluate the relationships among highway investment and system condition, performance, and user costs. Although the model is now old, it uses both short-run and long-run elasticities to estimate the induced demand generated by transportation projects ***(59)***. In the short run, the model assumes that changes in the price of transportation lead to movement along the short-run demand curve for travel. Traffic induced in the short run comes from diverted traffic, mode shifts, destination shifts, additional travel by current users, and time-of-travel shifts (in other words, short-run behavioral responses). The demand curve is considered fixed in the short run. Lee ***(15)*** refers to an increase in the quantity of travel demanded in the short run as "induced traffic." In transportation planning, this short-term horizon is typically about a year.

The HERS-ST model uses short-run and long-run elasticities to forecast traffic for future funding periods. Values selected for the short-run and long-run elasticity are -1.0 and -1.6, respectively. Further information about the HERS-ST procedures are available in the HERS-ST Technical Report ***(60)*** and Lee ***(59)***.

Induced trips will have an effect on several benefits categories and can affect how these benefits are calculated. In particular, the calculation of travel time savings is altered if induced demand exists. The increase in total traffic affects the change in VMT, and hence affects all benefits that rely on VMT, like emission cost savings. Increased traffic also impacts the calculation of total crashes and safety benefits.

Valuing Noise Impacts

Any roadway project that causes noise creates an externality with an economic value. Traffic noise can impair people's hearing, increase stress, disturb sleep, and contribute to ill health which in turn can reduce the property value of nearby homes. In cases where a transportation project has the potential to add significant amounts of traffic to an area, a traffic noise analysis may be required to determine the project's noise impact. If the impact is significant, the costs of noise abatement measures, such as sound walls, may need to be included as part of the economic valuation.

Calculating noise costs starts with quantifying noise impact, which is typically measured using A-weighted decibels (dBA). From there, a number of studies have attempted to monetize traffic noise costs. Most of these studies have been conducted using a hedonic pricing method, which measures how a change in traffic noise affect nearby residential property values.

Table B-3 summarizes results from previous noise cost studies. This table shows the per vehicle-mile cost of noise. Values are shown in real 2007 dollars and should be inflated to the base year of the analysis. Note that noise is considered to be a negative impact so noise costs would reduce economic benefits.

The general equation for calculating the undiscounted cost of noise is as follows and should be calculated for every year of the analysis period:

Noise Cost Savings = [(No-Build VMT, by vehicle type) – (Build VMT, by vehicle type)] × Noise Cost, by vehicle type ($/mi)

Table B-3. Values for Noise Externality – Selected Studies

Publication	Costs		Cost Value	2007 US $ / VMT
FHWA (1997) *Scope: Urban highways* *Units: 1997 cents per Vehicle - mile*	Automobile		0.11	0.001
	Pickup & Van		0.10	0.001
	Buses		1.72	0.022
	Combination Trucks		3.73	0.048
	All Vehicles		0.24	0.003
Delucchi and Hsu (1998) *Units: 1991 USD/1000 VMT*	Cars (Urban Arterial)		1.18	0.002
	Medium Trucks		7.02	0.011
	Heavy Trucks		20.07	0.031
	Buses		7.18	0.011
	Motorcycle		8.71	0.013
CE Delft (2008) *Scope: Urban roads* *Units: 2000 Euro cents per vehicle-km*	Car	Day	0.76	0.014
		Night	1.39	0.025
	Motorcycle	Day	1.53	0.027
		Night	2.78	0.050
	Bus	Day	3.81	0.068
		Night	6.95	0.124
	Heavy Trucks	Day	7.01	0.125
		Night	12.78	0.228

Including Changes in Operations and Maintenance Costs

O&M cost savings reflect reduced expenditures required to maintain a level of service. This is a relatively easy benefit to measure and value because O&M costs are typically goods and services that have a well-defined price. Savings of this type can come from improved roadway surface or a bridge design that is easier to maintain.

The value of undiscounted O&M costs savings is as follows and should be calculated for every year of the analysis period:

O&M Cost Savings Benefit = No-Build O&M Costs – Build O&M Costs

Including Other Benefits

The preceding benefits represent a reduction in the costs of transportation and are often the bulk of benefits realized by a project from a valuation standpoint. These benefits are also typically clearly defined and relatively straightforward to calculate. Other effects that can be included, but are not always straightforward, include:

- Equity and option value impacts that result from projects that increase transport system affordability and diversity
- Habitat and water quality
- Community impacts

These benefits can be measured and valued based on the priorities of the asset manager, but often do not represent a significant portion of total benefits. To get to total net benefits realized by users and the public at large, each benefit category is aggregated over the period of analysis and discounted back to present value terms. Note that benefits also include negative benefits ("dis-benefits") such as travel delays experienced during the construction period. These total discounted benefits will later be used to calculate the asset value.

Considering Inflation

Inflation is the increase in prices of goods and services over time. Inflation reflects a loss in the value of money over time, as it erodes the purchasing power of a currency. For economic valuations, inflation should be removed from calculations so that all dollar values are in real terms. This requires determining a base year in which all future costs and benefits dollar values are represented. Typically, the base year is set as the current year and all costs that are in real dollar terms for previous year must be inflated up and all real dollar value for year after the base year must be deflated down. This can be done using inflation factors available from BEA.

Note that the value of a benefit or cost may increase over time faster than inflation. This means that the economic value in real terms is increasing. In this case, inflation should be removed from the value, but the real value should be allowed to increase. For example, if the cost of a land purchase is expected to increase by 2% higher than inflation, this land cost should show a 2% increase per year in the economic analysis.

Discounting to Present Values

Up until this point discussion of economic values have been in terms of undiscounted values. To account for the assumption that a dollar today is worth more than a dollar in the future (above and beyond inflation) a discount rate needs to be introduced. The purpose of the discount rate is to put all present and future costs and benefits into common present value terms.

Initial costs, rehabilitation costs, end of project costs and any disbenefits incurred during construction are one-time costs or are realized over a limited period during the analysis period. Benefits and O&M costs are future streams of value that start accruing once the construction period is complete and continue for the duration of the analysis period.

The formula to calculate a discount factor that estimates present values for each year is shown below. Note that the equation is monotonically decreasing by a factor of the discount rate which will convert all values into the uniform context of present value. The undiscounted cost and benefits values calculated previously for each year of the analysis period should be multiplied by discount factor for the corresponding year.

Discount Factor = 1 ÷ [(1 + Discount Rate) ^ (Future Year – Base Year)]

Measuring Asset Values

The primary economic measure of asset value is the net present value (NPV). If the streams of benefits and costs have been discounted as described previously then these values can be summed for each category. The sum of each discounted benefit and cost category represents its present value. Summing the present values of benefits—including negative benefits—yields total discounted benefits. Doing the same for costs yields their total discounted present value. The equation for NPV is then:

NPV = Total Discounted Benefits – Total Discounted Costs

If the resulting NPV is greater than zero, then this indicates that benefits exceed costs and could suggest that the project is a worthwhile endeavor. Conversely if the NPV is less than zero then costs are greater than benefits and this suggests the project is not a worthwhile endeavor.

Another measure of value that can be calculated using discounted net benefits and costs is the benefit-cost ratio (BCR). This measure is useful if comparing options and benefits should be normalized to the relative costs of the options. This equation is similarly simple and be found by dividing net discounted benefits by discounted costs. In this case if the BCR is greater than 1 then net benefits area greater than costs and this could suggest that the project is a worthwhile endeavor. Conversely if the BCR is less than one then costs are greater than benefits and the project is likely not worth its implementation cost.

Additional Resources

Travel Time

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