BCA.Net

Reference Manual

Federal Highway Administration

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Contents

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Introduction

Description of *BCA.Net*

The Federal Highway Administration (FHWA) developed BCA.Net as an investment decision support tool for use by state and local authorities. The careful analysis and selection of highway investments serves to increase public returns for each dollar invested. BCA.Net was designed to implement the principles of project evaluation that were presented in FHWA's *Economic Analysis Primer* (see http://www.fhwa.dot.gov/infrastructure/asstmgmt/primer.pdf).

BCA.Net is a web-based application that enables the analysis of alternative strategies for highway maintenance and improvement, and supports resource allocation and investment decisions. It allows state and local decision makers to consider a broad range of design, timing and strategic alternatives based on an array of benefit-cost measures. *BCA.Net* evaluates the benefit-cost of highway improvements while explicitly reporting the results for each facility segment and each benefits category (e.g., time savings, reduced vehicle operating costs, improved safety, and reduced emissions).

A *BCA.Net* analysis generates, among additional indicators, the net present value (NPV) for a specified program of highway investments.   NPV is appropriate for measuring public returns because it captures a wide range of benefits that accrue to users of the transportation system and society as a whole. The *BCA.Net* analytic model calculates NPV by comparing the streams of expected economic benefits over time with the streams of investment, operating and maintenance, and other life-cycle costs. The model discounts later year benefits and costs to reflect the opportunity cost of capital. This process of discounting converts all values to present value equivalents thus enabling the comparison of benefits and costs realized in different time periods.

Some of the features of BCA.Net are:

- BCA.Net allows for multi-phased, multi-year programs of improvements, thus enabling a true lifecycle comparison of alternate strategies.

- BCA.Net enables the analysis of a range of capacity improvement strategies including lane widening, adding lanes and reversible lanes for roadways with skewed directional flows.

- BCA.Net models traffic conditions for multiple "representative days" to describe forecast facility use.

- BCA.Net evaluates intersection improvements including the replacement or introduction of traffic control devices and signals.

- BCA.Net explicitly models roadway dynamics for varying levels of traffic saturation.

- BCA.Net accounts for the effects of roadway conditions on trip cost and, in turn, the impact of trip cost changes on travel demand.

- BCA.Net provides a user-friendly platform for developing analyses and maintaining analysis data.

- BCA.Net has a full-featured risk analysis capability.

- BCA.Net runs on most computers with a browser and Internet connection and requires no special software.

BCA.Net's underlying methodology is consistent with best practice of benefit-cost analysis. The model is transparent in all of its assumptions and model inputs are readily accessible to users who may wish to adjust them to more closely reflect local conditions.

BCA.Net's risk analysis capability enables users to incorporate in an analysis the numerous uncertainties that are inherent in any forecast. Rather than relying on "best guess" inputs whose actual values may vary widely, risk analysis uses ranges for inputs. For a designated set of operational and policy variables in BCA.Net, users can set ranges describing probability distributions. These ranges reflect best available data and empirical evidence combined with any expert judgments that the user brings to bear in the analysis. *BCA.Net* includes a graphical interface that facilitates data entry and the visualization of probability distributions. *BCA.Net* presents its results, the outcomes of risk analysis simulations, as probability distributions. These results and their mode of presentation support informed decision-making by providing the full range of possible outcomes rather than relying upon a point estimate.

About this Document

This document is the *Reference Manual* for *BCA.Net* and it includes a description of the models, methods and formulas that *BCA.Net* uses to perform its calculations. There is also a section that describes the model inputs and their organization in *BCA.Net*.

The documentation for *BCA.Net* also includes under separate cover a *User's Manual* and several *Walkthrough Exercises* that the reader may find useful in gaining a better understanding of *BCA.Net*.

Model Overview

Introduction

This section provides and overview of the *BCA.Net* model.

The Analysis Frame of *BCA.Net*

The analysis frame of *BCA.Net* considers a proposed set of strategies, of maintenance and improvements, over a specified time horizon. The analysis of benefits and costs compares the present value of costs and benefits in the "alternate case" (usually, the "build" or with major investment case) to the costs and benefits in the "base case" (the "maintain" or without major investment case).

The following are the definitions and assumptions for the *BCA.Net* analysis frame.

Project and Segments

A highway facility that is the subject of analysis in *BCA.Net* is called the Project. A project will be comprised of one or more segments. A project segment has uniform facility characteristics, namely, number of lanes, speed-flow parameters and pavement serviceability index (PSI). A segment also has uniform travel demand and the travel demand characteristics (AADT, peaking, vehicle types) are set separately for each segment. The Project summary in the analysis results rolls up the benefit and costs for all project segments.

Base Case and Alternate Case

The Base Case usually represents the "no major investment" case (however, BCA.Net could be used with a Base Case that does include a major investment). In the Base Case, the analysis evaluates the operational effects and associated benefits and costs over the time horizon of the analysis with maintenance and minor improvements. An analysis will typically include a program of modest investments in the Base Case where these investments are part of a minimal fall back position that are most likely to be undertaken in lieu of more extensive investments.

In the Alternate Case, the analysis evaluates the benefits and costs under the assumption that the proposed investments are implemented according to a schedule of capital expenditures.

Strategies

In *BCA.Net* the Base and Alternate Cases are constructed from *Strategies*. A strategy includes three components: 1) facility characteristics realized after strategy implementation, 2) costs associated with a strategy and 3) the status of signals and devices after strategy implementation. The user develops the Base and Alternate Cases by specifying strategies and their years of implementation.

Scenarios

A scenario in *BCA.Net* is the collection of risk analysis input data for specially designated variables. The scenario input variables are grouped in the following categories: travel demand, social costs, project costs, prices and taxes.

The Time Horizon

Period of Analysis

The BCA.Net period of analysis is determined by the "start year" and "end year" values of the input scenario. A typical period of analysis for a highway project will be 30 or 35 years (BCA.Net will permit a period of analysis not exceeding 50 years). In each of the years of the period of analysis, BCA.Net evaluates travel demand, the status of the facility, and the benefits and costs that accrue to highway users and society. BCA.Net also evaluates the residual value of the facility, that is, the value of the useful remaining life of the investment in the facility at the end of the period of analysis, which is counted as a project benefit.

Near Term and Far Term

There are separate growth rate parameters in the model for the "near term" and the "far term". In many cases, planners face different near-term and far-term growth outlooks. For instance, a region may have sound forecasts for near-term rapid growth yet may view these as unsustainable in the far-term. By allowing the user to split the time horizon into a near- and far-term while determining the duration of the near-term, *BCA.Net* accommodates a wide range of likely growth paths.

The user determines the near- and far-terms by specifying in the input scenario definition a year called "the last year of near term". In summary, the three years that the user specifies in the input scenario definition are:

- the start year
- the last year of near term, and
- the end year

In the remainder of this document, these three years are referred to as the "boundary years".

The boundary years divide the period of analysis into a "near term", for years "start" through "last year near term", and, a "far term", for the subsequent years until the "end year".

For instance, if the start year is 2007 and the last year is 2036, the last year of near term could be 2011. From 2007 through 2011, the model applies the near term traffic growth rates. From 2012 through 2036, the model applies the far term growth rates.

Investment Timing

In a project's Base and Alternate Case, the user specifies one or more strategies and a year of implementation for each strategy. Each strategy contains a cost table, which includes a capital expenditure schedule that extends from 1 to 7 years. Year 1 of the schedule is the first year of expenditure (construction or right-of-way purchase). The effects of an improvement are realized in the evaluation of operations only in the first year following the last year of capital expenditure. For instance, if capital costs (right-of-way, construction, disruption) for Strategy A are scheduled in years 1 and 2, and the Alternate Case includes Strategy A with a year of implementation 2012, then costs are incurred in years 2012 and 2013 and the effects of the improvement are realized from year 2014 onwards.

Costs and Prices

The calculations of *BCA.Net* assume constant dollar values, and that relative prices - with the exception of fuel and oil - remain fixed over the period of analysis. If all relative prices were fixed (i.e., if the ratio of the prices of any two goods or services did not change) then there would be no need to track prices in the model at all. Because the price of fuel and oil relative to other prices is allowed to vary, there is a need to track the general price level (inflation) and the level of the price of fuel and oil. This is required in order to calculate the constant dollar price of fuel and oil. Oil-related prices are singled out due to their volatility, and because they will likely fluctuate in comparison to other prices. In *BCA.Net*, if the price of fuel and oil increases faster than inflation, then the share of vehicle operating costs in total benefits will increase.

The "discount rate" is a constant dollar rate, that is, it is net of general price inflation.

Highway Benefits and Costs

BCA.Net tracks the streams of benefits and costs that accrue as the result of decisions for highway improvement and maintenance. In general, the benefits are the benefits that accrue to both users (e.g., travelers on the facility) and non-users (e.g., the public-at-large that benefits from reduced emissions).

Benefits

The benefits in a *BCA.Net* analysis are the public benefits that accrue from roadway improvements. These are:

Time savings – the reduction in travel time by users of the roadway

Vehicle operating costs reductions – the reduction in expenditures by users on fuel, oil, tires, vehicle maintenance and depreciation

Safety – the reduction in casualties and property damage from roadway crashes.

Emissions – improved traffic flow on a roadway can result in reduced emissions.

There may be cases when one or more of the benefit categories will be negative as the result of a roadway improvement. For instance, it can occur that improved traffic flow results in higher speeds, which may save travel time (positive benefit) while increasing vehicle operating costs (negative benefit).

Costs

The costs in *BCA.Net* are the costs to purchase right-of-way, construction costs and, costs to operate and maintain the highway facilities. *BCA.Net* also considers the

disruption or work zone costs associated with improvements. These last costs are counted as a debit against the project benefits.

The BCA.Net Computational Model

The *BCA.Net* computational model draws on several existing models and best practice methods for the benefit-cost evaluation of highway projects. The principal models adapted that were adapted for use in *BCA.Net* are:

- The Highway Capacity Manual (HCM) 2000, Chapter 7, "Traffic Flow Parameters", for the evaluation of speed given hourly traffic on a facility.

- FHWA's Highway Economic Requirements System (HERS), for the evaluation of vehicle operating costs.

- The method described in *Using Input-Output Diagram to Determine Spatial and Temporal Extents of Queue Upstream of a Bottleneck*, Tim Lawson, David J. Lovell, and Carlos F. Daganza, Transportation Research Record 1572. pp. 140-147, was used to evaluate queuing delays at signals and devices.

The Model

Introduction

This section describes the analytic model of BCA.Net including all of the underlying equations, sources and assumptions.

The analytic model first evaluates the Base Case travel demand in terms of average hourly traffic in each of three periods of the day: peak, peak shoulder and off-peak. In this way demand on the facility is characterized for a specific, representative day (i.e., weekday commute). The user can specify multiple representative days and their weights in three years (first, last year near term, and last) and with these values BCA.Net derives annual estimates for each year in the period of analysis.

Given the Base Case facility characteristics and the average hourly traffic, the model evaluates the travel speed on each project segment. From the speed and demand, the model estimates the travel time and other user costs.   The same calculations are run using the Alternate Case facility characteristics and the Base Case Demand. The results of this calculation enable a specification of the marginal cost curve, and the model evaluates the equilibrium travel demand (where the marginal cost and demand curves intersect) and this travel demand is applied to the Alternate Case facility characteristics to derive the user costs for the alternate case. The model calculates the net benefits and the benefit-cost summaries from the benefit and cost streams in both cases.

The model is presented by its components, as follows:

- Traffic Model
- User Costs
- Project Costs
- Consumer Surplus
- Benefit-Cost Summary

Traffic Model

Average Annual Daily Traffic

Average annual daily traffic (AADT) in the Base Case is determined exogenously by the user in each of the three boundary years. Each of the boundary year AADT

values is adjusted for forecast uncertainty. *BCA.Net* uses the three AADT values adjusted for uncertainty and interpolates (using Aitken's method of linear cross means[1]) the AADT values for intermittent years in the period of analysis.

AADT for use in the Alternate Case is derived in the section on "Consumer Surplus".

Equation 1 Average Annual Daily Traffic on Segment in First Year (Base Case)

$$AADT_{B,syr} = \overline{AADT_{syr}} \cdot \left(1 + \Delta AADT\%_{syr}\right)$$

Where:

$\overline{AADT_{syr}}$ Estimate of average annual daily traffic on segment, before considering uncertainty

$\Delta AADT\%_{syr}$ Percent change from estimated average annual daily traffic due to uncertainty in start year

Equation 2 Average Annual Daily Traffic on Segment in Last Year Near Term (Base Case)

$$AADT_{B,lynt} = \overline{AADT_{lynt}} \cdot \left(1 + \Delta AADT\%_{lynt}\right)$$

Where:

$\overline{AADT_{lynt}}$ Estimate of average annual daily traffic on segment, before considering uncertainty in last year near term

$\Delta AADT\%_{lyrnt}$ Percent change from estimated average annual daily traffic due to uncertainty in last year near term

Equation 3 Average Annual Daily Traffic on Segment in Last Year (Base Case)

$$AADT_{B,ey} = \overline{AADT_{ey}} \cdot \left(1 + \Delta AADT\%_{ey}\right)$$

Where:

$\overline{AADT_{ey}}$ Estimate of average annual daily traffic on segment in end year, before considering uncertainty

$\Delta AADT\%_{ey}$ Percent change from estimated average annual daily traffic due to uncertainty in end year

Equation 4 Average Annual Traffic in Other Years (Base Case)

$$AADT_{B,yr} =$$
$$I(AADT_{B,syr}, AADT_{B,lyrnt}, AADT_{B,eyr}, yr)$$

Where:

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[1] "Numerical Analysis", I.M. Khabaza, pp 212-217, Pergamon Press, 1969

$AADT_{B,syr}$	Estimate of average annual daily traffic on segment in end year, before considering uncertainty
$AADT_{B,lyrnt}$	Percent change from estimated average annual daily traffic due to uncertainty in end year
$AADT_{B,e}$	Traffic Value on Segment in Last Year (Base Case)
yr	The year
I	I represents a function that returns the result of Aitken's method of linear cross-means.

Average Hourly Traffic (in each Traffic period)

The diagram below illustrates how a traffic profile is constructed. The user inputs a traffic profile for each representative day that is used for each facility segment in the analysis.

In the example, 2008, 2012 and 2027 are the boundary years of the analysis. The user specifies AADT for each of those years as shown in the top chart of Figure 1. In each of the three years, the user specifies how a day is divided among the three traffic periods: peak ("HI PEAK"), peak shoulder ("LO PEAK"), and off peak.

Finally, the user specifies for each how total daily traffic divides among the three traffic periods. Additionally, the user specifies the segmentation of traffic among three vehicle types: cars, trucks and buses.

Equations 5-8 show how average hourly traffic is derived from the input values, and allocated by direction of flow and converted to passenger car equivalents.

Figure 1 Traffic Profiles
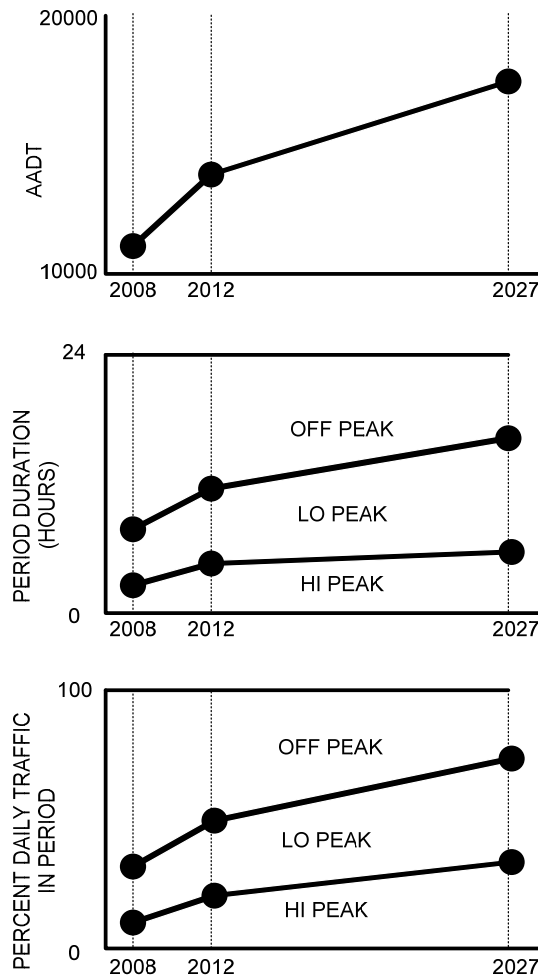
Equation 5 Average Daily Traffic (for traffic profile in boundary years)

$$ADT = \frac{AADT_{yr} \cdot AADTPC}{TPPERCDAY}$$

Where:

$AADT_{yr}$	Average annual daily traffic
$AADTPC$	Percentage of total annual average daily traffic in days represented by traffic profile
$TPPERCDAY$	Percentage of days in year represented by traffic profile

Equation 6 Percentage of Average Daily Vehicles by Type in Traffic Period (for boundary years)

$$PADT_{vehtype} = PINPER_{vehtype} \cdot DUR$$

Where:

$PINPER_{vehtype}$ — Percentage of average daily traffic by vehicle type per hour in period

DUR — Duration of period in hours

Equation 7 Percentage of Average Daily Vehicles by Type in Traffic Period in Direction of Flow (in designated years)

$$PADTF_{vehtype} = PADT_{vehtype} \cdot PFLOW$$

Where:

$PADTF_{vehtype}$ — Percentage of average daily vehicles by type in traffic period

$PFLOW$ — Percentage of total flow in direction of flow i (i= major, minor) in period

*Aggregate for Direction and Flow

Equation 8 Average Hourly Traffic by Vehicle Type and Direction of Flow in Period (in designated years)

$$AHT_{vehtype} = \frac{ADT \cdot PERCV_{vehtype} \cdot PADT_{vehtype}}{DUR}$$

Where:

ADT — Average daily traffic in year

$PERCV_{vehtype}$ — Percentage of daily vehicles of the specified vehicle type

$PADTF_{vehtype}$ — Percentage of average daily vehicles by type in traffic period in direction of flow

DUR — Duration of period in hours

Equation 9 Passenger Car Equivalents for each direction in each year

$$PCE = \sum \alpha_{vehtype} \cdot AHT_{vehtype}$$

Where:

$\alpha_{vehtype}$ — Equivalent number of passenger cars for the vehicle type (α_{AUTO}=1). α_{TRUCK} and α_{BUS} are user-supplied values.

$AHT_{vehtype}$ — Average hourly traffic by vehicle type in traffic period

Speed

BCA.Net assumes that traffic flow is unobstructed and that vehicles move in the segments at a constant speed (except when enter and exiting queues at signals and devices). The speed in each segment (for traffic period and particular traffic profile) is determined by the hourly traffic and the physical characteristics of the roadway. The speed-flow relationship is based on the *Highway Capacity Manual 2000*, and is illustrated in Figure 2 and described in equation 10. The speed on the segment is determined for each direction, which accounts for the number of lanes in each direction (recognizing that some lanes may be reversible and available lanes may not be fixed for all traffic periods).

Figure 2 Highway Capacity
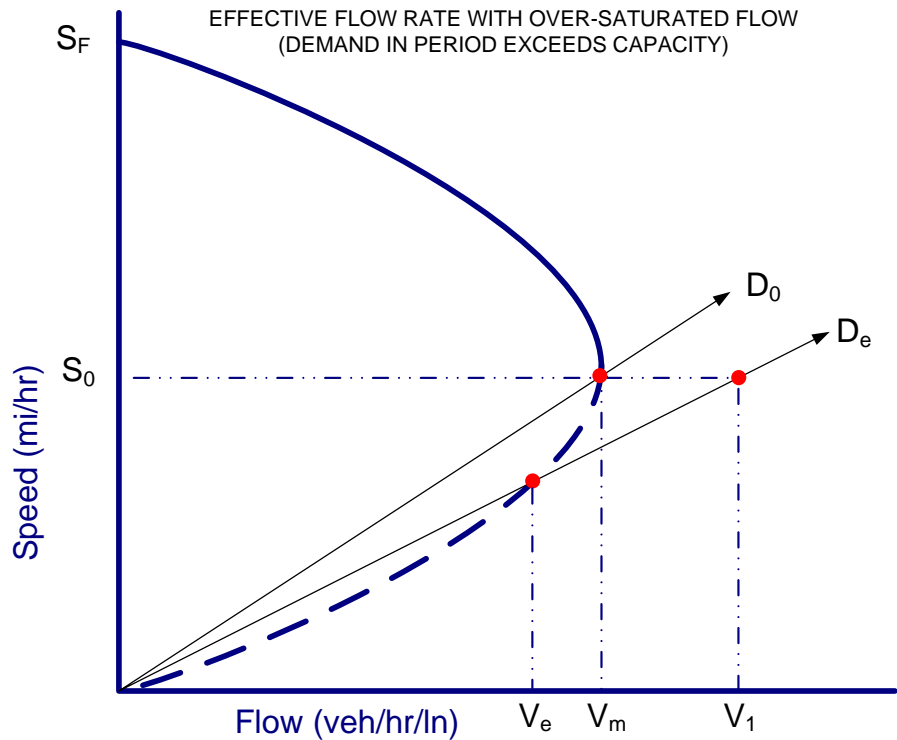
Equation 10 Vehicle Speed in Period by Direction

$$sp = \begin{cases} .5 \cdot s_{ff} \cdot \left(1 + \sqrt{1 - \dfrac{v}{v_{max}}}\right), & if\ v < v_{max} \\[2em] .5 \cdot s_{ff} \cdot \left(1 - \sqrt{1 - \dfrac{v_e}{v_{max}}}\right), & if\ v_{max} < v \leq 2v_{max} \\[2em] where \quad v_e = v\left(2 - \dfrac{v}{v_{max}}\right) \\[1.5em] 0\ , & if\ v > 2v_{max} \end{cases}$$

Where:

s_{ff} Free flow speed on the segment

v Passenger car equivalent, vehicle per hour per lane (PCE/LANES)

v_{max} Segment maximum flow rate, veh/hour/lane

Adjustments to Speed and Flow for Low Values of PSI

The relationship between speed and flow is modified slightly for highly deteriorated road surfaces, that is, when the Pavement Smoothness Index (PSI) falls below 2.5. In these circumstances the values for the free flow speed (S_{ff}) and maximum flow rate (v_{max}) are multiplied by an adjustment factor prior to their being applied in Equation 10 above.

When PSI is greater than 2.5, there is no adjustment (i.e., the scale factor has value of 1). For PSI less than 2.5 and greater than or equal to 1, the free flow speed and the maximum flow rate on the segment are scaled to reflect the effect of poor pavement smoothness on roadway capacity and performance. For PSI equal to 1, the value of the scale factor is .8. In *BCA.Net*, PSI cannot drop below the value of 1 (which follows the practice of the HERS model).

Equation 11 replicates the adjustment process in the HERS model for the effect of low PSI on speed.

Equation 11 Speed and Flow Adjustment Factor for Low Values of PSI

$$ADJPSI = \begin{cases} 1, \ for \ PSI \geq 2.5 \\ -1.016822128 + 2.033644256 \cdot F, \ for \ 1 \leq PSI < 2.5 \\ .8, \ for \ PSI < 1 \end{cases}$$

and

$$F = \frac{1}{1+z}$$

$$z = e^{1.914633271(-.073515333 \cdot PSI^2 + 1.183788333 \cdot PSI)}$$

Where:

PSI   Pavement smoothness index

Traffic Shifting between Periods

The average hourly traffic and speed are derived from the speed-flow relationship. When the roadway is oversaturated it may occur that traffic slows to intolerable slow speeds. If traffic in the peak period slows to a speed that is below a user-specified threshold, *BCA.Net* automatically shifts traffic from the peak to the peak shoulder traffic period until speed returns to the threshold level. If traffic demand is so great that traffic in the peak-shoulder is oversaturated to the point that speed drops below

the minimum threshold, then traffic is shifted from the peak-shoulder to the off-peak period. If, following the shifts in traffic, traffic in the off-peak slows to a speed less than the minimum, then *BCA.Net* stops its evaluation and reports an error. This error can be mitigated by either 1) adjusting demand in the later years of the analysis, or 2) adding roadway capacity to the case (Base or Alternate) where the error condition occurs.

Vehicle Hours without Signal or Device Delay

Equation 12 describes the count of vehicle hours given the speed and volume in each period of the day. The vehicle hours do not account for vehicle delay due to the presence of traffic signals or traffic control devices.

Equation 12 Vehicles Hours by Vehicle Type (without signal or device delay - per hour of facility operation in traffic period)

$$VH = \left(\frac{FACLEN}{sp} \right) \cdot AHT_{vehtype}$$

Where:

$FACLEN$ Length of facility in miles

Sp Speed of vehicles on facility in direction i, mph

$AHT_{vehtype}$ Average hourly traffic by vehicle type and direction of flow

Delay from Queuing at Signals

The presence of signals and traffic control devices on a segment means that traffic flow will not be unobstructed. Some vehicles will need to slow from the speed of unobstructed flow, come to a halt, wait and then resume traveling until returning to the unobstructed flow speed.

BCA.Net uses a technique[2] that remaps the conventional time-space queuing model into a graphical construct plotting the cumulative vehicles-in-queue against time. The analysis framework is shown in the figure below.

The figure shows the blockage of highway traffic flow that occurs at, say, a red signal. Referring to the figure, at point L the blockage begins, it ends at point J and the queue begins to disperse, at point K the last vehicle joins the queue and at point M all the queued vehicles have resumed free flow speed.

Time is plotted on the x-axis and the y-axis shows the cumulative number of affected vehicles. Curve V(t) is the "virtual" graph of traffic in free flow. The curves $B_1(t)$ and $B_2(t)$ show the number of queued vehicles. $D_2(t)$ shows the number of dispersed vehicles that have returned to free flow speed.

The following set of equations describes the calculation of delay and time-in-queue in *BCA.Net*.

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[2] *Using Input-Output Diagram to Determine Spatial and Temporal Extents of Queue Upstream of a Bottleneck*, Tim Lawson, David J. Lovell, and Carlos F. Daganza, Transportation Research Record 1572. pp. 140-147.

Figure 3 Model for Queuing at Signals and Devices
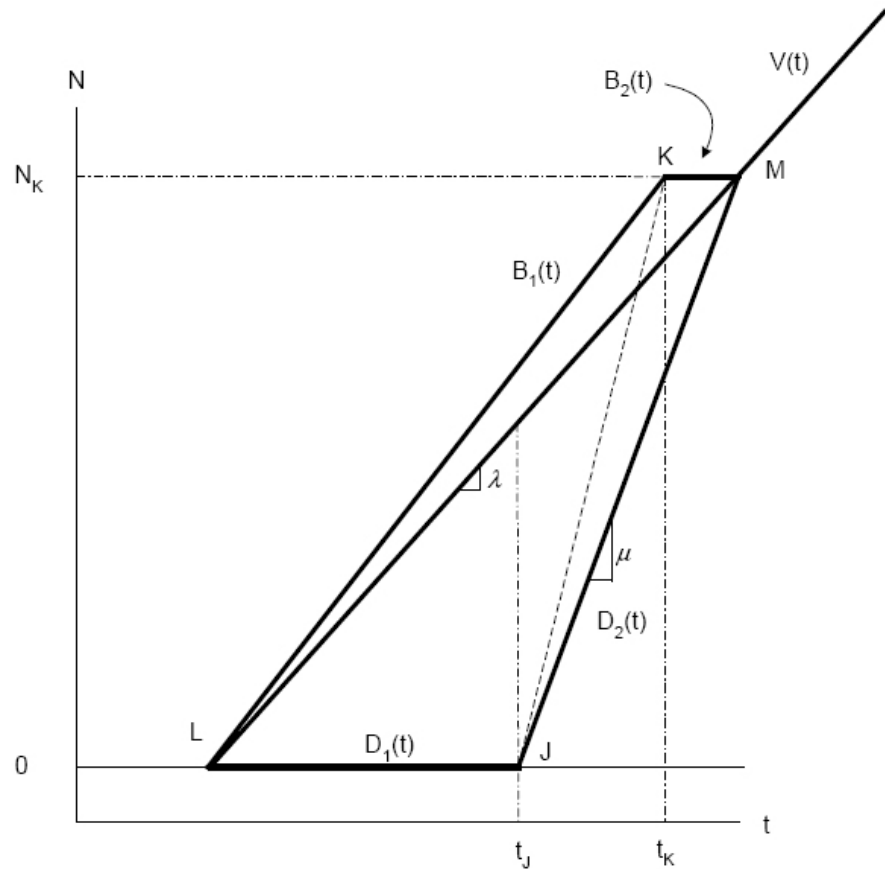
Signal Delay

Equation 13 Arrival Rate of Vehicles Arriving at Signal (veh / sec / lane)

$$ARATE = \frac{PCE}{\left(3600 \cdot LANES\right)}$$

Where:

PCE Hourly passenger car equivalents in period

$LANES$ Number of lanes

Equation 14 Block Time per Signal Cycle (seconds)

$$BT = \left(1 - PEFFGREEN\right) \cdot CYCLE \cdot \left(1 - CORR\right)$$

Where:

PEFFGREEN	Percent effective green in period
CYCLE	Duration of signal cycle (seconds)
CORR	Degree of correlation between traffic flow and effective green (0 to 1)

Equation 15 Number of Vehicles Affected When Not Green Per Lane

$$NK = \frac{ARATE \cdot MU \cdot BT}{MU - ARATE}$$

Where:

ARATE   Vehicle arrival rate, veh / sec / lane

MU   Vehicle dispersal rate, veh / sec / lane (sec to .5, or two cars per second)

BT   Signal block time in period

Equation 16 Vehicle Delay per Signal Cycle (hours delay)

$$W = NK \cdot \left[BT + \left(\frac{1}{MU} \right) - \left(\frac{1}{ARATE} \right) \right] \cdot \left[\frac{(NK+1)}{2} \right] \cdot \frac{LANES}{3600}$$

Where:

NK   Number of vehicles affects when signal not green per lane

MU   Vehicle dispersal rate, veh / sec / lane (set to .5, or two cars per second)

BT   Signal block time in period, seconds

ARATE   Vehicle arrival rate, veh /sec

LANES   Number of lanes

Equation 17 Vehicle Hours Delay Per Signal Cycle by Vehicle Type

$$VHSDS_{vehtype} = \frac{W \cdot AHT_{vehtype}}{PCE} \cdot \alpha_{vehtype}$$

Where:

W	Total vehicle delay at signal in period, hours
$AHT_{vehtype}$	Vehicle dispersal rate, veh / sec / lane (set to .5, or two cars per second)
PCE	Hourly passenger car equivalents
$\alpha_{vehtype}$	Equivalent number of passenger cars per vehicle type

Equation 18 Vehicle Hours Delay at Signal by Vehicle Type (per hour of facility operation in traffic period)

$$VHS_{vehtype} = \frac{3600}{CYCLE} \cdot VHSS_{vehtype}$$

Where:

$VHSS_{vehtype}$	Vehicle delay per signal cycle by vehicle type*
$CYCLE$	Duration of signal cycle in period, seconds

*Aggregate for signals on segment

Device Delay

Equation 19 Vehicle Delay at Device per hour by Vehicle Type (per hour of facility operation in traffic period)

$$VHD_{vehtype} = AHT_{vehtype} \cdot DEVDEL$$

Where:

$AHT_{vehtype}$	Average hourly traffic by vehicle type
$DEVDEL$	Delay per vehicle at device

*Aggregate for devices on segment

Total Vehicle Hours (Unobstructed Traffic and Delay due to Signals and Devices)

Equation 20 Vehicle Hours by Vehicle Type

$$TVH_{vehtype} = VH_{vehtype} + VHS_{vehtype} + VHD_{vehtype}$$

Where:

$VH_{vehtype}$ Vehicle hours delay per hour by vehicle type

$VDS_{vehtype}$ Vehicle hours delay per hour for all signals in segment in period

$VDD_{vehtype}$ Vehicle hours delay per hour for all devices in segment in period

User Costs

Introduction

The change in user costs with roadway improvements is the basis of project benefits. The user cost categories are as follows:

- Time savings
- Vehicle operating cost savings
- Emissions reductions
- Safety (reduction in number and severity of crashes)

Vehicle operating costs are further divided into the following component categories:

- Fuel
- Oil
- Tire wear
- Maintenance and repair
- Vehicle depreciation

The determinants of user costs are:

- Travel demand on the facility: average annual daily traffic (AADT), its seasonal distribution, the peaking characteristics of demand and its elasticity with respect to trip cost.
- The facility: its capacity, the presence of signals and devices, and, policies for managing the facility (i.e., reversible lanes).
- Prevailing costs and prices.

The previous section showed how *BCA.Net* calculates speed and vehicle hours given the demand (AADT and its distribution) and facility characteristics (i.e., freeflow speed, maximum flow, number of lanes, etc.). This section shows how the speed and average hourly traffic on the facility are translated into user costs.

Travel Time Costs

Travel time costs are the cost of the time spent traveling on the facility. For the auto and bus vehicle types, the cost is equal to the traveler hours on the facility times the value of time. For trucks, the value of time includes the cost of compensation for the driver and an estimate of the inventory time-value.

Equation 21 Annual Travel Time Costs Autos

$$TTC_{auto} = TVH_{auto} \cdot AVGOCC_{auto} \cdot VOT$$

Where:

TVH_{auto} Total annual vehicle hours, auto*

$AVGOCC_{vehtype}$ Average occupancy per vehicle, auto

VOT Per hour value of travel time, base year dollars

* Annual value derived from hourly values in traffic periods by aggregating daily hours of operation and then aggregating representative days by their weight in the year.

Equation 22 Annual Travel Time Costs Trucks

$$TTC_{trucks} = TVH_{trucks} \cdot VOTT$$

Where:

TVH_{trucks} Total vehicle hours, trucks*

$VOTT$ Per hour value of truck travel time, base year dollars

* Annual value derived from hourly values in traffic periods by aggregating daily hours of operation and then aggregating representative days by their weight in the year.

Equation 23 Annual Travel Time Costs Buses

$$TTC_{buses} = TVH_{buses} \cdot AVCOCC_{buses} \cdot VOT$$

Where:

TVH_{buses} Total vehicle hours, buses*

$AVCOCC_{vehtype}$ Average occupancy per vehicle, buses

VOT Per hour value of travel time, base year dollars

* Annual value derived from hourly values in traffic periods by aggregating daily hours of operation and then aggregating representative days by their weight in the year.

Equation 24 Annual Travel Time Costs for All Vehicle Types

$$TTC_{auto} = TTC_{auto} + TTC_{truck} + TTC_{bus}$$

Vehicle Operating Costs (VOC)

This section describes the calculations for vehicle operating costs (VOC). The vehicle operating cost categories are:

- Fuel

- Oil

- Tire wear

- Maintenance and repair, and

- Vehicle depreciation.

Note that all of the vehicle operating costs are those associated with vehicle use on the roadway segments of the project. These costs use-based costs and do not include non-use ownership costs that are invariant with respect to use (i.e., insurance costs and time-based vehicle depreciation).

The VOC for each cost category is calculated for one hour of operations of a facility segment for each traffic period (for each traffic profile, in each year and, for each of the base and alternate cases). These hourly values are weighted and rolled-up to arrive at the correct annual amounts for each cost category.

Vehicle Categories for VOC Calculations

The calculation of vehicle operating costs closely follows the HERS methodology. In HERS there are seven vehicle categories. In *BCA.Net* there are three vehicle types: cars, trucks and buses. *BCA.Net* vehicles are allocated to the seven HERS vehicle categories and the VOC for each category is calculated using the HERS formulas. The table below shows the HERS vehicle categories and the formulas for allocating the *BCA.Net* vehicles to these categories.

Cars in *BCA.Net* are allocated to the small and medium/large car categories by a user-supplied value representing the share of smaller cars of total cars (shown as %SMALLCARS in the table). Trucks are divided into the HERS vehicle categories based on shares of trucks by category in total truck VMT, based on year 2000 data (see table at http://www.fhwa.dot.gov/policy/hcas/final/two.htm). *BCA.Net* assumes that vehicles of type "bus" are similar in VOC to trucks of type "3+ Axle Single-Unit".

Table 1 Allocation of BCA.Net Vehicles to HERS Vehicle Categories

Category Number	HERS Vehicle Categories	BCA.Net Vehicles Applied to each HERS Vehicle Type
1	Small Auto	CARS * %SMALLCARS
2	Medium/Large Auto	CARS*(1-%SMALLCARS)
3	4-Tire Truck	TRUCKS*0.771
4	6-Tire Truck	TRUCKS*0.081
5	3+ Axle Single-Unit Truck	TRUCKS*0.015+BUS
6	3-4 Axle Combination Truck	TRUCKS*0.016
7	5+ Axle Combination	TRUCKS*0.117

VOC Fuel Consumption Calculations

There are three basic equations for calculating fuel consumption, and these correspond to the constant-speed fuel consumption (CSFC) equations in HERS. The three equations are shown in the following table. The first equation is used for HERS vehicle categories 1,3,4,5, and 7. The second equation is used for category 2 and the third equation is used for category 6. The coefficients (β values) vary for each vehicle category and, in one case, they vary depending upon whether the grade is nonzero or not. Following the table with the equations is a table showing a key for the use of the coefficients, followed by a table with the equation coefficients.

Table 2 Equations for VOC Fuel Consumption

HERS Vehicle Category	Equation (Units of Result: gallons / 1000 miles)
1, 3, 4, 5, 7	$\beta_0 + \beta_1 \cdot sp + \beta_2 \cdot gr + \beta_3 \cdot sp^2 + \beta_4 \cdot gr^2 + \beta_5 \cdot sp \cdot gr + \beta_6 \cdot sp^3 + \beta_7 \cdot gr^3 + \beta_8 \cdot sp \cdot gr^2 + \beta_9 \cdot sp^2 \cdot gr$
2	$\dfrac{\beta_0 + \beta_1 \cdot sp + \beta_2 \cdot gr + \beta_3 \cdot sp^3 + \beta_4 \cdot gr^2 + \beta_5 \cdot sp \cdot gr}{1 + \beta_6 \cdot sp + \beta_7 \cdot gr + \beta_8 \cdot sp^2 + \beta_9 \cdot gr^3 + \beta_{10} \cdot sp \cdot gr}$
6	$\dfrac{\beta_0 + \beta_1 \cdot sp + \beta_2 \cdot sp^2 + \beta_3 \cdot gr + \beta_4 \cdot gr^2}{1 + \beta_5 \cdot sp + \beta_6 \cdot gr + \beta_7 \cdot gr^2 + \beta_8 \cdot gr^3}$

Table 3 Key for Use of Following Coefficients Table in VOC Fuel Consumption Equations

Key	Use of Coefficients
0	Use with HERS vehicle category 1
1	Use with HERS vehicle category 2
2	Use with HERS vehicle category 3 and gr=0
3	Use with HERS vehicle category 3 and gr≠0
4	Use with HERS vehicle category 4
5	Use with HERS vehicle category 5
6	Use with HERS vehicle category 6
7	Use with HERS vehicle category 7

Table 4 Fuel Consumption Equation Coefficient Values

Key	Coefficient Subscript					
	0	**1**	**2**	**3**	**4**	**5**
1	99.80818939	-4.47133636	6.14751339	0.0758538	-0.08192929	-0.11962222
2	88.61991119	0.00569706	-2.9103651	0.04969501	4.9145503	0.00014085
3	111.5078507	-3.71101046	8.20157146	0.06191169	-0.88283688	0.08395169
4	111.3696823	-4.09633875	8.74931717	0.07719458	2.36999011	0.13992049
5	265.905365	-7.92043734	28.54430389	0.10670792	1.24824464	-0.38937345
6	288.1066589	-8.96271038	57.58854675	0.15855315	2.02922797	-0.57614183
7	436.0942993	-10.91005993	0.11718448	41.41351318	-4.61186647	0.00274623
8	537.5736084	-18.10119057	41.37110901	0.23751985	-1.2867074	0.56542301

(Continued)

Key	Coefficient Subscript				
	6	**7**	**8**	**9**	**10**
1	-0.00035499	-0.02189026	0.00303827	0.00116885	0
2	0.05004881	-0.00142875	0.3231267	-0.0009104	0.08770105
3	-0.00018132	0.10026991	-0.02144488	0.00211435	0
4	-0.00031641	0.18328315	0.01512856	0.0007224	0
5	-0.00018479	-0.13818547	-0.0202306	0.00301458	0
6	-0.00074092	-0.31559345	-0.02094944	0.00512714	0
7	-0.09975458	0.01743216	-0.00147755	0	0
8	-0.00075331	0.06569115	-0.06130394	0.00116294	0

Equation 25 VOC Hourly Gasoline Consumption by HERS Vehicle Category

$$VOCFGC = CSFC \cdot \frac{PSIADJF}{ADJ} \cdot \frac{LEN}{1000} \cdot veh \cdot g$$

Where:

CSFC	Constant speed fuel consumption, gallons per 1000 miles
PSIADJF	Pavement smoothness index adjustment factor, for vehicle category
ADJF	Adjustment factor, fuel, for vehicle category
LEN	Length of facility, miles
veh	Number of vehicles in vehicle category in traffic period per hour
g	Share of vehicles in vehicle category that use gasoline (set as 1 for HERS vehicle categories 1 through 4 and 0 for categories 5 through 7)

Equation 26 VOC Hourly Diesel Consumption by HERS Vehicle Category

$$VOCFDC = VOCFGC \cdot \frac{1-g}{g}$$

Where:

VOCFGC	Hourly gasoline consumption, gallons
g	Share of vehicles in vehicle category that use gasoline (set as 1 for HERS vehicle categories 1 through 4 and 0 for categories 5 through 7)

The fuel cost net of fuel tax is the monetary amount used in the benefits calculation and represents the cost to society for the consumption of gasoline (the benefit-cost framework considers the fuel tax to be a transfer and not a resource use). However, *BCA.Net* uses the fuel cost including the tax on fuel when considering travel cost and its impact on travel demand (i.e., the consumer is not indifferent to the fuel tax and regards it like any other cost component when making travel decisions).

Equation 27 VOC Fuel Cost- Gasoline (net of tax)

$$VOCFG = VOCFGC \cdot GASBASE \cdot \frac{PFUEL}{PGEN}$$

Where:

VOCFGC	Vehicle operating costs fuel consumption of gasoline-based vehicles
GASBASE	Base year per gallon cost of gasoline net of state and local taxes
PFUEL	Fuel price index, base year = 100
PGEN	General price index, base year = 100

Equation 28 Fuel Tax - Gasoline

$$VOCFGTAX = VOCFGC \cdot FTAX$$

Where:

VOCFGC	Vehicle operating costs fuel consumption of gasoline-based vehicles (aggregated for all vehicle categories)
FTAX	Per gallon tax on fuel, dollars

Equation 29 VOC Fuel Cost- Diesel (net of tax)

$$VOCFD = VOCFDC \cdot DIESELBASE \cdot \frac{PFUEL}{PGEN}$$

Where:

VOCFDC	Vehicle operating costs fuel consumption of diesel-based vehicles
DIESELBASE	Base year per gallon cost of diesel net of state and local taxes
PFVEL	Fuel prince index, base year = 100
PGEN	General price index, base year = 100

Equation 30 Fuel Tax - Diesel

$$VOCFDTAX = VOCFD \cdot FTAX$$

Where:

VOCFD	Vehicle operating costs fuel consumption of diesel-based vehicles
FTAX	Per gallon tax on fuel, dollars

Equation 31 VOC Fuel Cost- Total Net of Taxes

$$VOCF = VOCFG + VOCFD$$

Where:

VOCFG	Fuel cost net of tax, gasoline
VOCFD	Fuel cost net of tax, diesel

Equation 32 Fuel Cost- Total Tax

$$VOCTTAX = VOCFGTAX + VOCFDTAX$$

Where:

VOCFGTAX	Vehicle operating costs fuel consumption gasoline tax
VOCFDTAX	Vehicle operating costs fuel consumption diesel tax

For the following VOC cost categories, there are separate equations for each HERS vehicle category. In addition, within each vehicle category there are multiple equations, and the use of a particular equation depends upon the values of vehicle speed and the grade of the facility. For each cost category/vehicle category combination there is a logic diagram that illustrates under which conditions a particular equation is used. In the diagrams and equations sp stands for vehicle speed and gr stands for facility grade.

In the tables below, "*" stands for multiplication and "^" stands for exponentiation. "Exp(x)" means "e (the base of the natural logarithm) raised to the power x". "Log" is the natural logarithm.

VOC Oil Calculations

The equations in the tables in this section are the equations for calculating the constant speed oil consumption (quarts / 1000 miles).

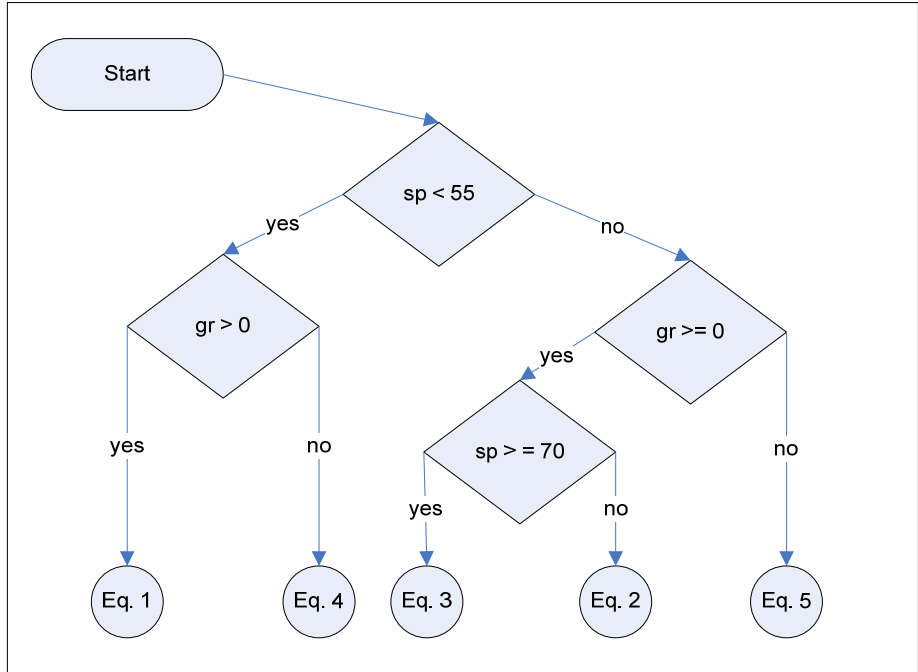*Figure 4 VOC Oil Calculation Small Cars- Logic to Select Equation*

Table 5 Equations for VOC Oil Small Cars Calculation

1	Exp(2.7835 - 0.79034 * Log(sp) - 1.1346 / (sp ^ 1.5) + 0.65342 * (gr ^ 0.5))
2	-170.4 + 34.02 * Log(sp) + 1939 /sp + 0.4747 * gr - 0.003296 * sp * gr
3	-170.4 + 34.02 * Log(sp) + 1939 / sp + 0.27 * gr
4	1.0435 + (327.89 / ((1 + (((sp + 7.1977) / 3.0141) ^ 2)) * (1 + (((gr + 8.0484) / 2.8984) ^ 2))))
5	-170.4 + 34.02 * Log(sp) + 1939 / sp

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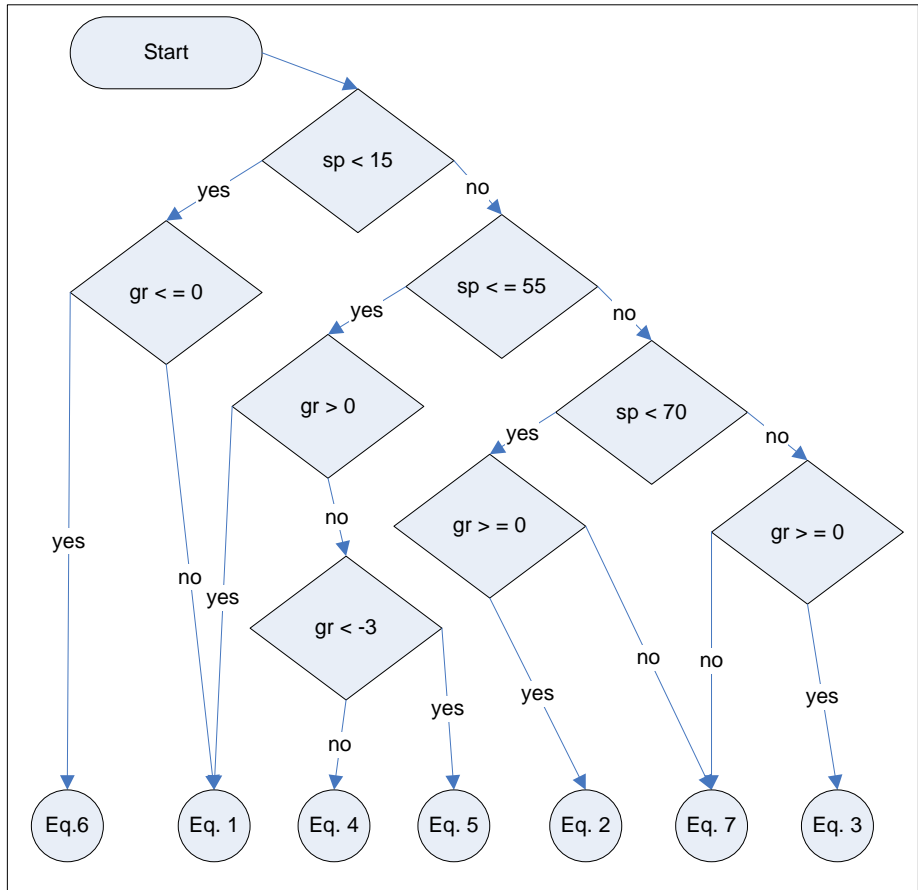*Figure 5 VOC Oil Calculation Medium-Large Cars- Logic to Select Equation*

Table 6 Equations for VOC Oil Medium-Large Cars Calculation

1	$48.4 + 0.00867 * sp \wedge 2 + 0.0577 * sp * gr$
2	$9.5234 - 0.29873 * sp + 0.0026913 * sp \wedge 2 + 0.28997 * gr \wedge 1.00129$
3	$-173.3 + 34.6 * Log(sp) + 1973 / sp + 0.29 * gr$
4	$0.42295 + 0.35839 * sp - 0.029984 * (sp \wedge 2) + 0.0010392 * (sp \wedge 3) - 0.000016196 * (sp \wedge 4) + 0.000000093539 * (sp \wedge 5) - 0.0024 * gr$
5	$1 / (-0.18739 + 0.0014953 * (sp \wedge 1.5) - 1.7461 / gr)$
6	$Exp(1.7713 - 0.12178 * (sp \wedge 0.5) * Log(sp) + 0.14636 * gr + 0.11002 * gr \wedge 2 + 0.0082804 * gr \wedge 3)$
7	$-173.3 + 34.6 * Log(sp) + 1973 / sp$

Figure 6 VOC Oil Calculation 4 Tire Trucks- Logic to Select Equation
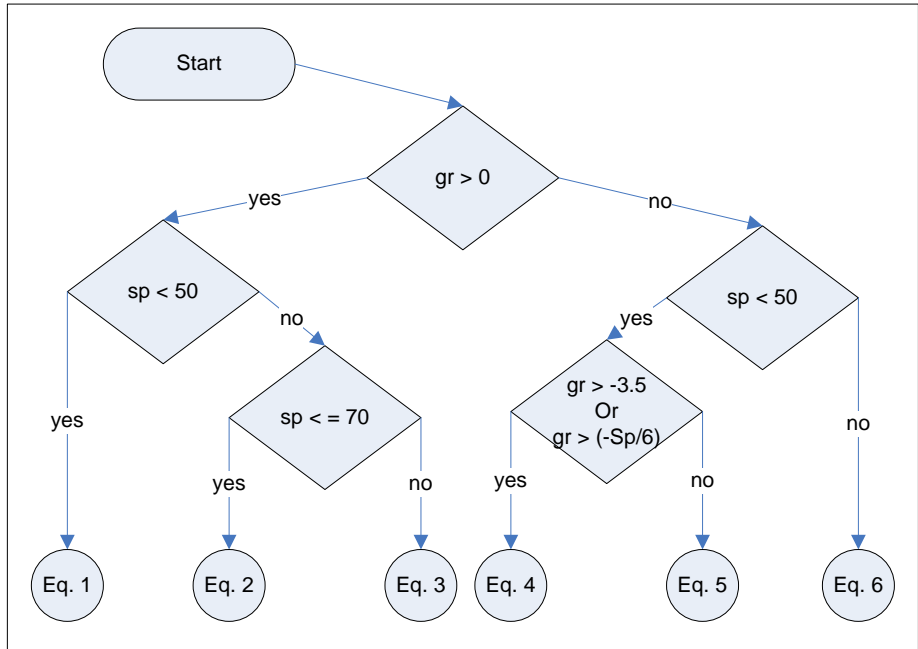
Table 7 Equations for VOC Oil 4 Tire Trucks Calculation

1	Exp(2.47 - 0.604 * Log(sp) - 0.00994 * gr ^ 2 + 0.277 * gr - 0.001248 * sp * gr)
2	16.41 + 0.004424 * sp ^ 2 - 0.5255 * sp + 1.296 * gr - 0.2664 * Log(sp) * gr
3	16.41 + 0.004424 * sp ^ 2 - 0.5255 * sp + 0.19 * gr
4	8.45 + 0.0000352 * sp ^ 3 - 0.00567 * sp ^ 2 + 0.37 * sp - 4.12 * Log(sp)
5	Exp(0.92 - 0.000295 * sp ^ 2 - 0.751 * Log(sp) - 0.0269 * gr ^ 2 - 0.584 * gr)
6	16.41 + 0.004424 * sp ^ 2 - 0.5255 * sp

Figure 7 VOC Oil Calculation 6 Tire, 2 Axle Trucks- Logic to Select Equation

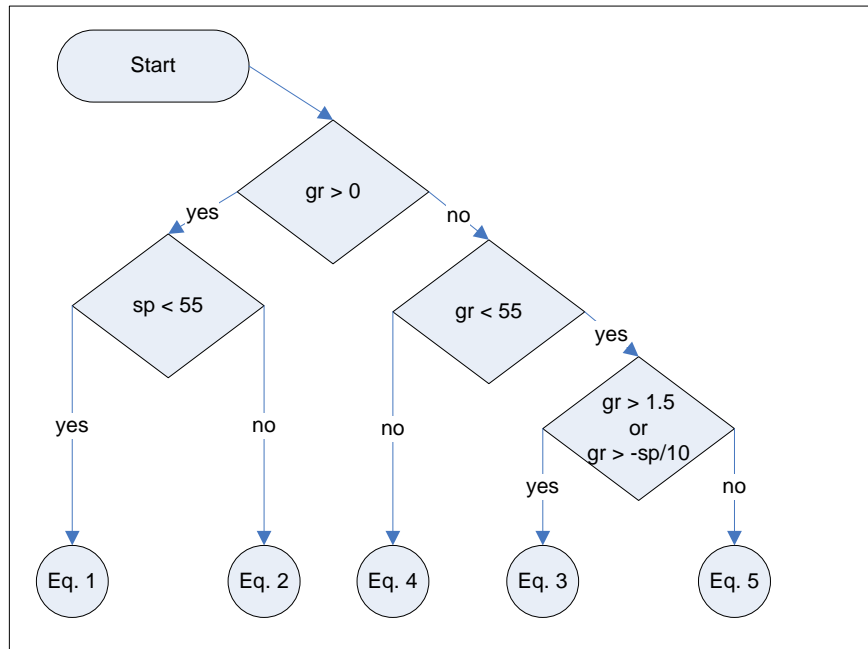*Table 8 Equations for VOC Oil6 Tire, 2 Axle Trucks Calculation*

1     $\mathrm{Exp}(3.8424 - 0.93964 * \mathrm{Log}(sp) - 1.7418 / sp + 0.80327 * gr \wedge 0.5)$

2     $51.76 + 0.002513 * sp \wedge 2 - 14.29 * \mathrm{Log}(sp) + 0.7485 * gr$

3     $13.98 + 0.0000603 * sp \wedge 3 - 0.00857 * sp \wedge 2 + 0.523 * sp - 6.17 * \mathrm{Log}(sp)$

4     $\mathrm{Exp}(1.41 + 0.000519 * sp \wedge 2 - 0.0845 * sp - 0.0344 * gr \wedge 2 - 0.649 * gr)$

5     $51.76 + 0.002513 * sp \wedge 2 - 14.29 * \mathrm{Log}(sp)$

Figure 8 VOC Oil Calculation 3 Axle Single Unit Trucks- Logic to Select Equation
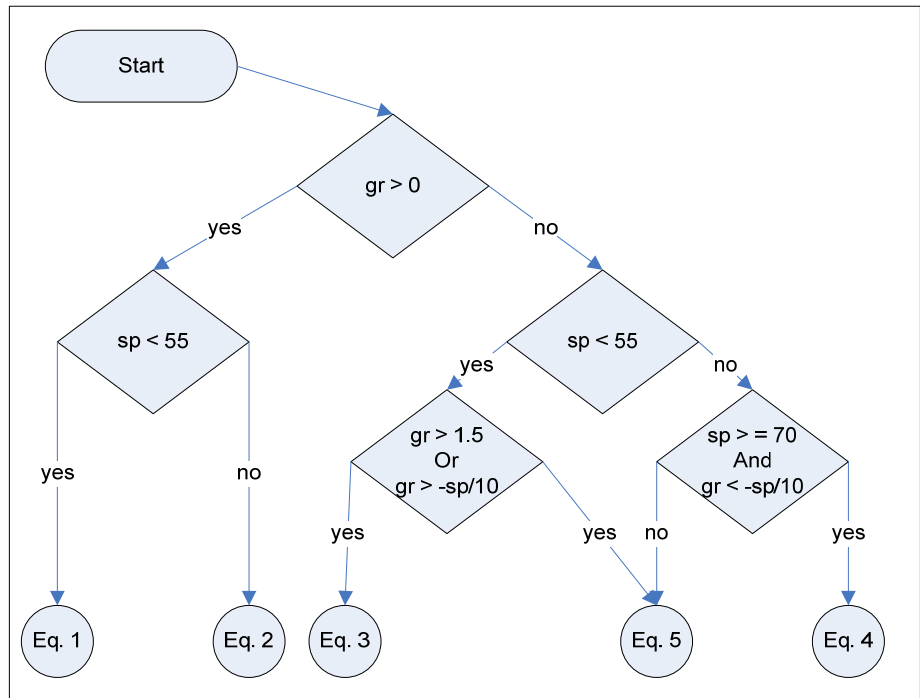
Table 9 Equation for VOC Oil 3 Axle Single Unit Trucks Calculation

1   Exp(4.36 + 0.00711 * sp - 0.869 * Log(sp) - 0.01712 * gr ^ 2 + 0.338 * gr)

2   20.2 + 0.0000724 * sp ^ 3 - 0.0103 * sp ^ 2 + 0.662 * sp - 8.52 * Log(sp)

3   Exp(1.77 + 0.00055 * sp ^ 2 - 0.0769 * sp - 0.0343 * gr ^ 2 - 0.646 * gr)

4   22.85 + 0.006514 * sp ^ 2 - 0.7188 * sp + 1.615 * gr

5   22.85 + 0.006514 * sp ^ 2 - 0.7188 * sp

6   Exp(1.77 + 0.00055 * sp ^ 2 - 0.0769 * sp - 0.0343 * gr ^ 2 - 0.646 * gr)

Figure 9 VOC Oil Calculation 3-4 Axle Combination Trucks- Logic to Select Equation

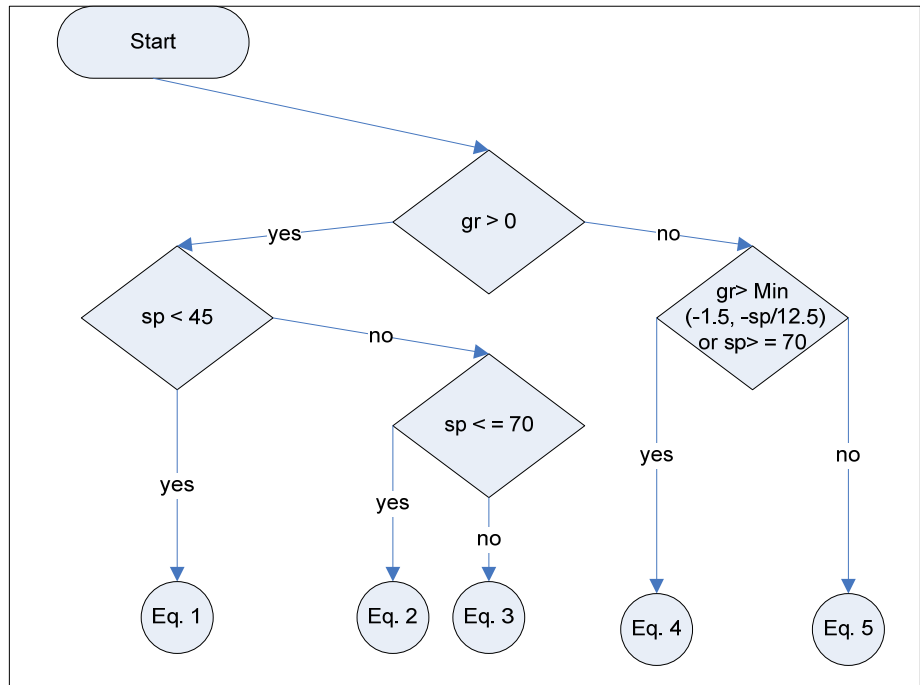*Table 10 Equation for VOC Oil 3-4 Axle Combination Trucks Calculation*

1   Exp(3.92 - 0.661 * Log(sp) - 0.01718 * gr ^ 2 + 0.361 * gr - 0.00064 * sp *gr)

2   78.59 + 0.003813 * sp ^ 2 - 21.76 * Log(sp) + 2.1254 * gr - 0.0109 * sp * gr

3   78.59 + 0.003813 * sp ^ 2 - 21.76 * Log(sp) + 1.41 * gr

4   20.2 + 0.0000724 * sp ^ 3 - 0.01034 * sp ^ 2 0.662 * sp - 8.52 * Log(sp)

5   Exp(1.85 + 0.000458 * sp ^ 2 - 0.0746 * sp - 0.0336 * gr ^ 2 - 0.638 * gr)

Figure 10 VOC Oil Calculation 5+ Axle Combination Trucks- Logic to Select Equation
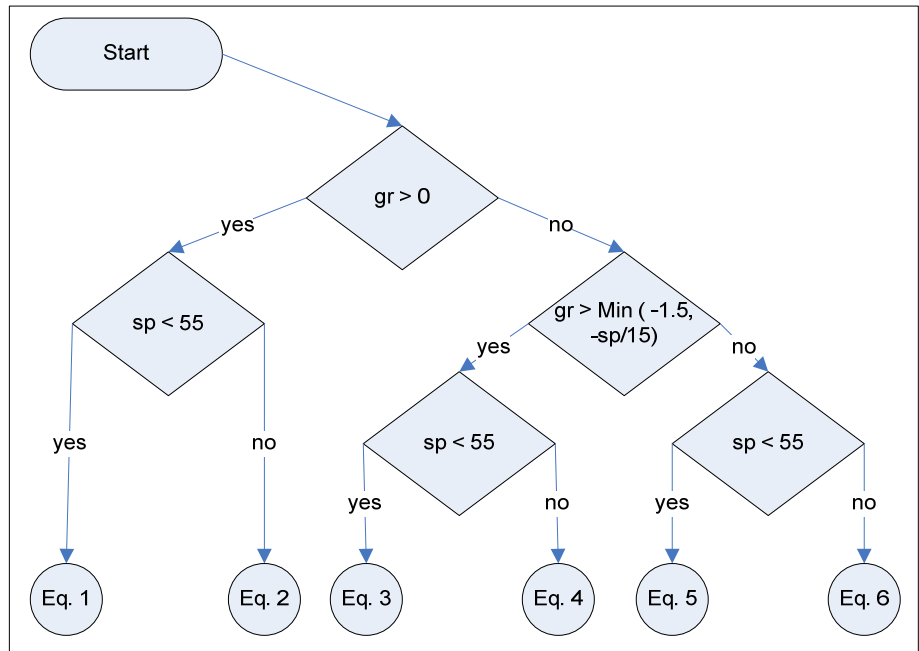
Table 11 Equations for VOC Oil Calculation

1   Exp(4.6 - 0.668 * Log(sp) - 0.01879 * gr ^ 2 + 0.394 * gr - 0.000873 * sp * gr)

2   9.383 + 0.003478 * sp ^ 2 - 0.271 * sp + 3.04 * gr

3   42.6 + 0.000189 * sp ^ 3 - 0.0273 * sp ^ 2 + 1.633 * sp - 18.96 * Log(sp)

4   9.383 + 0.003478 * sp ^ 2 - 0.271 * sp

5   Exp(2.52 + 0.000397 * sp ^ 2 - 0.0675 * sp - 0.0353 * gr ^ 2 - 0.652 * gr)

6   115.8 + 0.5094 * sp - 37.27 * Log(sp) - 3.064 * gr

Equation 33 VOC Oil Cost

$$VOCO = CSOC \cdot \left(\frac{PSIADJ_{vehcat,\ oil}}{ADJ_{vehcat,\ oil}} \right) \cdot \left(\frac{LEN}{1000} \right) \cdot POILBASE \cdot \frac{PFUEL}{PGEN}$$

Where:

$CSOC$	Constant speed oil consumption
$PSIADJ_{vehcat,\ oil}$	Pavement smoothness index adjustment factor
$ADJ_{vehcat,\ oil}$	Adjustment factor, fuel
LEN	Length of facility, miles
$POILBASE$	Price of oil in base year, dollars/quart
$PFUEL$	Price of fuel in base year, dollars/quart

VOC Maintenance and Repair Calculations

Figure 11 VOC Maintenance and Repair Calculation Small Cars- Logic to Select Equation
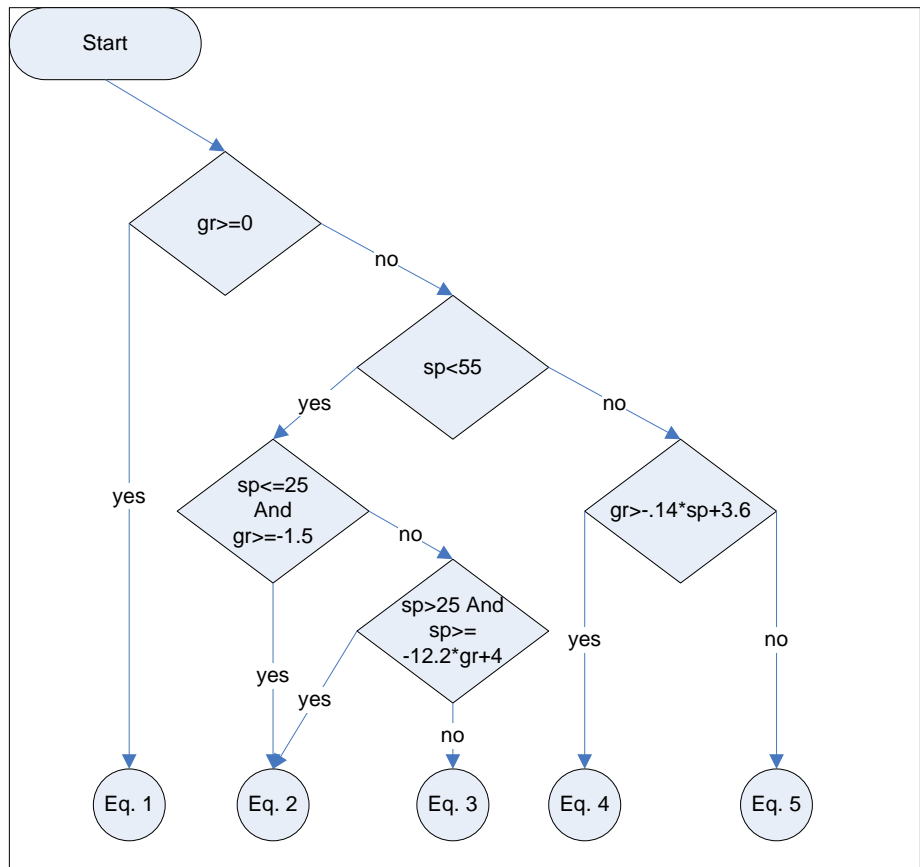
Table 12 Equations for VOC Maintenance and Repair Small Cars Calculation

1    $48.3 + 0.00865 * sp \wedge 2 + 0.0516 * sp * gr$

2    $45.1 + 0.00582 * sp \wedge 2 + 0.23 * sp + 0.0502 * sp$

3    $-5.83 - 0.01932 * sp \wedge 2 - 23.4 * gr$

4    $73.35 + 0.01397 * sp \wedge 2 - 0.7398 * sp + 0.04994$

5    $4.27 - 0.0208 * sp \wedge 2 - 23.63 * gr$

Figure 12 VOC Maintenance and Repair Calculation Medium-Large Cars- Logic to Select Equation
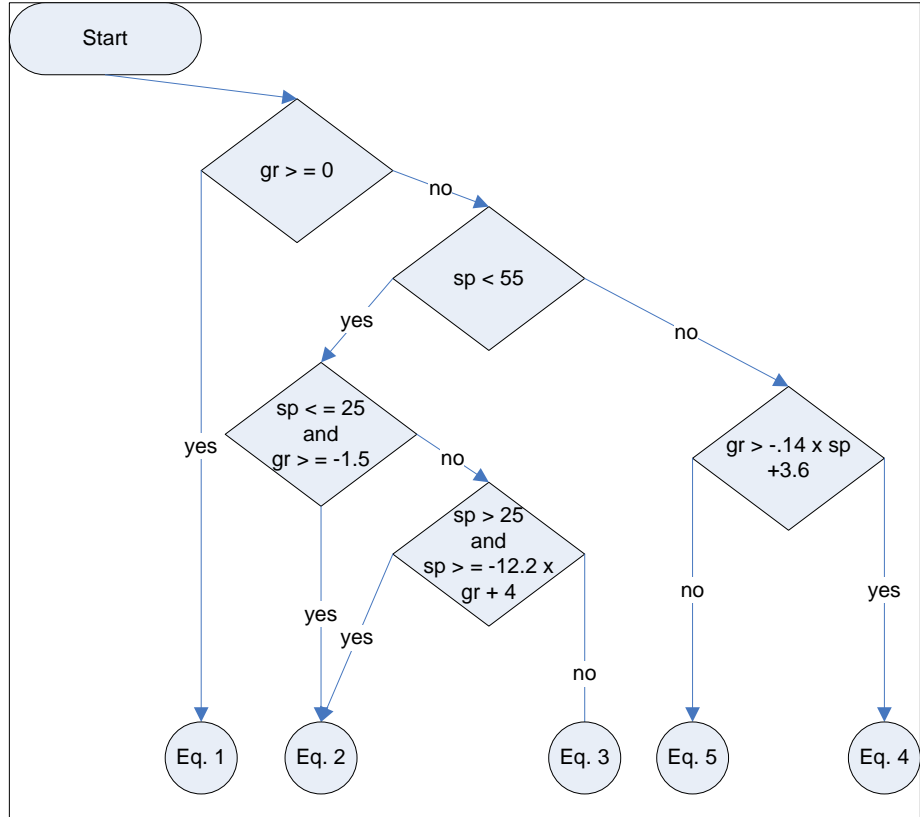
Table 13 Equations for VOC Maintenance and Repair Medium-Large Cars Calculation

1	48.4 + 0.00867 * sp ^ 2 + 0.0577 * sp * gr
2	.19 + 0.00584 * sp ^ 2 + 0.229 * sp + 0.0562 * sp * gr
3	-6.67 - 0.018 * sp ^ 2 - 23.4 * gr
4	72.46 + 0.01373 * sp ^ 2 - 0.7081 * sp + 0.05597 * sp * gr
5	-5.415 - 0.01912 * sp ^ 2 - 23.51 * gr

Figure 13 VOC Maintenance and Repair Calculation 4 Tire Trucks- Logic to Select Equation
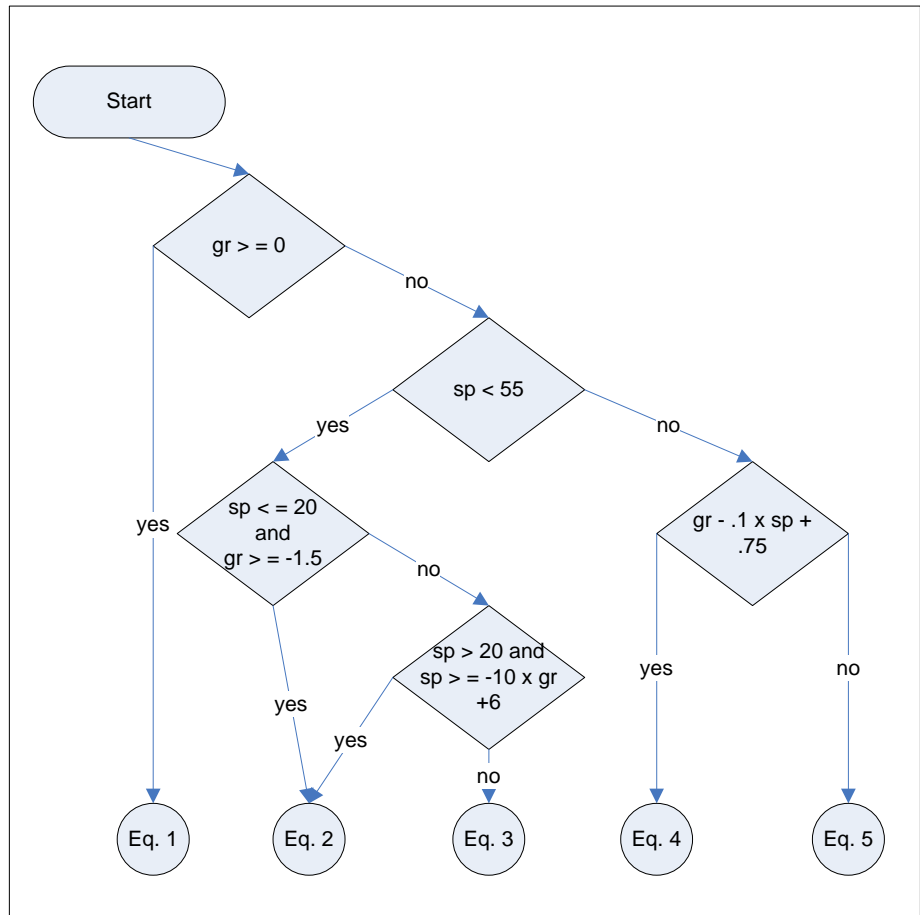
Table 14 Equations for VOC Maintenance and Repair 4 Tire Trucks Calculation

1    $49.2 + 0.00881 * sp \wedge 2 + 0.0545 * sp * gr$

2    $46.0 + 0.00595 * sp \wedge 2 + 0.231 * sp + 0.0531 * sp * gr$

3    $-12.43 - 0.019 * sp \wedge 2 - 23.5 * gr$

4    $72.36 + 0.01373 * sp \wedge 2 - 0.6841 * sp + 0.0532 * sp * gr$

5    $-13.83 - 0.0197 * sp \wedge 2 - 24.01 * gr$

Figure 14 VOC Maintenance and Repair Calculation 6 Tire, 2 Axle Trucks- Logic to Select Equation
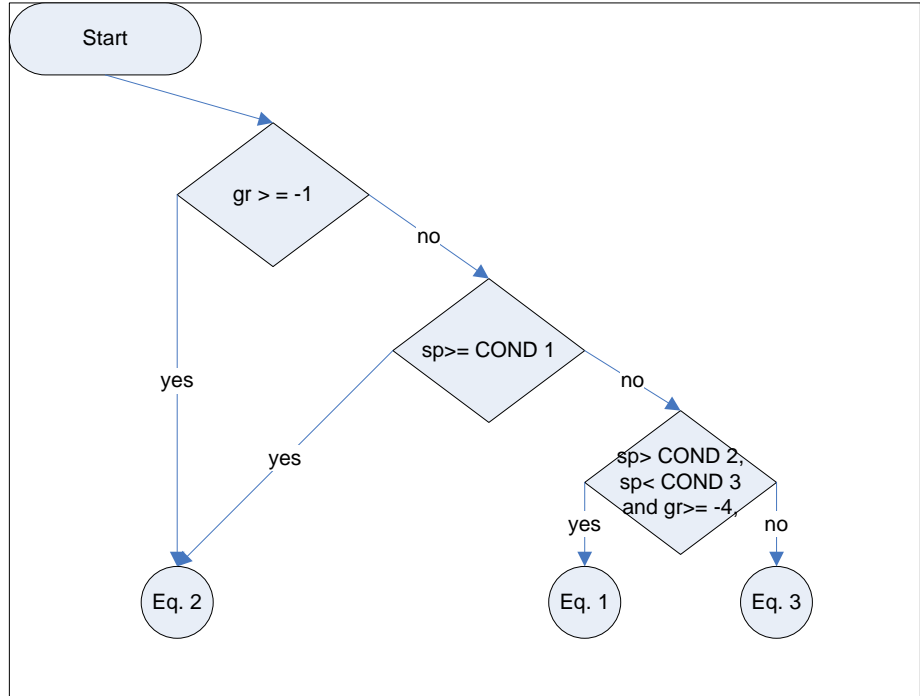
Table 15 Conditions for VOC Maintenance and Repair 6 Tire, 2 Axle Trucks Calculations

COND 1	$-1.6667 * gr ^ 3 - 17.5 * gr ^ 2 - 70.833 * gr - 40$
COND 2	$-1.6667 * gr ^ 3 - 17.5 * gr ^ 2 - 70.833 * gr - 45$
COND 3	$-1.6667 * gr ^ 3 - 17.5 * gr ^ 2 - 70.833 * gr - 40$

Table 16 Equations for VOC Maintenance and Repair 6 Tire, 2 Axle Trucks Calculation

1	$1 / (0.96223 + 0.0000023017 * sp ^ 3 - 0.33129 * Exp(sp / 44.4878) + 0.48203 / gr - 0.00029083 * Exp(-gr))$
2	$44.2 + 0.01147 * sp ^ 2 + 0.1462 * sp * gr$
3	$-0.722 - 0.00697 * sp ^ 2 - 15.9 * gr$

Figure 15 VOC Maintenance and Repair Calculation 3 Axle Single Unit Trucks- Logic to Select Equation
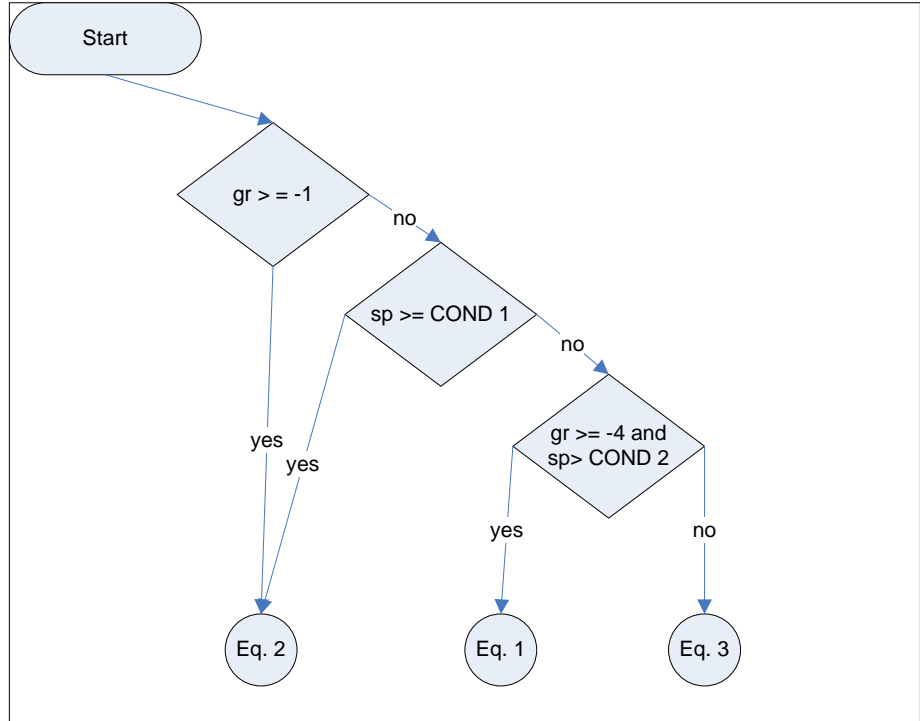
Table 17 Conditions for VOC Maintenance and Repair 3 Axle Single Unit Trucks Calculations

COND 1 $-1.6667 * gr \wedge 3 - 17.5 * gr \wedge 2 - 75.833 * gr - 40$

COND 2 $-1.6667 * gr \wedge 3 - 17.5 * gr \wedge 2 - 75.833 * gr - 45$

Table 18 Equations for VOC Maintenance and Repair 3 Axle Single Unit Trucks Calculation

1     $1046.8 - 499.21 * Log(sp) + 106.76 * (Log(sp)) \wedge 2 + 601.98 * gr + 154.36 * gr \wedge 2 + 15.039 * gr \wedge 3$

2     $46 + 0.008 * sp \wedge 2 + 0.146 * sp * gr$

3     $1.6996 + 0.094776 * sp - 0.016324 * sp \wedge 2 + 0.00037673 * sp \wedge 3 - 0.0000040767 * sp \wedge 4 + 0.000000014984 * sp \wedge 5 - 14.684 * gr$

Figure 16 VOC Maintenance and Repair Calculation 3-4 Axle Combination Trucks- Logic to Select Equation
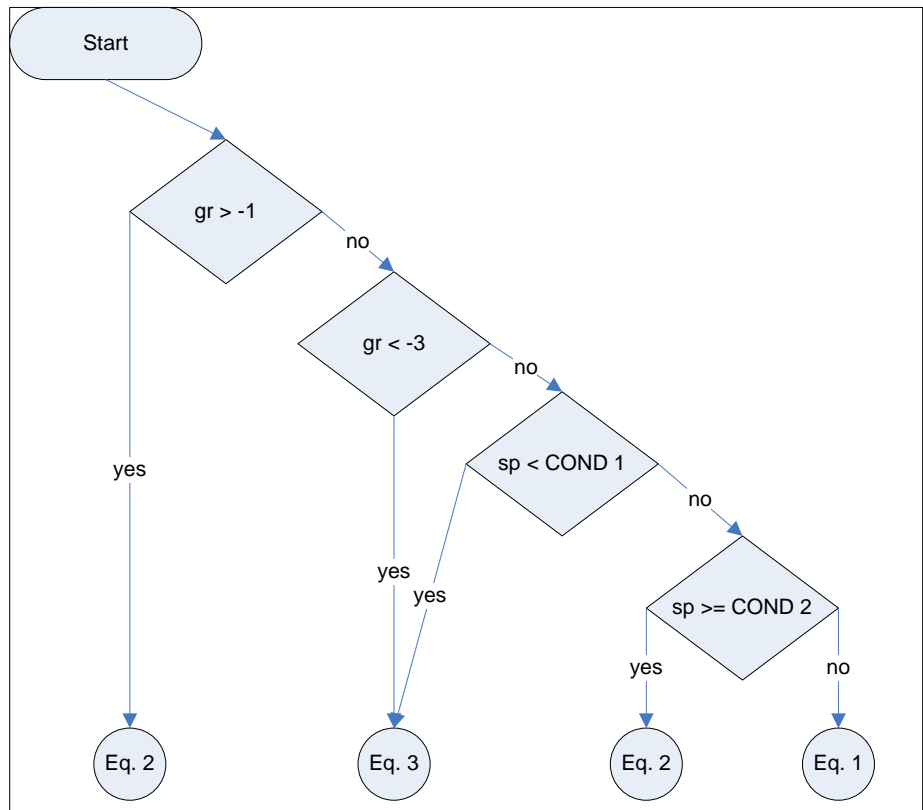
Table 19 Conditions for VOC Maintenance and Repair 3-4 axle Combination Trucks

COND 1	-7.5 x gr^2 - 52.5 x gr - 25
COND 2	-7.5 x gr^2 - 52.5 x gr - 20

Table 20 Equations for VOC Maintenance and Repair 3-4 Axle Combination Trucks Calculation

1   $169.6 + 6.4867 * sp + 333.98 * gr + 48.825 * gr \wedge 2$

2   $46 + 0.008 * sp \wedge 2 + 0.146 * sp * gr$

3   $2.44881 - 0.0404901 * sp \wedge (1.5) - 15.8112 * gr$

:

Figure 17 VOC Maintenance and Repair Calculation 5+ Axle Combination Trucks- Logic to Select Equation
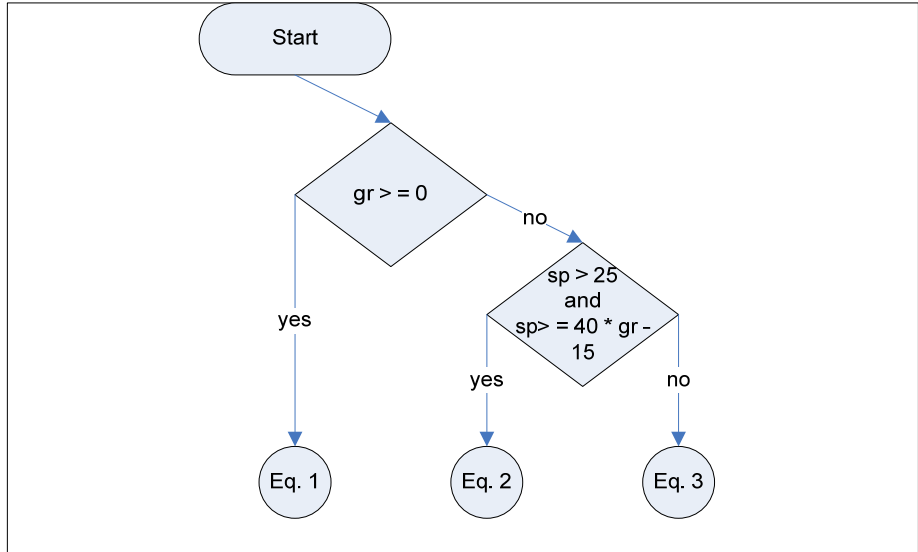
Table 21 Equations for VOC Maintenance and Repair 5+ Axle Combination Trucks Calculation

1	44.9 + 0.01148 * sp ^ 2 + 0.254 * sp * gr
2	78.7 + 1.545 * sp - 20.6 * Log(sp) + 0.254 * sp * gr
3	0.996 - 0.00149 * sp ^ 2 - 15.8 * gr

Equation 34 Maintenance and Repair Cost

$$VOCM = CSMR \cdot \left(\frac{PSIADJ_{vehcat, \, mr}}{ADJ_{vehcat, \, mr}} \right) \cdot \left(\frac{LEN}{1000} \right) \cdot$$

$$MRCOST_{vehcat,1995} \cdot \frac{PGEN_{baseyear}}{PGEN_{1995}} \cdot .001$$

Where:

$CSMR$	Constant speed maintenance and repair
$PSIADJ_{vevsye, \, oil}$	Pavement smoothness index adjustment factor
$ADJ_{vehcat, \, oil}$	Adjustment factor, fuel
LEN	Length of facility, miles
$MRCOST_{vehcat,1995}$	Cost of maintenance and repair for vehicle category in 1995, dollars
$PGEN$	General price index, base year = 100

VOC Tire Wear Calculation

Figure 18 VOC Tire Wear Calculation Small Cars- Logic to Select Equation
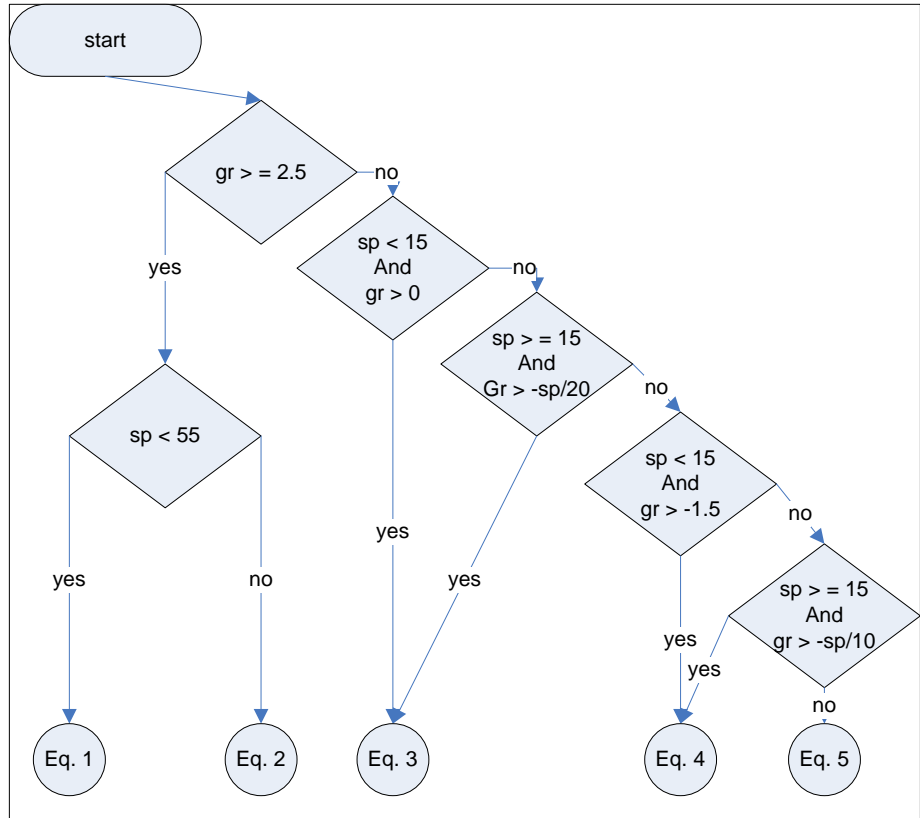
Table 22 Equations for VOC Tire Wear Small Cars Calculation

1 Exp(-2.55 + 0.0001621 * sp ^ 2 + 0.01441 * sp + 1.473 * Log(gr) - 0.001638 * sp * gr)

2 1.314 + 0.000733 * sp ^ 2 - 0.05758 * sp + 0.01514 * gr ^ 2 + 0.003997 * sp * gr

3 0.1959 + 0.00000251 * sp ^ 3 - 0.0352 * Log(sp) + 0.01754 * gr ^ 2 + 0.00348 * sp * gr

4 0.0604 + 0.0000000292 * sp ^ 4 + 0.0000796 * sp ^ 2 + 0.0274 * gr ^ 2 + 0.074 * gr + 0.0000568 * sp ^ 2

5 Exp(-5.39 - 0.000895 * sp ^ 2 + 0.0962 * gr + 2.83 * Log(-gr) - 0.00397 * sp * gr)

Figure 19 VOC Tire Wear Calculation Medium-Large Cars- Logic to Select Equation

Start

dp < 55

no → gr > = 0.5

yes → gr > 2.5

gr >= 0.5: no → gr > -sp/10 + 1 Or sp > = 80

gr > 2.5: no → sp < 15 And gr > 0

sp < 15 And gr > 0: no → sp > = 15 And gr > = -sp/20

sp > = 15 And gr > = -sp/20: no → sp < 15 And gr > -1.5

sp < 15 And gr > -1.5: no → sp > = 15 And gr> -sp/10

gr >= 0.5: yes → Eq. 5

gr > -sp/10 + 1 Or sp > = 80: yes → Eq. 6; no → Eq. 7

sp < 15 And gr > 0: yes → Eq. 2

sp > = 15 And gr > = -sp/20: yes → Eq. 3

sp < 15 And gr > -1.5: yes → Eq. 3

sp > = 15 And gr> -sp/10: yes → Eq. 4; no → Eq. 4

gr > 2.5: yes → Eq. 1
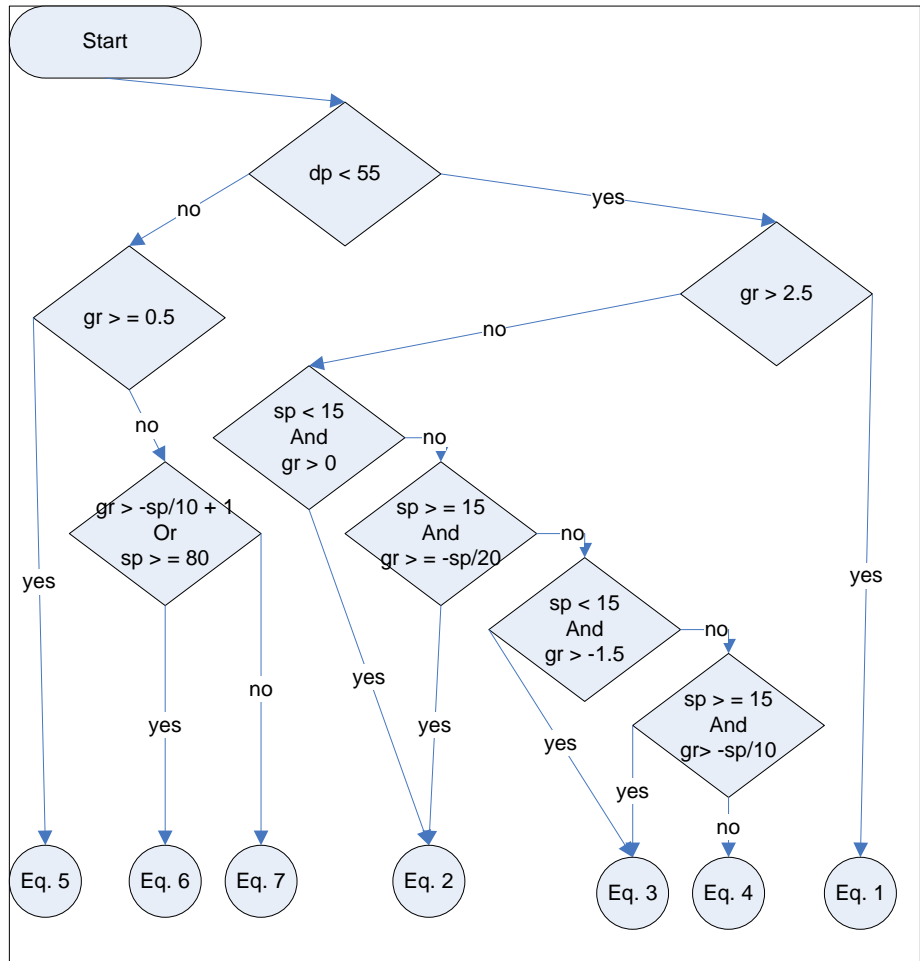
Table 23 Equations for VOC Tire Wear Medium-Large Cars Calculation

1	$Exp(-2.39 + 0.0001564 * sp \wedge 2 + 0.01367 * sp + 1.475 * Log(gr) - 0.001586 * sp * gr)$
2	$0.229 + 0.00000265 * sp \wedge 3 - 0.0403 * Log(sp) + 0.0214 * gr \wedge 2 + 0.00392 * sp * gr$
3	$0.08 + 0.000003 * sp \wedge 3 + 0.029 * gr \wedge 2 + 0.0828 * gr + 0.000056 * sp \wedge 2 * gr$
4	$Exp(-5.22 - 0.000771 * sp \wedge 2 + 0.0843 * gr + 2.81 * Log(-gr) - 0.00323 * sp * gr)$
5	$1.318 + 0.000743 * sp \wedge 2 - 0.05661 * sp + 0.01941 * gr \wedge 2 + 0.00417 * sp * gr$
6	$-0.2022 + 0.000237 * sp \wedge 2 + 0.0213 * gr \wedge 2 - 1.0322 * gr + 0.3099 * Log(sp) * gr$
7	$-0.2613 + 0.000164 * sp \wedge 2 + 0.02065 * gr \wedge 2 + 0.005452 * sp * gr - 0.03975 * Log(sp) * gr$

Figure 20 VOC Tire Wear Calculation 4 Tire Trucks- Logic to Select Equation
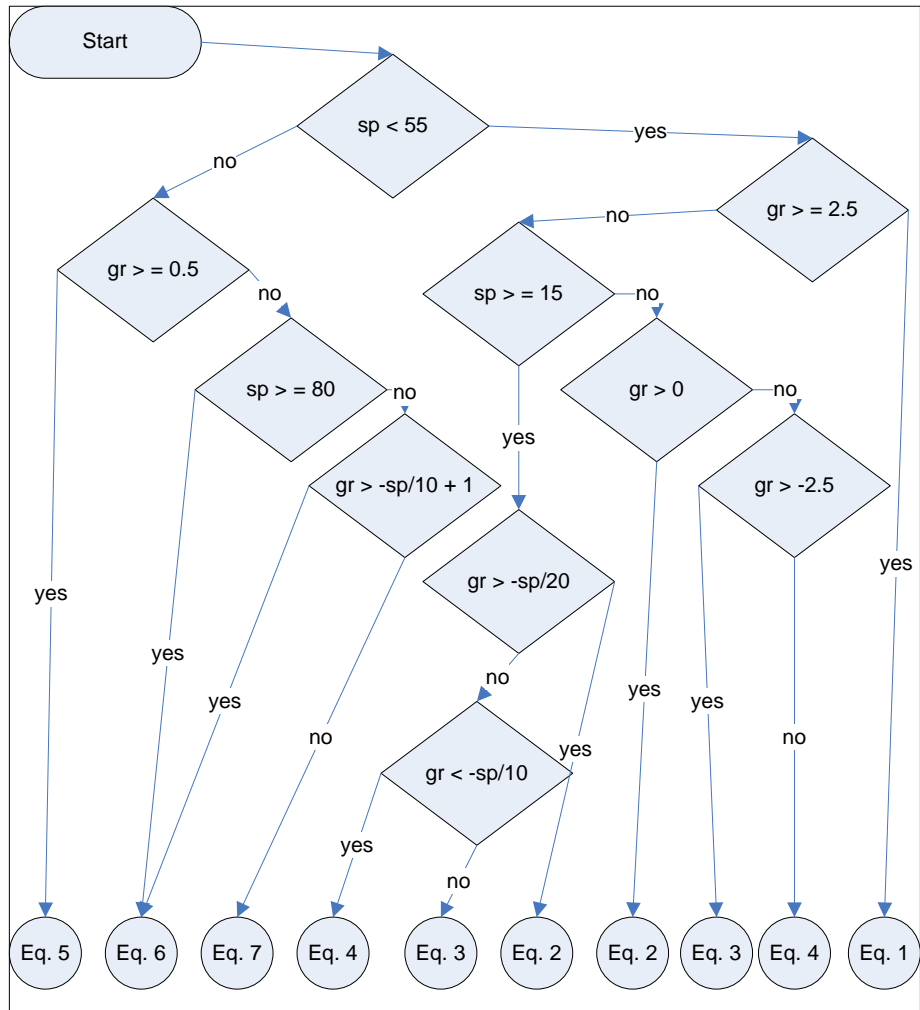
Table 24 Equations for VOC Tire Wear 4 Tire Trucks Calculation

1. Exp(-2.08 + 0.0001517 * sp ^ 2 + 0.012 * sp + 1.367 * Log(gr) - 0.001389 * sp * gr)

2. 0.297 + 2.9 * 10 ^ (-6) * sp ^ 3 - 0.0421 * Log(sp) + 0.0234 * gr ^ 2 + 0.00429 * sp * gr

3. 0.1294 + 3.64 * 10 ^ (-6) * sp ^ 3 + 0.0324 * gr ^ 2 + 0.1085 * gr + 0.0000631 * sp ^ 2 * gr

4. Exp(-5.45 - 4.13 * 10 ^ (-6) * sp ^ 3 - 0.01377 * sp + 2.79 * Log(-gr))

5. 1.365 + 0.000736 * sp ^ 2 - 0.05471 * sp + 0.0197 * gr ^ 2 + 0.004395 * sp * gr

6. Abs(-0.1554 + 0.000258 * sp ^ 2 + 0.0205 * gr ^ 2 - 0.05138 * gr + 0.005058 * sp * gr)

7. Max(0.01, -0.2177 + 0.000208 * sp ^ 2 + 0.02376 * gr ^ 2 + 0.005895 * sp * gr - 0.03288 * Log(sp) * gr)

Figure 21 VOC Tire Wear Calculation 6 Tire 2 Axle Trucks- Logic to Select Equation
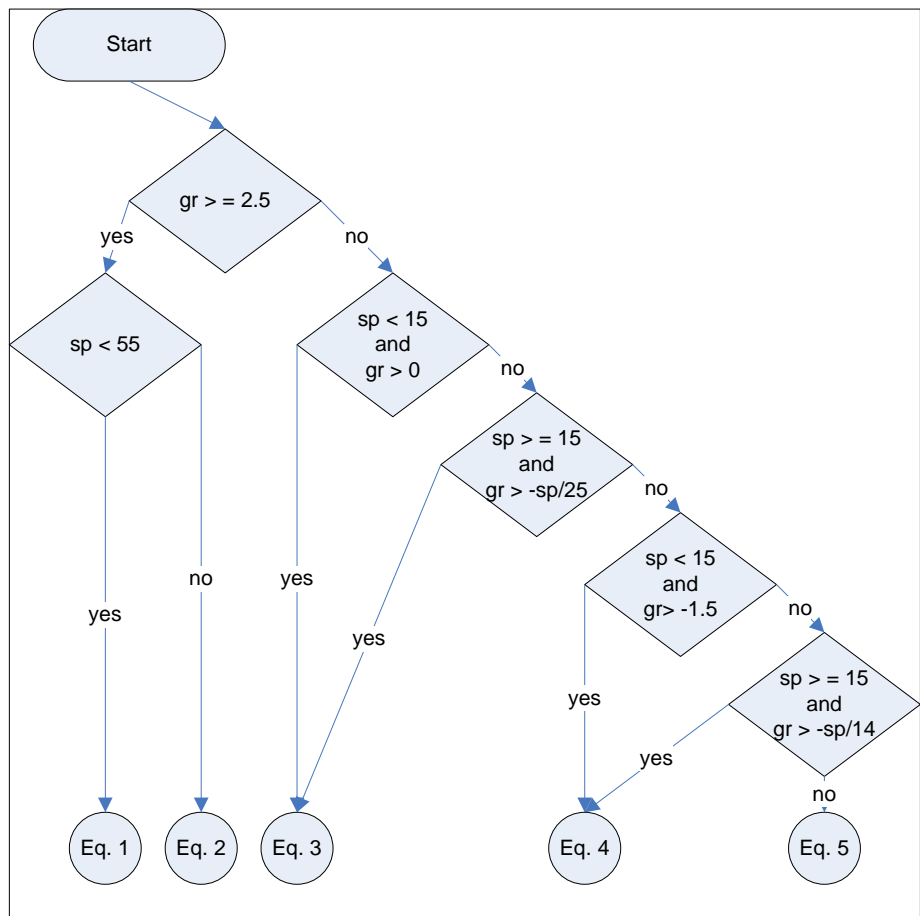
Table 25 Equations for VOC Tire Wear 6 Tire, 2 Axle Trucks Calculation

1. $Exp(-1.572 + 0.0000943 * sp^2 + 0.01509 * sp + 1.65 * Log(gr) - 0.001535 * sp * gr)$

2. $2.206 + 0.001267 * sp^2 - 0.09683 * sp + 0.07733 * gr^2 + 0.01096 * sp * gr$

3. $0.353 + 0.0000045 * sp^3 - 0.0556 * Log(sp) \ 0.0855 * gr^2 + 0.01012 * sp * gr$

4. $0.104 + 0.0000000537 * sp^4 + 0.0001578 * sp^2 + 0.1282 * gr^2 + 0.222 * gr + 0.000168 * sp^2 * gr$

5. $Exp(-3.16 - 0.00000335 * sp^3 - 0.0308 * sp + 2.28 * Log(-gr) - 0.00377 * sp * gr)$

Figure 22 VOC Tire Wear Calculation 3 Axle Single Unit Trucks- Logic to Select Equation
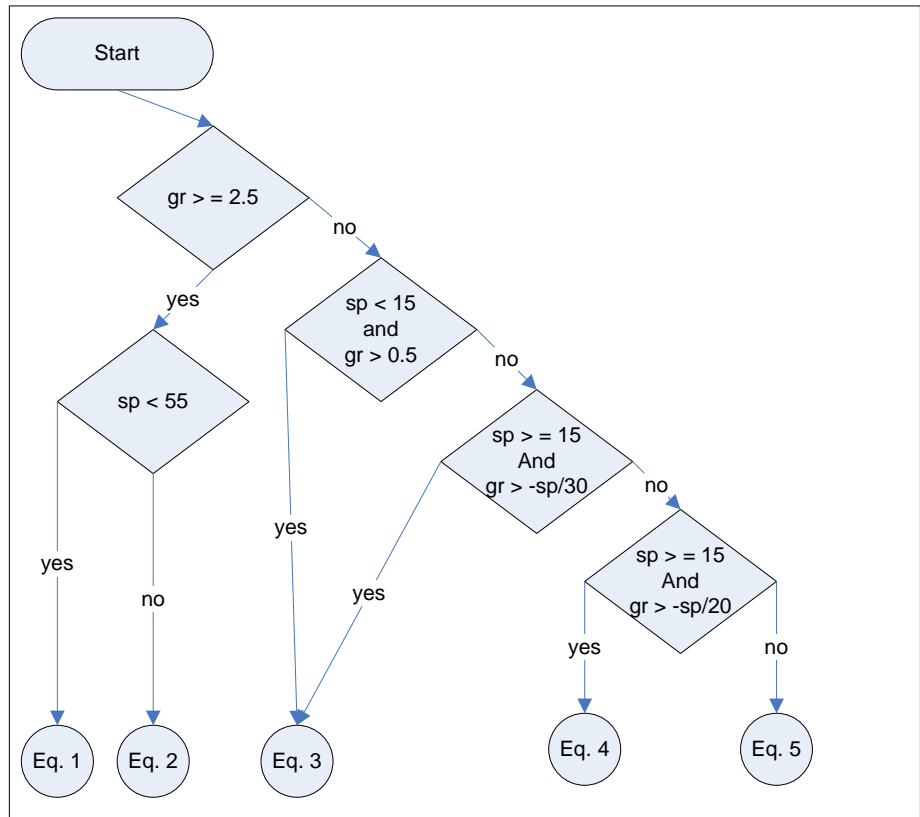
Table 26 Equations for VOC Tire Wear 3 Axle Single Unit Trucks Calculation

1   Exp(-1.71 + 0.0000511 * sp ^ 2 + 0.01134 * sp + 1.575 * Log(gr) - 0.001038 * sp * gr)

2   1.085 + 0.000405 * sp ^ 2 - 0.03274 * sp + 0.05955 * gr ^ 2 + 0.00577 * sp * gr

3   0.0896 + 0.0001308 * sp ^ 2 + 0.0552 * gr ^ 2 + 0.1181 * gr + 0.00402 * sp * gr

4   0.0345 + 0.000387 * sp ^ 2 + 0.257 * gr ^ 2 + 0.01988 * sp * gr

5   Exp(-3.3 - 0.0275 * sp + 0.1868 * gr + 2.92 * Log(-gr) - 0.00275 * sp * gr)

Figure 23 VOC Tire Wear Calculation 3-4 Axle Combination Trucks- Logic to Select Equation
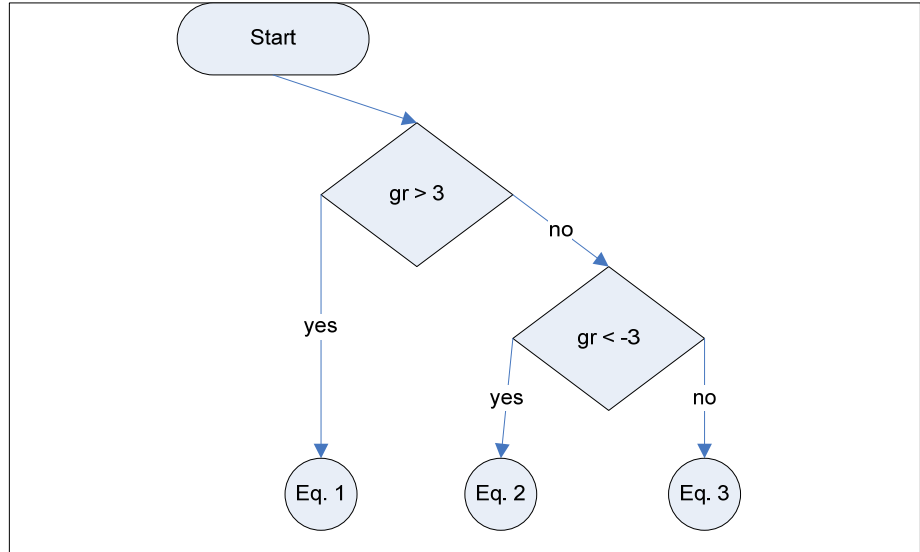
Table 27 Equations for VOC Tire Wear 3-4 Axle Combination Trucks Calculation

1    $0.27453 - 0.016411 * sp + 0.090845 * gr + 0.00035502 * sp \wedge 2 + 0.047978 * gr \wedge 2 + 0.0042709 * sp * gr$

2    $Abs(-0.14758 + 0.01337 * sp + 0.0040158 * gr - 0.000053182 * sp \wedge 2 + 0.052391 * gr \wedge 2 + 0.0044432 * sp * gr)$

3    $0.15566 - 0.0058457 * sp + 0.041763 * gr + 0.00021374 * sp \wedge 2 + 0.056992 * gr \wedge 2 + 0.0050156 * sp * gr$

:

Figure 24 VOC Tire Wear Calculation 5+ Axle Combination Trucks- Logic to Select Equation
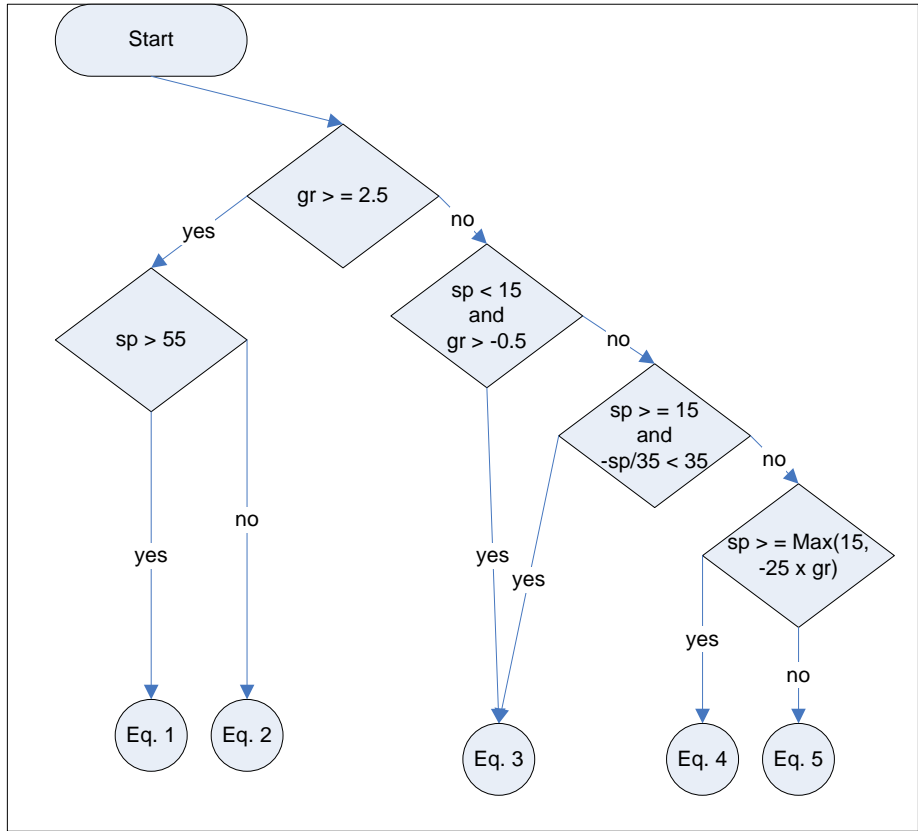
Table 28 Equations for VOC Tire Wear 5+ Axle Combination Trucks Calculation

1. Exp(-1.6 + 0.0000684 * sp ^ 2 + 0.00608 * sp + 1.567 * Log(gr) - 0.000762 * sp * gr)

2. 1.122 + 0.000357 * sp ^ 2 - 0.03264 * sp + 0.06295 * gr ^ 2 + 0.005081 * sp * gr

3. 0.1432 + 0.000001248 * sp ^ 3 + 0.0639 * gr ^ 2 + 0.1167 * gr + 0.00332 * sp * gr

4. -0.1283 + 0.000001442 * sp ^ 3 + 0.01044 * sp + 0.208 * gr ^ 2 + 0.01337 * sp * gr

5. Exp(-3.05 - 0.0000015 * sp ^ 3 - 0.01358 * sp + 2.13 * Log(-gr) - 0.001779 * sp * gr)

Equation 35 Tire Wear Cost

$$VOCT = CSTW \cdot \left(\frac{PSIADJ_{vehcat,\ tw}}{ADJ_{vehcat,\ tw}} \right) \cdot \left(\frac{LEN}{1000} \right) \cdot$$
$$TWCOST_{vehcat,1995} \cdot \frac{PGEN_{baseyear}}{PGEN_{1995}} \cdot .01$$

Where:

CSTW	Constant speed tire wear, percent worn / 1000 miles
$PSIADJ_{vevsye,\ oil}$	Pavement smoothness index adjustment factor
$ADJ_{vehcat,\ oil}$	Adjustment factor, fuel
LEN	Length of facility, miles
$TWCOST_{vehcat,1995}$	Cost of tires for vehicle category in 1995, dollars
PGEN	General price index, base year = 100

VOC Vehicle Depreciation

Equation 36 Constant Speed Depreciation for Small Cars (% new price / 1000 miles)

$$CSVD = 2.2 + 0.001596 \cdot sp - 0.38 \cdot Log(sp)$$

Equation 37 Constant Speed Depreciation for Medium/Large Cars (% new price / 1000 miles)

$$CSVD = 1.725 + 0.001892 \cdot sp - 0.311 \cdot Log(sp)$$

Equation 38 Constant Speed Depreciation for 4-Tire Trucks (% new price / 1000 miles)

$$CSVD = 0.742 + 0.000589 \cdot sp - 0.1307 \cdot Log(sp)$$

Equation 39 Constant Speed Depreciation for 6-Tire 2-Axle and 3-Axle Single Unit Trucks (% new price / 1000 miles)

$$CSVD = \begin{cases} 1.126 + 0.00279 \cdot sp - 0.247 \cdot Log(sp), \text{ for } sp < 55 \\ 0.05657 + \dfrac{1.598}{sp}, \text{ for } sp \geq 55 \end{cases}$$

Equation 40 Constant Speed Depreciation for 3-4 Axle Combination Trucks (% new price / 1000 miles)

$$CSVD = \begin{cases} 0.354 + 0.000974 \cdot sp - 0.0806 \cdot Log(sp), \text{ for } sp < 55 \\ 0.2006 + \dfrac{4.936}{sp}, \text{ for } sp \geq 55 \end{cases}$$

Equation 41 Constant Speed Depreciation for5+ Axle Combination Trucks (% new price / 1000 miles)

$$CSVD = \begin{cases} 0.395 + 0.001215 \cdot sp - 0.094 \cdot Log(sp), \text{ for } sp < 55 \\ 0.05657 + \dfrac{1.598}{sp}, \text{ for } sp \geq 55 \end{cases}$$

Equation 42 Vehicle Depreciation Cost, base year dollars

$$VOCD = CSVD \cdot \left(\frac{PSIADJ_{vehcat,\, tw}}{ADJ_{vehcat,\, tw}} \right) \cdot \left(\frac{LEN}{1000} \right) \cdot$$

$$VEHCOST_{vehcat,1995} \cdot \frac{PGEN_{baseyear}}{PGEN_{1995}} \cdot .0001$$

Where:

$CSVD$	Constant speed vehicle depreciation (% new price / 1000 miles)
$PSIADJ_{vevsye,\, oil}$	Pavement smoothness index adjustment factor
$ADJ_{vehcat,\, oil}$	Adjustment factor, fuel
LEN	Length of facility, miles
$VEHCOST_{vehcat,1995}$	Cost of new vehicle for vehicle category in 1995, dollars
$PGEN$	General price index, base year = 100

VOC - Summary

VOC=VOCF+VOCO+VOCM+VOCT+VOCD

Where:

$VOCF$	Vehicle operating cost, fuel
$VOCO$	Vehicle operating cost, oil
$VOCM$	Vehicle operating cost, maintenance and repair
$VOCT$	Vehicle operating cost, tire wear
$VOCD$	Vehicle operating cost, vehicle depreciation

Safety

[Describe basic safety principals, crash types and that more than one injury/fatality per crash]

Equation 43 Cost of Crashes (by crash type and per hour of operations in traffic period)

$$CC = \frac{PCE \cdot CRRATE \cdot CRSHARE_{Type} \cdot CRCOST_{Type}}{1000000}$$

Where:

PCE	Passenger Car Equivalence (per hour of operations in traffic period)
LEN	Length of facility mile
$CRRATE$	Crashes per million vehicle miles
$CRSHARE_{Type}$	Percent of crash type of total (crash types: fatal, injury, property damage only)
$CRCOST$	Cost per crash by type

Emissions

[Explain that the emissions rate functions are based on tables from HERS]

Equation 44 Quantity of Emissions, metric tons

$$ EM = EMRATE_{vehtype,\ emtype}(sp) \cdot LEN \cdot \frac{AHT_{vehtype}}{1000000} $$

Where:

$EMRATE_{vehtype,\ emtype\ (sp)}$	Vehicle emissions rate as a function of speed, grams per vehicle mile, emissions type one CO, NOx, VOC
LEN	Length of facility, miles
$AHT_{vehtype}$	Average hourly traffic by vehicle type

Equation 45 Emission Cost

$$ EMC = EM \cdot PEM_{emtype} $$

Where:

EM	Quantity of emissions, metric tons
PEM_{emtype}	Cost per metric ton by emission type

Project Costs

Capital Costs of the Project

Capital costs (not to be confused with "the cost of capital", represented in *BCA.Net* as the discount rate) are one-time expenditures and unavoidable user costs that are incurred for roadway development and upgrades. There are three categories of capital costs in *BCA.Net*: construction costs, right-of-way costs, and disruption costs. Each of these cost categories and the accounting for each is described below. Note that non-retrievable ("sunk") costs incurred prior to the project decision should not be included in the benefit-cost analysis.

Construction Costs

Construction costs are the labor, material and administrative costs of new roadway development or existing roadway upgrade. These costs include costs for planning, engineering, excavation, filling, grading, paving, drainage, structures, signage, fencing, noise abatement and any other out-of-pocket cost associated with roadway development (not including purchase of right-of-way).

Constructions costs are specified in *BCA.Net* in a capital expenditure schedule (as part of an investment strategy) and a schedule may extend up to seven years.   These costs should be expressed in constant base year dollars.

Construction costs are charged to the project in full in the year of their expenditure.

Construction costs form the depreciable cost basis of the facility (right-of-way is in the cost basis of the facility, but is non-depreciable). In *BCA.Net* the construction cost component of the facility depreciates at a fixed rate and the remaining ("residual") value at the end of the analysis period is credited back to the project (i.e., the residual value, discounted accordingly, offsets the project cost).

Right-Of-Way Costs

Costs of right-of-way are the costs, usually in the form of land purchase, for acquiring the rights to land for highway development and use. Right-of-way costs should reflect the fair market value for the properties acquired inclusive of any associated administrative costs.

Right-of-way costs are specified in *BCA.Net* in a capital expenditure schedule (as part of an investment strategy) and a schedule may extend up to seven years.   These costs should be expressed in constant base year dollars.

Right-of-way costs are charged to the project in full in the year of their expenditure.

In constant dollar terms, the value of the project right-of-way does not depreciate (nor does value of the project land holdings appreciate in value in the analysis framework). The full cost of right-of-way acquisition is included in the project's residual value at the end of the analysis period and offsets the project cost (at its discounted present value).

Disruption (Work Zone) Costs

Disruption costs are the estimated user costs associated with roadway development. These costs are, typically, the costs of congestion and delay due to lane closures and detours associated with construction. These costs, which area user input, should be estimated using the same values of time and other assumptions that are used in the evaluation of user costs for project benefits.

Disruption costs are specified in *BCA.Net* in a capital expenditure schedule (as part of an investment strategy) and a schedule may extend up to seven years.   These costs should be expressed in constant base year dollars.

In *BCA.Net* disruption costs are not included in the depreciable cost basis of the project.

Because disruption costs may be a very significant capital cost component, charging for these costs in the year in which they occur may bias the outcome of an analysis due to the timing of a refurbishment cycle combined with a specific period of analysis. In order to avoid this potential source of bias, *BCA.Net* spreads the disruption costs into equal charges over the anticipated useful life of the facility based on the rate of depreciation. The equal charges account for the discount rate so that charging the disruption cost payments over a number of years is equivalent (i.e.,

no impact on NPV) to charging the disruption costs in the years in which they occurred.

If there are disruption costs toward the end of the period of analysis then there may remain a balance of uncharged disruption costs at the end of the analysis period. This is consistent with the method of crediting back the project's residual value.

Capital Costs for Project Summary

In the Project Summary of the results, project costs do not include the disruption cost payment. Disruption cost payments, because they are user costs, are counted as a negative in the benefits column.

Capital costs may be specified in the capital expenditure schedule as one of the following: total cost, cost per facility-mile, or cost per lane-mile. These costs are converted to total costs in the analysis.

Equation 46 Annual Capital Cost for Project Summary

$$CAPCOSTPS = (CONSTCOST + ROWCOST) \cdot UNITMULT$$

Where:

CONSTCOST	Construction costs in year, designated units
ROWCOST	Cost of right-of-way acquisition in year, designated units
UNITMULT	If cost units are "Total Cost", then UNITMULT=1
	If cost units are "Per Facility Mile", then UNITMULT=FACILITY_LENGTH
	If cost units are "Per Facility Lane-Mile", then UNITMULT=FACILITY_LENGTH x NUMBER_LANES

Disruption cost charges are debits against the project for disruption costs. The following equation shows the calculation of the disruption cost charges for disruption costs occurring in a year yr. The charge is made in each of the years between the year in which the costs occur (yr) and the year in which the entire disruption cost has been charged out (yr+n-1).

Equation 47 Disruption Cost (Work Zone) Annual Charge (for Disruption Costs in Year yr)

$$DISRCHR = \frac{DISRCOST_{yr} \cdot UNITMULT \cdot r \cdot (1+r)^n}{(1+r)^{n+1} - (1+r)}$$

Where:

$DISRCOST_{yr}$	Disruption cost in year yr
r	Discount rate
n	The charge period in years (set to 1 over the depreciation rate, rounded to the nearest integer)
UNITMULT	If cost units are "Total Cost", then UNITMULT=1
	If cost units are "Per Facility Mile", then UNITMULT=FACILITY_LENGTH
	If cost units are "Per Facility Lane-Mile", then UNITMULT=FACILITY_LENGTH x NUMBER_LANES

The project residual value represents an estimate of the remaining useful life in the project at the end of the analysis period. This amount is a positive component of the project Net Present Value (NPV), that is, it offsets the project cost.

Equation 48 Residual Value (Present Value)

$$RESVAL = \frac{\sum_{iyr=0}^{n-1} \left(\dfrac{CONSTCOST_{iyr}}{(1-DEPRATE)^{n-iyr}} + ROWCOST_{iyr} \right)}{(1+r)^{n+1}}$$

Where:

$CONSTCOSTS_{iyr}$	Construction costs in year iyr
$ROWCOST_{iyr}$	Cost of land acquisition in year iyr
$DEPRATE$	Depreciation rate
r	Discount rate
iyr	Year of investment
n	Number of years in the analysis period

Operating, Maintenance and Other Life Cycle Costs

In *BCA*.Net the user specifies the annualized equivalent of 1) operating and maintenance (O&M) costs, and 2) other life cycle costs. These amounts are specified for each project segment in the "base year facility characteristics" view of the Project page. These values are also specified in the investment Strategies. In the year following the last year of a project's capital expenditure, when implementing a Strategy, the O&M and other life cycle costs supersede the values that were previously charged in each year. These values are charged in each year until they are superseded by values associated with a subsequent Strategy.

Total Project Cost

Total project cost (in each year) is the sum of: capital costs (less disruption costs), O&M and other life cycle costs. The present value of the total project costs comprise the denominator of the benefit-cost ratio.

Consumer Surplus

Consumer surplus represents society's total willingness-to-pay (WTP) for the services of the roadway facility. Consumer surplus is used in the analysis to capture the effects of changes in the costs of travel, and to identify the benefits of improvements to both existing and new users of the roadway.

Figure 25 Consumer Surplus
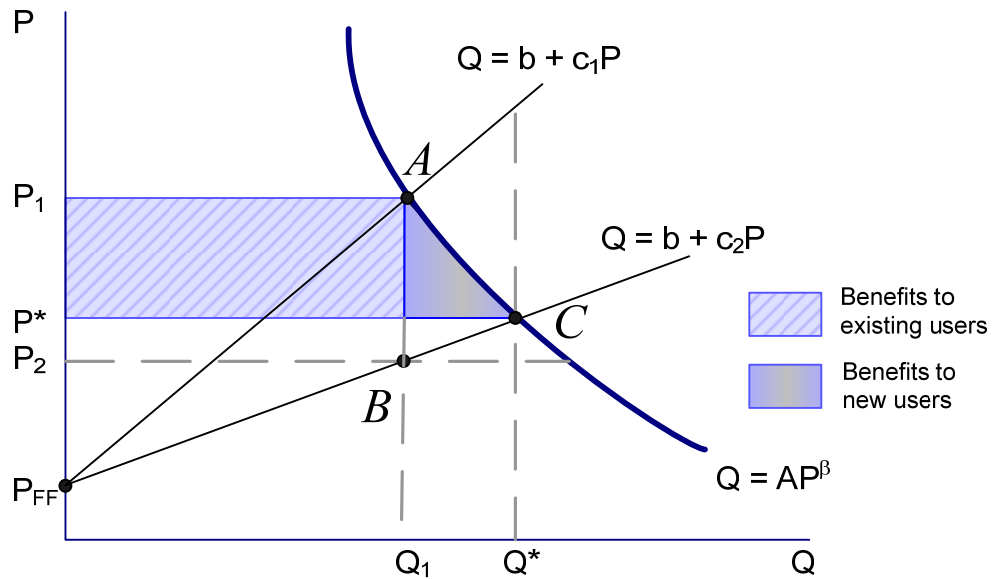
Process for Evaluating User Costs in the Alternate Case

The figure above illustrates the analytic process used in *BCA.Net*. The downward sloping curve represents the demand for travel on the project segment. The x-axis, labeled "Q", gives the average annual daily travel (AADT) on the segment and the y-axis (labeled "P"), gives the generalized cost of travel, which is the user cost per trip (net of the emissions cost, which presumably does not impact a user's decision to make a particular trip). The two upward sloping lines are a stylized representations of the marginal user's cost per trip, which increases as the roadway congests.

In the Base Case, represented by point A, AADT is Q_1 and the cost per trip is P_1. In *BCA.Net*, AADT in the Base Case is a user input. P_1 is imputed from the calculated users costs in the year. P_{FF} is the assumed "freeflow" (i.e., uncongested) cost per trip. By applying the Base Case AADT to the "improved", or Alternate Case, facility, we can find P_2 from the total user costs at point B. The line joining P_{FF} and P_2 is marginal user's cost per trip line in the alternate case. From this line and the demand curve, *BCA.Net* calculates Q^*, which represents AADT that accounts for the impact of the reduced cost per trip on demand. This new AADT is used with the improved facility in the Alternate Case to derive the user costs in the Alternate Case.

The following summarizes the process for calculating the user costs in the alternate case:

- Given AADT, calculate the user costs in the Base Case (Point A in the figure).

- With the Alternate Case improvements, calculate the user costs using the given (Base Case) AADT (Point B in the figure).

- Derive the Alternate Case AADT given: 1) the demand curve and the elasticity of demand with respect to trip cost, and 2) the marginal user's cost per trip.

- Calculate the Alternate Case user costs given the improved facility and the Alternate Case demand (AADT).

- This process is implemented for the three boundary years, and the Alternate Case AADT is interpolated for the other years.

The following equations represent the process described in the above paragraph.

Note that the notation in the following equations differs from the notation in the diagram.

Equation 49 Base Case Average Annual Generalized Cost of Travel (cost per trip)

$$P_B = \frac{PQ_B}{ADT_B}$$

Where:

PQ_B User costs in the base case

ADT_B Average annual daily traffic in the base case

Equation 50 General Equation Constant

$$A = ADT_B \cdot P_B^{-\beta}$$

Where:

ADT_B Average annual daily traffic in the base case

P_B Average annual generalized cost of travel in the base case

β Elasticity of travel demand with respect to generalized cost

Equation 51 Generalized Cost of Travel in Alternate Case with Base Case Demand

$$P_A = \frac{PQ_A}{ADT_B}$$

Where:

ADT_B Average annual daily traffic in the base case

PQ_A User costs in the alternate case with base case demand

Equation 52 Slope of Marginal Cost (Congestion) Line for the Alternate Case

$$b = \frac{(P_A - ff_c)}{ADT_B}$$

Where:

P_A — Generalized cost of travel in alternate case with base case demand

ADT_B — Average annual traffic in base case

ff_c — Free flow cost of trip on segment

Equation 53 The Equilibrium Generalized Cost of Travel in the Alternate Case

$$P^* = \frac{-a_1 + mP_B + a_1 q_1 + b}{1 - a_1 \cdot m}$$

$$q_1 = AP^{*\beta}$$

$$q_2 = \frac{P^* - b}{a_1}$$

Iterate to solve until $\left| q_1 - q_2 \right| < .0001 \cdot ADT_B$

Where:

A — Constant of demand equation

β — Elasticity

a_1 — Slope of alternate case congestion line

b — Generalized cost of travel with free flow demand

P_1 — Imputed generalized cost of travel in the base case

q_2 — Estimated cost given P^*

q_1 — Estimated demand given P^*

Figure 26 AADT in the Alternate Case

$$ADT^* = \left(\frac{P^*}{A} \right)^{\frac{1}{\beta}}$$

Where the values on the right-hand side are described in the previous equation.

The AADT in the Alternate Case is used in the calculation of speed, average hourly traffic and user costs in the alternate case.

Benefit-Cost Indicators and Summary

Benefit and Cost Streams

The benefit streams are the Alternate Case user costs less the Base Case user costs. The stream of benefits in the last year of the analysis period includes the residual value of the project. The disruption cost charges in each year are deducted from the benefit stream.

Benefits are aggregated over all the segments of the project.

Figure 27 Annual Benefit in Each Year

$$B = TS + VOC + EM + CC - DCC + RV$$

Where:

TS   Travel time savings

VOC   Vehicle operating cost savings

EM   Emission reductions

CC   Crash cost reductions

RV   Residual value of project (last year only)

The cost streams are the project costs realized in each year

Figure 28 Annual Benefit in Each Year

$$C = CONSTCOST + ROWCOST + OMCOST + OLC$$

Where:

CONSTCOST   Construction costs

ROWCOST   Rigth-of-way costs

OMCOST   Operating and maintenance costs

OLC   Other life cycle costs

Net Present Value

In the present value calculations, benefits and costs that are realized in different years are made comparable with one another through discounting. In the formulas below, B_{iyr} stands for "benefits in year iyr", $C_{iy}r$ stands for "costs in year iyr", r is the discount rate and n is the number of years in the period of analysis.

Net Present Value is the single best measure of project worth and for comparing project alternatives. If a project alternative has NPV>0 then the project passes the benefit-cost hurdle and, there may be economic merit in its selection.

Equation 54 Present Value of Project Benefits

$$PVB = \sum_{iyr=1}^{n} \frac{B_{iyr}}{(1+r)^n}$$

Equation 55 Present Value of Project Costs

$$PVC = \sum_{iyr=1}^{n} \frac{C_{iyr}}{(1+r)^n}$$

Equation 56 Net Present Value

$$NPV = PVB - PVC$$

Benefit-Cost Ratio

The benefit-cost ratio is a measure of "bang for the buck", or, benefit received for each dollar invested. A project passes the benefit-cost hurdle if its benefit-cost ratio exceeds 1.

Figure 29 Benefit-Cost Ratio

$$BCR = \frac{PVB}{PVC}$$

Internal Rate of Return

The internal rate of return (IRR) calculation finds the discount rate that would result in a net present value equal to 0. IRR is useful for communicating results – it can be compared, in a manner of speaking, to the rate of return on a financial asset. However, it is not a good metric for comparing project alternatives. Moreover, if the net benefit stream changes sign more than once, there may be multiple IRRs and, in these cases, the measure is difficult to interpret.

Model Structure and Data Organization

Extensive description and discussion of the BCA.Net model's structure and data organization are provided in BCA.Net Highway Project Benefit-Cost Analysis System User's Manual and in the various Walkthrough Training Exercises provided in the Help section of the model's website.

Data Tables

Input Variables

Table 29 Strategies- Identifiers and effects

Variable	Units	Default Value	Minimum Value	Maximum Value
Freeflow Speed	mph	50		
Maximum Flow Rate	veh/hr/lane	1700		
Number of Lanes	numerical	2	greater than number or reversible lanes	
Number of reversible lanes	numerical	0	0	less than number of lanes
PSI	1-5 Scale	4		
Pavement Deterioration Rate	Change in PSI/Year	0.1		
Percent Grade	Percent	0	0	100
Crash Rate	Accidents per million VMT	1.5		
Facility Type	categorical	Rural/Suburban Arterial	n/a	n/a
Change in Facility Length	miles	0		

Table 30 Strategies- Costs

Variable	Units	Default Value	Minimum Value	Maximum Value
Rights of Way Costs year 1	thous$	0		
Rights of Way Costs year 2	thous$	0		
Rights of Way Costs year 3	thous$	0		
Rights of Way Costs year 4	thous$	0		
Rights of Way Costs year 5	thous$	0		

Rights of Way Costs year 6	thous$	0		
Construction Costs year 1	thous$	0		
Construction Costs year 2	thous$	0		
Construction Costs year 3	thous$	0		
Construction Costs year 4	thous$	0		
Construction Costs year 5	thous$	0		
Construction Costs year 6	thous$	0		
Work Disruption Costs year 1	thous$	0		
Work Disruption Costs year 2	thous$	0		
Work Disruption Costs year 3	thous$	0		
Work Disruption Costs year 4	thous$	0		
Work Disruption Costs year 5	thous$	0		
Work Disruption Costs year 6	thous$	0		
Cost Units	Value indicating: costs/facility-mile, costs/lane-mile, total costs	Costs/ Lane-mile	n/a	n/a

Table 31 Strategies- Signals and Devices

Variable	Units	Default Value	Minimum Value	Maximum Value
Traffic Signals changes	Yes/No	No	n/a	n/a
Length of Signal Cycle	seconds	90	10	1200
Percent Eff. Green Dir. Greater Use	percent	50	0	100
Percent Flow corr. Green Dir. Greater Use	percent	0	0	100
Percent Eff. Green Dir. Lesser Use	percent	50	0	100
Percent Flow Corr. Green Dir. Lesser Use	percent	0	0	100
Traffic Control Devices changes	Yes/No	No	n/a	n/a
Average Delay per small vehicle peak period	seconds	90	0	3600
Average Delay per small vehicle peak shoulder	seconds	90	0	3600
Average Delay per Small Vehicle Off-Peak Period	seconds	90	0	3600

Table 32 Project- Base Year Facility Characteristics

Variable	Units	Default Value	Minimum Value	Maximum Value
Facility Type	categorical	Rural/Suburban Arterial	n/a	n/a

			greater than number or reversible lanes	
Number of Lanes	numerical	2		
Reversible Lanes	numerical	0	0	less than number of lanes
Freeflow Speed	mph	50		
Maximum Flow Rate	veh/hr/lane	1700		
Length	miles	4		
Pavement Serviceability index	1-5 numerical rating	3.5		
Pavement deterioration rate, annual change in PSI	numerical	0.1		
Crash Rate: Accidents per Million VMT	Million VMT	1.5		
Cost Units	Value indicating: costs/facility-mile, costs/lane-mile, total costs	Costs/ Lane-mile	n/a	n/a
Operating and Maint. Cost	thous. $	3.5		
Other Lifecycle Cost	thous. $	0		

Table 33 Project- Traffic Characteristics

Variable	Units	Default Value	Minimum Value	Maximum Value
Average Annual Daily Traffic, Start Year	numerical	15000		
Average Annual Daily Traffic, Last Year Near Term	numerical	18000		
Average Annual Daily Traffic, End Year	numerical	24000		
Average Annual Rate of Growth, Last Year Near Term	percent	3.09		
Average Annual Rate of Growth, End Year	percent	1.26		
Duration Peak Period	hours	3		
Duration Peak Shoulder	hours	6		
Percent of Year	percent	100	0	100
Percent of Annual Traffic	percent	100	0	100
Truck percentage	percent	5	0	100
Truck Distribution	categorical	uniform	n/a	n/a
Automobile Percentage	Percent	94	0	100
Automobile distribution	categorical	commute 1	n/a	n/a
Bus percentage	percent	1	0	100
Bus distribution	categorical	commute 1	n/a	n/a

Table 34 Project- Traffic Signals and Control Devices

Variable	Units	Default Value	Minimum Value	Maximum Value
Length of Signal Cycle	seconds	90	10	1200
Percent Eff. Green Dir. Greater Use	percent	50	0	100
Percent Flow corr. Green Dir. Greater Use	percent	0	0	100
Percent Eff. Green Dir. Lesser Use	percent	50	0	100
Percent Flow Corr. Green Dir. Lesser Use	percent	0	0	100
Average Delay per small vehicle peak period	seconds	90	0	3600
Average Delay per small vehicle peak shoulder	seconds	90	0	3600
Average Delay per Small Vehicle Off-Peak Period	seconds	90	0	3600

Table 35 Project- Base Case and Alternate Case

Variable	Units	Default Value	Minimum Value	Maximum Value
Base case strategy i	description	Resurface narrow	n/a	n/a
Year of implementation of base case strategy i	year	2009	2005	2060
alternate case strategy i	description	Widen lanes	n/a	n/a
Year of implementation of alternate case strategy i	year	2009	2005	2060

Table 36 Parameter- Traffic Distribution

Variable	Units	Default Value	Minimum Value	Maximum Value
Peak- average percent of daily traffic per hour in period	percent	50	0	100
Peak of traffic in period, percent in direction of greater use (50-100)	percent	4.167	0	100
Peak Shoulder- average percent of daily traffic per hour in period	percent	50	0	100
Peak Shoulder of traffic in period, percent in direction of greater use	percent	4.167	0	100

Table 37 Scenario- Traffic Demand and Traffic Composition

Variable	Units	Default Value	Minimum Value	Maximum Value
Traffic Uncertainty Factory, first year	percent	0	-30	30

Traffic Uncertainty Factory, last year near term	percent	0	-30	30
Traffic Uncertainty Factor, end year	percent	0	-30	30
Average vehicle occupancy, automobile	numerical	1.1	1	10
Average Bus occupancy	numerical	10	1	80
Percent of Automobiles, small	percent	65	0	100
Truck Passenger Car Equivalent	numerical	1.8	1.1	5
Bus Passenger Car Equivalent	numerical	2.7	1.1	5
Annulization Factor	numerical	280	50	366
Minimum speed in peak period	mph	10	0.5	60
Effective Elasticity of demand w.r.t. cost	numerical	-0.1	-10	0

Table 38 Scenario- Social Costs

Variable	Units	Default Value	Minimum Value	Maximum Value
Discount rate	numerical	5	0	25
Depreciation rate	numerical	4	0	25
Value of time, auto passenger	$/ hr	11.2	1	200
Value of time, truck	$ / hr	18.1	1	200
Value of time, bus passenger	$ / hr	11.2	1	200
Value of fatal crash	thous. $	3900	10	100000
Value of injury crash	thous. $	80	5	50000
Value of PDO Crash	thous. $	5.8	0.5	50000
Gasoline Price in base year	$ / gallon	2.2	0.1	30
Diesel Price in base year	$ / gallon	1.9	0.1	30
Oil price in base year	$ / qt.	4.25	0.1	10
CO emissions cost	$ / ton	0	0	500
NOx emissions cost	$ / ton	0	0	10000
VOC emissions cost	$ / ton	0	0	10000

Table 39 Scenario- Project Cost Factors

Variable	Units	Default Value	Minimum Value	Maximum Value
Project scope factor	value	1	0.1	5
Right-of-way acquisition factor	value	1	0.1	5
Disruption from construction cost factor	value	1	0.1	5
O&M cost factor	value	1	0.1	5
Other lifecycle cost factor	value	1	0.1	5

Table 40 Scenario- Prices

Variable	Units	Default Value	Minimum Value	Maximum Value
Oil Price Index (by year)	Base = 100	100	10	999

Table 41 Scenario- Policies

Variable	Units	Default Value	Minimum Value	Maximum Value
Fuel tax in base case (by year)	$ / gal.	0.5	0	10
Fuel tax in alternate case (by year)	$ / gal.	0.5	0	10

Table 42 Simulation

Variable	Units	Default Value	Minimum Value	Maximum Value
Number of Trials	numerical	51	3	10000
Random Speed	numerical	1		
Sampling Method	categorical	Latin Hypercube	n/a	n/a
Central Values Only	Yes/No	No	n/a	n/a
Reallocate peak traffic if speed falls below minimum	Yes/No	Yes	n/a	n/a
Run risk sensitivity analysis	Yes/No	Yes	n/a	n/a

Output Variables

Table 43 Simulation- Results

Variable	Location	Units
Travel time savings	Simulation- Benefit-Cost Summary	thous. PV$
Vehicle operating cost savings	Simulation- Benefit-Cost Summary	thous. PV$
Safety benefits	Simulation- Benefit-Cost Summary	thous. PV$
Environmental benefits	Simulation- Benefit-Cost Summary	thous. PV$
Project residual value	Simulation- Benefit-Cost Summary	thous. PV$
Disbenefit of traffic disruption from construction	Simulation- Benefit-Cost Summary	thous. PV$
Total benefits	Simulation- Benefit-Cost Summary	thous. PV$
Of this, benefits to new users	Simulation- Benefit-Cost Summary	thous. PV$
Total costs	Simulation- Benefit-Cost Summary	thous. PV$
Net benefits	Simulation- Benefit-Cost Summary	thous. PV$
Benefit-cost ratio	Simulation- Benefit-Cost Summary	ratio
Rate of return	Simulation- Benefit-Cost Summary	percent
Base Case - Travel time cost	Simulation- VOC-Travel Time	thous. PV$
Alt Case - Travel time cost	Simulation- VOC-Travel Time	thous. PV$
Net benefit - Travel time cost	Simulation- VOC-Travel Time	thous. PV$

Base Case - Fuel cost	Simulation- VOC-Fuel Consumption	thous. PV$
Alt Case - Fuel cost	Simulation- VOC-Fuel Consumption	thous. PV$
Net Benefit - Fuel cost	Simulation- VOC-Fuel Consumption	thous. PV$
Base Case - Oil cost	Simulation-VOC-Oil Consumption	thous. PV$
Alt Case - Oil cost	Simulation-VOC-Oil Consumption	thous. PV$
Net Benefit - Oil cost	Simulation-VOC-Oil Consumption	thous. PV$
Base Case - Tire wear cost	Simulation- VOC-Tire Wear	thous. PV$
Alt Case - Tire wear cost	Simulation- VOC-Tire Wear	thous. PV$
Net Benefit - Tire wear cost	Simulation- VOC-Tire Wear	thous. PV$
Base Case - Maint. & repair cost	Simulation- VOC-Maintenance and Repair	thous. PV$
Alt Case - Maint. & repair cost	Simulation- VOC-Maintenance and Repair	thous. PV$
Net Benefit - Maint. & repair cost	Simulation- VOC-Maintenance and Repair	thous. PV$
Base Case - Depreciation cost	Simulation- VOC-Depreciation	thous. PV$
Alt Case - Depreciation cost	Simulation- VOC-Depreciation	thous. PV$
Net Benefit - Depreciation cost	Simulation- VOC-Depreciation	thous. PV$
Base Case - Safety cost	Simulation- VOC-Safety	thous. PV$
Alt Case - Safety cost	Simulation- VOC-Safety	thous. PV$
Net Benefit - Safety cost	Simulation- VOC-Safety	thous. PV$
Base Case - Environmental cost	Simulation- VOC-Environmental	thous. PV$
Alt Case - Environmental cost	Simulation- VOC-Environmental	thous. PV$
Net Benefit - Environmental cost	Simulation- VOC-Environmental	thous. PV$
Base Case - Project costs	Simulation- VOC-Project	thous. PV$
Alt Case - Project costs	Simulation- VOC-Project	thous. PV$
Net Cost - Project costs	Simulation- VOC-Project	thous. PV$

Glossary of Terms

Base Year

The base year is the year that precedes the start year of the period of analysis selected for the project.

Benefit-Cost Ratio

The benefit-cost ratio is a measure of economic worth. It is the present value of the project benefits divided by the present value of the project costs. The costs in the denominator include only the net resource expenditures required to build or maintain the highway infrastructure or otherwise provide highway services. All other effects (i.e., user costs, environmental costs, disruption costs of construction) are captured in the numerator of the benefit-cost ratio. If the benefit-cost ratio exceeds 1, then the project passes the benefit-cost test.

The benefit-cost ratio is a good measure of "bang for the buck", that is, benefits received for public dollar expended. However, its use to prioritize projects for funding should be undertaken carefully. In the case of projects or alternatives that are mutually exclusive, a project with a lower benefit-cost ratio may yield greater net benefit (i.e., higher NPV) and may be generally preferable than a project with a higher benefit-cost ratio. More information on this is available in the FHWA's Economic Analysis Primer.

Bins

(This pertains to the risk analysis features of *BCA.Net*.) The range for a simulation result variable, i.e., the values bounded by its minimum and maximum values, is divided into equal portions called bins.   The result value from each trial "falls" into one of these bins. Charting the result value's range on the horizontal axis and the probability of a result value falling in each of the bins yields the histogram chart.

Case (Base and Alternate)

A case is a set of assumptions regarding the decision variables of an agency affecting the provision of highway-related services. These decision variables will, in general, include options of whether, what, and when to build. However, a case could consider non-build management measures, like redirection of traffic or policies of taxing or tolling.

A benefit-cost analysis calculates the total present value of the transportation benefits and costs of the alternate case that are additional to the transportation benefits and costs of the base case. A well-specified "base case" will, in most circumstances, represent the set of maintenance and minor improvements that would most likely be undertaken in lieu of a major investment. The "alternate case" will typically represent an improvement involving a significant construction component.

In *BCA.Net* cases, base and alternate, are developed for each project segment in the **Project** page (Project>View>Base case and alternative case) by selecting a strategy and its year of implementation. A case may have more than one strategy. For instance, an alternate case for a segment may involve rehabilitating the facility in 2007 and adding lanes in 2015.

Cumulative Probability Distribution

(This pertains to the risk analysis features of *BCA.Net*.) A cumulative probability distribution is constructed by adding (or cumulating) the frequency of the probability density function. A cumulative probability distribution is an "upwardly sloping" curve, where each point on the curve gives the probability that the variable will be equal to or less than the value on the x-axis. The y-axis of the cumulative probability distribution ranges between 0 and 1. The cumulative probability distribution equals zero for a variable's minimum value and rises to 1 at a variable's maximum value.

De-Cumulative Probability Distribution

(This pertains to the risk analysis features of *BCA.Net*.) A de-cumulative probability distribution is constructed by subtracting (or de-cumulating) a variable's probability frequency starting with a probability of 1. A de-cumulative probability distribution is a "downward sloping" curve, where the curve gives the probability of the variable exceeding the value along the x-axis. The de-cumulative probability is 1 for a variable's minimum value and is 0 for its maximum value (i.e., the y-axis ranges between 1 and 0).

Deterministic

The term deterministic indicates that there is no uncertainty attributed to a given value, variable or model. Models that include random variables are called probabilistic or stochastic.

Dollar Values

Dollar values in the model are constant, base year dollars (also called "real dollars"). Present value dollars in the model are discounted to the end of the base year.

End Year

The end year is the last year of an analysis period. This is one of three years that the user must set in the Scenario view of the **Manage** page.

For example, suppose the analysis period of a benefit-cost analysis was twenty-five years and the near-term planning horizon was five years. If the start year is 2006, then the respective years of the analysis in this example would be:

Start Year	Last Year Near Term	End Year

2006	2010	2030

For each segment of a project, the user sets the forecast levels of traffic and traffic profiles for representative days in each of the three years. The base year for this analysis would be 2005, the year before the start year of the period of analysis.

In the benefit-cost analysis with *BCA.Net* the effects of improvements and their respective costs and benefits are measured in each year from the start year to the end year, inclusive. Benefits and costs in the analysis are discounted to the beginning of the start year (i.e., the end of the base year). The residual value of the project – which is the depreciated value of capital improvements at the end of the end year – is added to the benefit-cost summary as a benefit.

Histogram

(This pertains to the risk analysis features of *BCA.Net*.) A histogram shows the frequency of a discrete random variable and is used to display the frequency distribution of Monte Carlo simulation result variables. In a histogram, the result values are gathered in bins and the height of the bars correspond to the frequency with which values fall in the respective bins.

Kurtosis

(This pertains to the risk analysis features of *BCA.Net*.) Kurtosis is a statistical measure of a distribution's peakedness. Flatter distributions (with thin tails) are called platykurtic and peaked distributions (with fat tails) are called leptokurtic. The formula for kurtosis is:

$$\left(\frac{n(n+1)}{(n-1)(n-2)(n-3)} \frac{\sum_i (x_i - \overline{x})^4}{s^4} \right) - \frac{3(n-1)^2}{(n-2)(n-3)}$$

where $\overline{x}$ is the mean of the observations, s is the standard deviation, and n is the number of observations.

Last Year Near-Term

The last year near-term is the last year of near-term planning. This is one of three years that the user must set in the Scenario view of the **Manage** page.

For example, suppose the time horizon of a benefit-cost analysis was twenty-five years and the near-term planning horizon was five years. If the start year is 2006, then the respective years of the analysis in this example would be:

Start Year	Last Year Near Term	End Year
2006	2010	2030

In the benefit-cost analysis with *BCA.Net* the effects of improvements and their respective costs and benefits are measured in each year from the start year to the end year, inclusive. Benefits and costs in the analysis are discounted to the beginning of the start year (i.e., the end of the base year).

For each segment of a project the user sets the forecast levels of traffic and traffic profiles for representative days in each of the three years.

Latin Hypercube

(This pertains to the risk analysis features of *BCA.Net*.) Latin Hypercube is an alternative statistical sampling method to the Monte Carlo method. This is a stratified sampling method, which means that the range for each input variable is divided into strata and one random sample is taken from each stratum. This method ensures that low probability events are sampled in the simulation. It enables faster convergence to the result distribution than with the Monte Carlo sampling method.

Lower 10% Value

(This pertains to the risk analysis features of *BCA.Net*.) The lower 10% value is the 10th percentile value and is the lower limit of an 80% confidence interval as input by the user.

Mean Value

(This pertains to the risk analysis features of *BCA.Net*.) The mean value for a collection of observations of a random variable is its expected value and equals the sum of the observations divided by the number of observations. For skewed distributions, the mean value is off the median value and is located in the direction of the distribution's skew.

Median Value

(This pertains to the risk analysis features of *BCA.Net*.) The median value is the 50th percentile: there is equal probability that the value for a random variable will lie above or below the median.

Mode

(This pertains to the risk analysis features of *BCA.Net*.) The mode of a probability distribution is the value for which the probability density function is at a maximum. The value has the highest probability (and is sometimes called "the most likely value", not to be confused with the mean or expected value).

Monte Carlo

(This pertains to the risk analysis features of *BCA.Net*.) Monte Carlo is the method of sampling from random variables by taking a random number on the 0-1 interval , call it "a", and finding the value of the random variable whose cumulative probability equals a. Repeated Monte Carlo sampling on a number of random variables that are inputs to a model and repeatedly solving the model to arrive at probability distributions for the result variables is called Monte Carlo simulation.

Net Present Value

The net present value, NPV, of a project is the present value sum of benefits less the present value sum of costs over the period of analysis. The net present value is the principal measure of economic worth of a project. When NPV>0, the project passes the benefit-cost test.

Period of Analysis

(This is also called the time horizon or analysis period in the documentation). The period of analysis is the period during which the benefits and costs due to the effects of changes to the road infrastructure or traffic flowing on it are measured and compared. The period of analysis begins with the start year and ends with the end year. There may also be construction during the base year (the year that immediately precedes the start year) and these costs are included in the benefit-cost summary.

Present Value

The present value is a single number that expresses a future cost or benefit stream in terms of an equivalent value realized in the present. The formula for the present value is given as:

$$PV = \sum_{i=1}^{n} \frac{v_i}{(1+dr)^i}$$

where v_i is a value in the ith year of the analysis, dr is the discount rate and n is the number of years in the period of analysis.

Probability

(This pertains to the risk analysis features of *BCA.Net*.) Probability is the likelihood of the occurrence of a value or event.

Probability Density Function

This is the same as probability distribution.

Probability Distribution

(This pertains to the risk analysis features of *BCA.Net*.) A probability distribution or probability density function shows a continuous random variable's frequency of occurrence over its range.

Project

A project is a collection of one or more segments that are to be improved. The benefit-cost results summary aggregates the results from the segments in a project.

Random seed

(This pertains to the risk analysis features of *BCA.Net*.) The random seed is a number that initializes the generation of random numbers used in a Monte Carlo (or Latin Hypercube) simulation. For the same random seed and the same number of trials given no change in the model or inputs, the results of two Monte Carlo simulations will be identical.

Rate of Return

The project rate of return is an indicator of economic worth. The rate of return is equal to the discount rate that if applied to the stream of net benefits, would yield a

net present value of 0. If the rate of return exceeds the discount rate, then the project passes the benefit-cost test. The rate of return is useful in communicating benefit-cost results to laymen, because the metric somewhat resembles the return on a financial asset.

Some care is required in interpreting the rate of return, because in cases where the stream of net benefits changes sign more than once (e.g., goes from negative to positive and then back to negative), multiple rates of return may exist. This can occur, for instance, if there are multi-phased investments in the period of analysis.

Risk

(This pertains to the risk analysis features of *BCA.Net*.) The term refers to measured uncertainty in a forecast outcome. Colloquially, risk is often associated with undesirable or downside outcomes (as in "hedging against risk"). In a risk analysis, risk is reflected in the probability distributions of result variables.

Risk Analysis

Risk analysis is a term applied to several methods for quantifying uncertainty in forecasts. The risk analysis methods used in *BCA.Net* are called Monte Carlo simulation.

Scenario

A scenario is a collection of general data for use in the benefit-cost analysis. The scenario variables are organized into several groups: travel demand and traffic composition; social costs; project cost factors; prices; policy variables; and, non-transportation benefits. Users can assign fixed values or probabilistic ranges to each variable from the **Scenario** page. Probabilistic ranges are used as risk analysis inputs in the benefit-cost analysis. The scenario definition, which is set on the **Manage** page, includes the three analysis years: start year, last year near term and last year.

Segment

A segment is a specific highway facility that is uniform with regard to: 1) its physical and performance characteristics, and 2) traffic flowing on it. The data for a segment include: base year characteristics (i.e., length, number of lanes, maximum flow, grade, etc.); traffic profiles for each of three years (start year, last year near term, last year); and, a base and alternate case, each of which is a collection of improvement/maintenance strategies and their respective years of implementation. A project may consist of one or more segments.

Simulation

(This pertains to the risk analysis features of *BCA.Net*.) Simulation is a numeric method for finding solutions to analytically complex problems by "simulating" repeated, real world occurrences.

Skewness

(This pertains to the risk analysis features of *BCA.Net*.) Skewness is a measure of the asymmetry of a distribution. The probability density function of a skewed

distribution has a longer tail on its skewed side. A right skewed distribution has skewness greater than 0 and a left skewed distribution has skewness less than 0. The formula for skewness is:

$$\frac{n}{(n-1)(n-2)} \frac{\sum_i (x_i - \overline{x})^3}{s^3}$$

where $\overline{x}$ is the mean of the observations, s is the standard deviation and n is the number of observations.

Standard deviation

(This pertains to the risk analysis features of *BCA.Net*.) The standard deviation, which is the square root of the variance, is the principal descriptive statistic after the mean value. Knowing only a distribution's mean value and standard deviation, an upper bound can be found on the probability of any value in a variable's range. The standard deviation reported for the results is the sample standard deviation, given by the formula:

$$\sqrt{\frac{n \sum x^2 - \left(\sum x\right)^2}{n(n-1)}}$$

where n is the number of trials.

Start Year

The start year is the first year of an analysis. This is one of three years that the user must set in the Scenario view of the **Manage** page.

For example, suppose the time horizon of a benefit-cost analysis was twenty-five years and the near-term planning horizon was five years. If the start year is 2006, then the respective years of the analysis in this example would be:

Start Year	Last Year Near Term	End Year
2006	2010	2030

For each segment of a project the user sets the forecast levels of traffic and traffic profiles for representative days in each of the three years.

The start year is the first year in which an analysis may register differences between the base and the alternate cases. The start year is the year following the base year for the analysis. In the benefit-cost analysis with *BCA.Net* the effects of improvements and their respective costs and benefits are measured in each year from the start year to the end year, inclusive. Benefits and costs in the analysis are discounted to the beginning of the start year (which is equivalent to the end of the base year).

Strategy

A strategy is an improvement or maintenance program. Strategies are referenced in the base and alternate cases of project segments. In *BCA*.Net, a strategy is independent of a project and can be deployed in more than one project or project segment.

There are three components to a strategy: effects; traffic signals and devices; and, costs. The effects of a strategy are the target facility characteristics (i.e., maximum flow, number of lanes, improved pavement condition, etc.) that result from an improvement (or, represent the presumed facility status under a specified maintenance regime).

The costs of a strategy include a multi-year cost schedule that specifies: right-of-way (ROW) costs; capital improvement costs; and, anticipated costs of disruption due to construction. The multi-year cost schedule begins at Year 1 and can extend up to Year 7. Year 1 of the multi-year schedule is the year of implementation that is specified in the project segment case that deploys the strategy. Strategy costs also include an annual "O&M" cost and "other lifecycle" cost.

Strategy costs (ROW, Capital, Disruption, O&M and Other Lifecycle) are in thousands of constant base year dollars. When specifying costs, the user can specify the cost units as one of the following: total costs for the segment, costs per facility-mile, or costs per lane-mile.

An investment strategy is one that has non-zero capital costs in at least one year. The effects of an investment strategy are realized in the year following the last year of non-zero investment. From the year in which strategy effects are realized, "O&M Costs" and "Other Lifecyle Costs" recur in each year. These costs replace the costs from the base year facility characteristics or from strategies implemented in the case in previous years. Care should be taken to assure that the base year facility characteristics data are compatible with the data specified for O&M Costs and Other Lifecycle Costs" in the strategies.

The effects associated with a non-investment strategy are immediate in the year of implementation. "O&M Costs" and "Other Lifecycle Costs" recur in each year from the year of implementation. These costs replace the costs from the base year facility characteristics or from strategies implemented in previous years.

Traffic Distribution

The traffic distribution describes the intensity of traffic during three different periods of the day: Peak, peak shoulder and off-peak. The traffic distribution specifies the percent of daily traffic per hour in each period (the user specifies the peak and peak shoulder while the off-peak is calculated as the remaining traffic). Additionally, the traffic distribution includes a specification of the percent of traffic in the direction of greater flow – a value between 50 and 100. The traffic distributions are specified in the **Parameters** page of *BCA.Net*.

Traffic Profile

A traffic profile describes a representative day of traffic on a segment for each of the three years – start year, last year near-term and end year. A segment may have one or several traffic profiles, depending on whether traffic varies by time of week (e.g., weekday vs. weekend) or time of year (e.g., tourist season).

For each year, the traffic profile includes a percent of total days in the year and, a percent of annual traffic. If there is only one traffic profile for the segment, then these values must equal 100 for that profile. If there are several traffic profiles in a segment, then the sum of the percent of total days and the percent of annual traffic must each sum to 100. Traffic profiles are specified in the **Project** page of *BCA.Net*.

The traffic profile also specifies the duration of each of the travel periods, peak and peak shoulder, in hours. For each of the three vehicle types (auto, truck, bus) the user specifies the traffic distribution for each.

Note that daily traffic profiles are converted to annual traffic levels in the by means of the "Annualization Factor", which is specified in the "Travel demand and travel composition" data group on the **Scenario** page.

Trial

(This pertains to the risk analysis features of *BCA.Net*.) A trial is one solution of a model in a simulation. A simulation consists of many trials. In each trial, every input variable is populated with a data value sampled from the variable's probability distribution.

Upper 10% Value

(This pertains to the risk analysis features of *BCA.Net*.) The upper 10% value is the 90th percentile of a probability distribution and the upper limit of an 80% confidence interval.

Variable

(This pertains to the risk analysis features of *BCA.Net*.) A variable is a model element that can be assigned more than one value. A fixed-value input variable can assume only one value. A random variable can assume a range of values according to its probability distribution.

Variance

(This pertains to the risk analysis features of *BCA.Net*.) The variance is a measure of the dispersion of values in a probability distribution, and is a measure of risk. The variance is the average of the squared deviations about the mean. The variance gives disproportionate weight to "outliers," values that are far away from the mean. The variance is the square of the standard deviation.

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