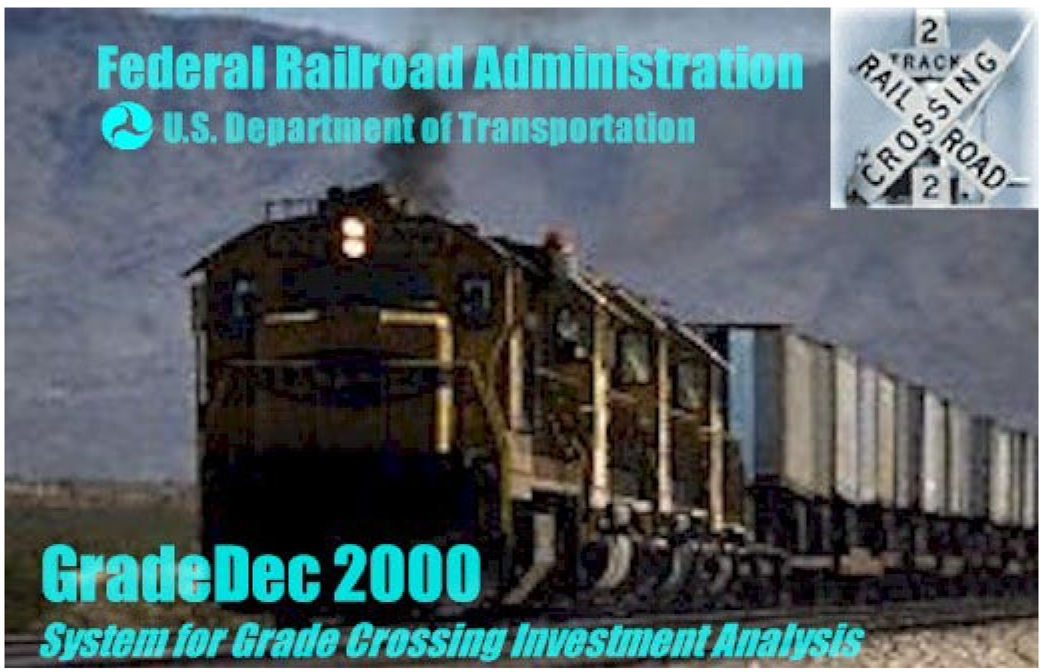
GradeDec 2000 version 2.0

Reference Manual

Federal Railroad Administration



Office of Policy and Program Development

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Introduction

GradeDec 2000

Description and Objective

The Federal Railroad Administration (FRA) developed *GradeDec 2000* as an investment decision support tool for use by state and local authorities. The careful analysis and selection of highway-rail grade crossing investments serves to increase public returns for each dollar invested.

GradeDec 2000 is a stand-alone, software package that enables the analysis of impacts from grade crossing improvements and supports resource allocation and investment decisions. It allows state and local decision makers to prioritize highway-rail grade crossing investments based upon an array of benefit-cost measures. *GradeDec 2000* evaluates the benefit-cost of grade crossing improvements while explicitly reporting the results for each grade crossing and each benefits category (safety, time savings, vehicle operating costs, reduced emissions, network and local benefits). Localities can use *GradeDec 2000* to focus on the benefit metric of greatest local interest. For instance, an area marked by high levels of highway congestion at grade crossings can identify the improvements that offer the prospects for congestion mitigation. For a rural area with acute safety issues, *GradeDec 2000* assists in identifying the investments that will promote accident reduction.

GradeDec 2000 facilitates a structured analysis. The analysis process in *GradeDec 2000* is as important as the end result. *GradeDec 2000* can be useful as a tool for managing data and partial analyses and does not require that users address all of its features. For instance, users can import data and conduct safety analyses without defining alternatives and running a full investment analysis.

A *GradeDec 2000* investment analysis finds the economic rate of return for a specified program of highway-rail grade crossing investments in a corridor or region. The economic rate of return 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, i.e., reductions in accidents and emissions, time and vehicle operating cost savings. *GradeDec2000* calculates the economic rate of return 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 cost realized in different time periods.

GradeDec 2000's analysis of grade crossing improvements is both at the individual grade crossing and at the corridor or regional level. Outputs include result metrics for the individual grade crossings and for the corridor or region as a whole. A series of up to 600 grade crossing improvements can be evaluated simultaneously. *GradeDec 2000* also reports an array of intermediate result metrics that are useful in interpreting the results.

GradeDec 2000's underlying methodology is consistent with the current benefit-cost methodologies employed by United States Department of Transportation Agencies (Federal Railroad Administration, Federal Highway Administration, Federal Transit Administration, and Federal Aviation Administration) and with Executive Order 12893, which governs the principles of federal infrastructure investment. 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.

GradeDec 2000 integrates several modeling capabilities in a single package. It includes separate modeling modules for corridor and regional analysis. The corridor analysis module evaluates crossing improvements along a single rail alignment. The corridor analysis accounts for impacts on the adjacent highway network and shifts in highway to routes with improved crossings. The module for regional analysis evaluates crossing improvements in a region (county or several counties) regardless of the crossings being located on a single or multiple rail alignments.

Both the corridor and the regional analysis modules of *GradeDec 2000* include the US DOT Accident Prediction and Severity Model. The corridor analysis module includes as well the grade crossing risk mitigation model for high speed rail that was developed by the Volpe National Transportation Systems Center.

GradeDec 2000 includes a risk analysis modeling capability. This capability enables the user to accommodate the numerous uncertainties that are inherent in any forecast. Rather than relying on "best guess" inputs whose actual values may vary widely, risk analysis incorporates input ranges. For a designated set of operational and policy variables in *GradeDec 2000*, 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. *GradeDec 2000* includes a graphical interface that facilitates data entry and the visualization of probability distributions. *GradeDec 2000* 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.

GradeDec 2000 represents a major upgrade from the previous release of GradeDec. It incorporates additional analytic algorithms and handles many more grade crossings simultaneously. *GradeDec 2000* strives to meet the needs of both experienced and novice users. Experienced analysts can take advantage of newer features and capabilities while less experienced analysts can rely upon pre-defined default values and should find *GradeDec 2000* easy to use for conducting an analysis.

About This Document

This document is the reference for the *GradeDec 2000* model. The remainder of this document presents the model components, the computation algorithms, and descriptions of the data inputs to the model.

In order to best utilize the *GradeDec 2000* model you should refer to the companion volume to this document called "User's Manual for *GradeDec 2000"*.

This document is not a benefit-cost analysis manual. It assumes that readers are generally familiar with benefit-cost analysis, its application and some basic concepts like present value and rate of return. Useful references for using benefit-cost analysis can be found in NCHRP Report No. 342, the AASHTO Redbook and Transport Canada's Benefit-Cost Manual.

Model Overview

Introduction

GradeDec 2000 is a grade crossing investment analysis tool that includes both a platform for organizing the data for your analysis and a computational risk analysis model. This Overview presents the frame of analysis, the computational model and the data and their organization.

The Analysis Frame of GradeDec 2000

The analysis frame of *GradeDec 2000* considers a proposed set of grade crossing investments on a rail corridor, or a region, over a specified time horizon. The analysis of benefits and costs compares the present value of costs and benefits in the "alternate case" (with investment) to the costs and benefits in the "base case" (without investment).

The following are the definitions and assumptions for the *GradeDec 2000* analysis frame:

Grade Crossing Investments

A grade crossing investment is a one-time, capital outlay or set of measures that transforms grade crossings in a corridor or region in any of the following ways.

- **Grade crossing device type change**, where "types" are passive, lights, gates, "new technology"[1] and, as well, closure or grade separation.
- **Additions of supplementary measures to gated crossings.** These supplementary measures include: four quadrant gates without detection, four quadrant gates with detection, four quadrant gates with

[1] New technology is a placeholder type for any prospective new device or combination of devices. The user can set a parameter that determines the effectiveness of the new technology relative to a gated crossing.

60 feet medians, mountable curbs, barrier curbs, one-way streets, and photo enforcement.

- **Changes to highway traffic flows in a corridor** using traffic management measures like signage and signaling intended to re-assign traffic away from high-exposure/high-risk crossings during peak exposure periods of the day.

The device type, supplementary measures and traffic management measures at grade crossings determine in the analysis the expected number of accidents and their severity. When proposed investments include grade crossing closures and separations, *GradeDec 2000* evaluates any additional re-allocation of traffic that is likely to occur.

Base Case and Alternate Case

The Base Case represents the "no investment" scenario. In the Base Case, the analysis evaluates the operational impacts and associated benefits and costs over the time horizon of the analysis with the assumption of no investment. Strictly speaking, an analysis may (and should) include a program of modest investments in the Base Case if these investments are part of a minimal fall back position and are most likely to be undertaken regardless of the decision on the more extensive investments.

In the Alternate Case, the analysis evaluates the benefits and costs under the assumption that the proposed investments have been implemented.

In *GradeDec 2000* the following parameters are set for each of the two cases:

- Type of each grade crossing
- Supplementary measures at gated crossings
- AADT at crossings (which are the same for both cases unless the improvement program specifically includes traffic management measures for re-assigning traffic)
- Accident rates by severity
- O&M and other lifecycle costs
- Capital investment (alternate case only).

Corridor or Region

GradeDec 2000 evaluates a collection of grade crossings in a single analysis. The user must select whether to include the crossings for evaluation in a corridor or in a region. *GradeDec 2000* has a separate analytic model for corridors and for regions. The corridor model provides greater analytic depth than the regional model. The following features are available in the corridor model, but not in the regional model:

Choice of high speed rail model or DOT model for accident prediction and severity,

- Re-assignment of highway traffic at grade separated or closed crossings,

- Estimation of benefits from a reduction in delay on the adjacent highway network.

If the crossings for evaluation lie on a single rail alignment, then the user should use the corridor model. On the other hand, if the candidate crossings for improvement span several alignments and are grouped in a region, then the user should use the regional model. *GradeDec 2000* is able to extract data directly from the National Grade Crossing Inventory database, or other external source, and import the data directly into a corridor or region

The Corridor

The rail corridor is a single, continuous alignment of one or more railroad tracks. The corridor may include up to 600 grade crossings that are candidates for improvement. The *GradeDec 2000* model characterizes the rail corridor by several parameters:

- The average daily number of trains by type (passenger, freight and switch) in the base year (see definition below).
- The time-of-day distribution of rail traffic (there are five pre-defined, time-of-day traffic distributions)
- A Boolean (yes/no) flag that specifies whether grade crossing closings are synchronized with the highway traffic signaling system in the corridor.
- A factor for technology improvement. New technologies include non-conventional barriers and systems that provide timely notification to approaching trains of vehicle intrusion. Due to the absence of historical data on the performance of devices of these types, GradeDec 2000 does not provide historically based estimates of new technology impacts. Values supplied for this factor represent the analyst's best judgment regarding the likely impact of new technology relative to conventional flashing lights and gates closure. For instance, a value of 0.5 for this factor will reduce by half the accident risk relative to flashing lights and gates.

The corridor model analysis evaluates the impacts of closures and separations along the rail corridor. For closed crossings in the alternate case, the highway traffic from the crossing is re-allocated to adjacent crossings in the corridor. For grade separation improvements, the model estimates the attracted traffic to the grade separated crossing from adjacent crossings (see sections below on traffic re-assignment).

In addition to time savings benefits for highway vehicles at the crossing, the corridor model calculates the impact of reduced queuing at the crossings on highway network delays

The Region

The regional analysis considers crossings in a geographic region: a county, several counties or any collection of crossings that may or may not be part of a common alignment. The regional analysis does not account for any re-assignment of highway traffic in the event of closure or separation. Because there is no accounting for re-allocated traffic if a crossing is closed, the analyst needs to specify a parameter in the crossing data entry that indicates the percent reduction in user costs for the closed crossing. See the discussion on this parameter ("percent benefits at closed crossing") in the data entry section.

Like a corridor, a region can include for analysis up to 500 grade crossings.

While a regional analysis provides less depth, the analyst can import most of the required data directly for a designated region from the National Grade Crossing Inventory Database (provided with the *GradeDec 2000* package).

The Time Horizon

The time horizon of a GradeDec 2000 analysis is determined by the "start year" and "end year" values of the input scenario. The analysis assumes that all investments in the corridor are executed in "year 0" (the base year) and that benefits accrue beginning in "year 1" (start year). For instance, if a scenario has start year 2001 and end year 2024 then the model assumes investments in the corridor have been completed by the end of 2000 (the base year) and are fully operational from the beginning of 2001. Benefits from the investment will accrue in the alternate case beginning in year 2001. The analysis assumes that benefits and costs are realized at year end. The "present value" calculation converts dollar values over the time horizon of the proposed investments to their equivalent dollar value at the beginning of the start year (i.e., benefits in the start year are discounted).

There are separate growth rate parameters in the model for the "near term" and the "far term". In many cases, planners face differing 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, *GradeDec 2000* 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". The last year of near term is a year between the start year and end year. For instance, if the start year is 2001 and the last year is 2024, the last year of near term could be 2005. From the start year until and including the last year of near term, the model applies the near term growth rates for highway and rail traffic. From the year following the last year of near term and until the last year of the analysis, the model applies the far term growth rates.

Costs and Prices

The calculations of *GradeDec 2000* assume constant dollar values and that relative prices, with the exception of fuel and oil, remain fixed over the time horizon of the investment. 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 necessary in order to calculate the constant dollar price of fuel and oil. Fuel (and oil) is singled out due to the volatility of fuel prices. The fuel and oil cost will likely fluctuate in comparison to other prices. In *GradeDec 2000*, 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.

The GradeDec 2000 Computational Model

GradeDec 2000 includes the following analytic components:

- Re-assignment of highway traffic due to closures and grade separation (corridor model only)
- Calculation of safety benefits through predicted accidents and severity in the base and alternate cases
- Calculation of other benefits from crossing improvements
- Present value and benefit-cost summary including consumer surplus calculation for the corridor or region

For the estimation of safety benefits *GradeDec 2000* employs one of two different computational models depending upon the user's selections. These are:

- **U.S. Department of Transportation (DOT) Accident Prediction and Severity Model (APS) and Resource Allocation Method**
- **Volpe National Transportation System Center (VNTSC) High-Speed Rail (HSR) Accident Severity Model**

When using the corridor model, the user can choose which of the two models to use. For the regional model, only the DOT APS model is available. Both models estimate predicted accidents by severity category for the base case and alternate case. The difference between the quantities of incidents is then monetized (i.e., multiplied by a unit cost per incident) and summed by grade crossing and year to arrive at annual safety benefits.

In the DOT APS the incident metrics are "fatal accidents" (accidents with at least one fatality), "injury accidents" (accidents with no fatalities and at least one injury), and "property damage only" accidents. The HSR model estimates fatalities and injuries for both the highway and rail modes while examining casualties for different types of accidents and their probabilities of occurrence.

The following sections describe how the two safety models are integrated with the modes of usage of *GradeDec 2000*.

The DOT Accident Prediction and Severity Model (APS) and the Resource Allocation Method

This model is described in the document *Summary of the DOT Rail-Highway Crossing Resource Allocation Procedure-Revisited,* Office of Safety, Federal Railroad Administration, June 1987, Report No. DOT/FRA/OS-87/05. The model includes three components: a formula for accident prediction, a formula for severity prediction and a model for resource allocation. The formulas for accident prediction and severity are based upon regression analyses of accidents and grade crossing characteristics. APS is applied in *GradeDec 2000* as described in the above document with one modification: *GradeDec 2000* corrects for the correlation between time-of-day distribution between rail and highway traffic.

The DOT method for resource allocation estimates the safety at crossings after improvement by applying "effectiveness multipliers" to the base case APS model results. These multipliers were derived from separate analyses of grade crossings and improvements. *GradeDec 2000* uses the resource allocation method in the corridor model (when the DOT APS model is chosen and not the HSR model) only in cases where there is no re-assignment of highway traffic at a crossing due to closures or separation. When average annual daily traffic changes at a crossing from the base to alternate case due to re-assignment, then the DOT APS is reapplied to the improved crossing characteristics and the new level of highway traffic.

The DOT APS formulas and the resource allocation method are always used in the regional model, using the same correction as the corridor model for correlation of time-of-day traffic distribution on the rail and highway modes.

The VNTSC High Speed Rail Accident Severity Formulas

The HSR model is an optional feature of the corridor model in *GradeDec 2000*. The model used follows procedure described in *Assessment of Risks for High Speed Rail Grade Crossings on the Empire Corridor*, Mark Mironer and Michael Coltman, High Speed Ground Transportation Division, VNTSC, April 1998. This model uses the same accident prediction methodology as the DOT model, but has distinct accident severity formulas. The model is based on an analysis of grade crossing accidents while focusing on the accident types (train strikes vehicle, vehicle strikes train), the impact of severe derailment and fatalities among train as well as highway vehicle occupants. Unlike the DOT APS formulas, the HSR formulas are sensitive to train speed.

The following table presents a summary of *GradeDec 2000* features according to mode of usage:

Table 1 GradeDec 2000 Computation Model Features by Mode of Usage

	Corridor		Region
	DOT Accident Prediction and Severity Model	**HSR Accident Severity Model**	**DOT Accident Prediction and Severity Model**
Re-assignment of highway traffic with closure?	Yes	Yes	No, user sets percent of benefits with closure
Re-assignment of highway traffic with grade separation?	Optional	Optional	No
Application of DOT resource allocation method?	Yes, only if no change in AADT between base and alternate cases	No	Yes
Calculation of train fatalities?	No	Yes	No
Calculation of network delay impact from queuing at crossing?	Yes	Yes	No
Accounting for signal synchronization?	Yes	Yes	No
	For all GradeDec 2000 Models		
Calculation of safety benefits, time savings, vehicle operating cost and emissions reduction at crossings?	Yes		
Calculation of consumer surplus for corridor/region and benefits summary?			
Reporting of benefits breakout by crossing and benefits category?			
Charting of ranked safety risk by crossing in corridor or region?			
Ranking of benefit-cost of results by crossing?			
Advanced data access and management?			
Risk analysis using either Monte Carlo or Latin Hypercube simulation?			
Risk sensitivity analysis and tornado charts?			
Choice of three probability distributions for inputs?			
Visualization of input probability distributions with charts and tables?			
Cumulative, de-cumulative and histogram charts for all results?			
Reports generator for results, scenarios, corridor/region?			

Data and Data Organization in GradeDec 2000

This section provides a brief overview of data and their organization in *GradeDec 2000.* Data are organized into elements that correspond to their function in the model.

The four principal data elements are:

- Corridor or region data
- Grade crossing data
- Scenario (risk analysis) data
- Model parameter and default data

The corridor data include the corridor-level data covering base year rail operations, rail time-of-day traffic distribution, and a toggle designating whether there is grade crossing signal integration with the neighboring highway network. Corridor data also includes a technology parameter that represents the impact of a new technology crossing relative to a conventional gated crossing. The data for a region includes its description and technology parameter, while the rail characteristics are included in the crossing data.

The grade crossing data include the physical characteristics of the grade crossing, crossing type for base and alternate case, accident rates and cost data. Accident rates are stored with the crossing data for exposition purposes only. Predicted accidents are recalculated for each year of the evaluation when a simulation is run.

The scenario data include the policy variables and forecast values that are necessary for generating the forecast streams of benefits and costs. These data are organized into four data sets: rail operations, highway, social costs and price indexes.

The data tables include technical coefficients for fuel burn and emission rates. They also contain the default data for capital costs, time-of-day traffic distributions and the model parameters for the high speed rail accident severity model. The user can edit and modify all of the data and parameters described in this section.

The Model

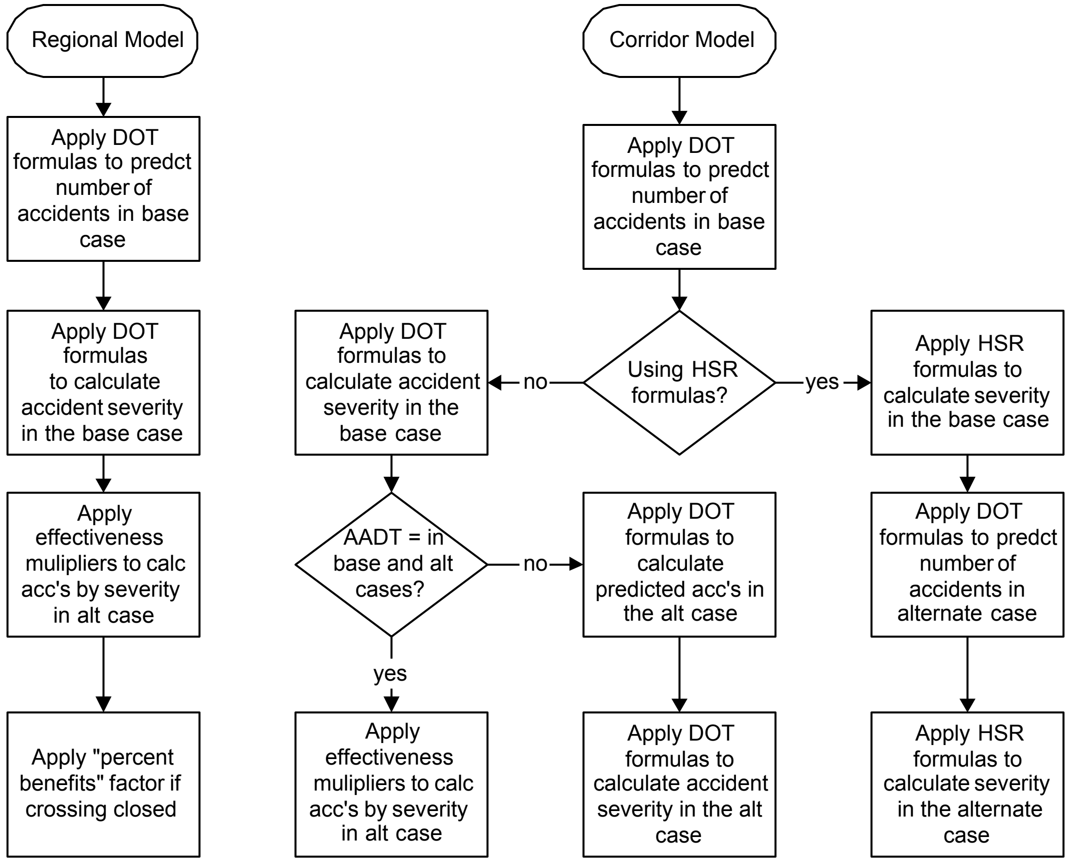
Introduction

This section presents the computational model that was discussed in the "Model Overview". For each model component, explanations and formulas are provided. The following section covers the data and data organization of *GradeDec 2000*.

Accident Prediction and Severity

The accident prediction and severity formulas in GradeDec 2000 are based upon the two sources cited in the introduction. These equations are applied in accordance with the mode of usage (corridor or regional model). In the corridor model, the user can specify whether to use the HSR formulas or the DOT formulas. Moreover, in the corridor model the alternate case calculation of accident prediction and severity will depend upon whether grade crossing improvements in the corridor, through closures and/or separation, result in re-allocation of highway traffic among crossings. The procedure by which GradeDec 2000 applies the different formulas is shown in the following figure.

Figure 1 Application of Accident Prediction and Severity Formulas



The following sections describe the accident prediction and severity equations in *GradeDec 2000.*

Forecast Highway and Rail Traffic

GradeDec 2000 forecasts average daily highway traffic, by vehicle type, and number of trains, by train type, at each crossing based on base year traffic and traffic rates of growth for the near and the far term.

The formula for the highway traffic forecast at a crossings is:

Equation 1 Average Annual Daily Traffic (Highway) at Crossing

$$AADT_{year} = AADT_{year-1} \cdot \left(1 + \frac{AADTgr}{100}\right)$$

$$AADTgr = \begin{cases} AADTntgr, \text{ if } year \le lynt \\ AADTftgr, \text{ if } year > lynt \end{cases}$$

$$AADT_{year,vtype} = \beta_{vtype} \cdot AADT_{year}$$

where:

year	the current year of the analysis
$AADT_{year}$	average annual daily traffic in current year (all vehicle types)
$AADT_{year-1}$	average annual daily traffic in previous year (all vehicle types)
AADTgr	annual growth rate of AADT, percent
AADTntgr	annual growth rate of AADT in near term, percent
AADTftgr	annual growth rate of AADT in far term, percent
lynt	last year of near term
vtype	vehicle type (i.e., auto, truck or bus)
β_{vtype}	share vehicle type of total highway traffic
$AADT_{year,vtype}$	average annual daily traffic in current year by vehicle type

Equation 2 Average Daily Trains at Crossing

$$TV_{year} = TV_{year-1} \cdot \left(1 + \frac{TVgr}{100}\right)$$

$$TVgr = \begin{cases} TVntgr, \text{ if } year \le lynt \\ TVftgr, \text{ if } year > lynt \end{cases}$$

$$TV_{year,ttype} = TV_{year} \cdot \frac{tvb_{ttype}}{\sum_{ttype} tvb_{ttype}}$$

where:

year	the current year of the analysis
TV_{year}	average daily trains in current year (all train types)
TV_{year-1}	average daily trains in previous year (all highway vehicle types)
TVgr	annual growth rate of average daily trains
TVntgr	annual growth rate of average annual daily trains in near term
TVftgr	annual growth rate of average annual daily trains in far term
lynt	last year of near term
ttype	train type (i.e., passenger, freight, switch)
tvb_{ttype}	trains in base year by type
$TV_{year, ttype}$	average daily trains in current year by type

Exposure and Correlation of Time-of-Day Distributions by Highway and Rail

The principal explanatory factor for predicting accidents at grade crossings is exposure. Exposure is the probability that a train and a highway vehicle will both arrive at a grade crossing at the same time, thus allowing for the possibility of an accident. Exposure, and the effects of grade crossings improvements, will vary significantly depending upon whether the time-of-day distributions of rail and highway traffic are highly correlated (temporal match), or, are highly uncorrelated (temporal mismatch). As an extreme example, if all rail traffic was at night while all highway traffic was by day there would be no risk of accidents and no vehicles would ever stand waiting at a closed crossing.

The two safety models used in *GradeDec 2000* do not account for the correlation between the time-of-day distributions of rail and highway traffic. *GradeDec* 2000 incorporates a modification to correct for this and requires that the user specify the time-of-day traffic distribution for the rail corridor, or in the case of the regional model, the user specifies the rail traffic time-of-day distribution for each crossing. The user also specifies the time-of-day distribution of highway traffic at each crossing for each of three traffic segments: car, truck and bus.

The distributions in *GradeDec 2000* divide the daily traffic into four six-hour periods. The user interface of *GradeDec 2000* lets the user select from among five pre-set traffic distributions. These are labeled: uniform, peak AM, peak PM, day flat and night flat.

Figure 2 Traffic Distribution Profiles

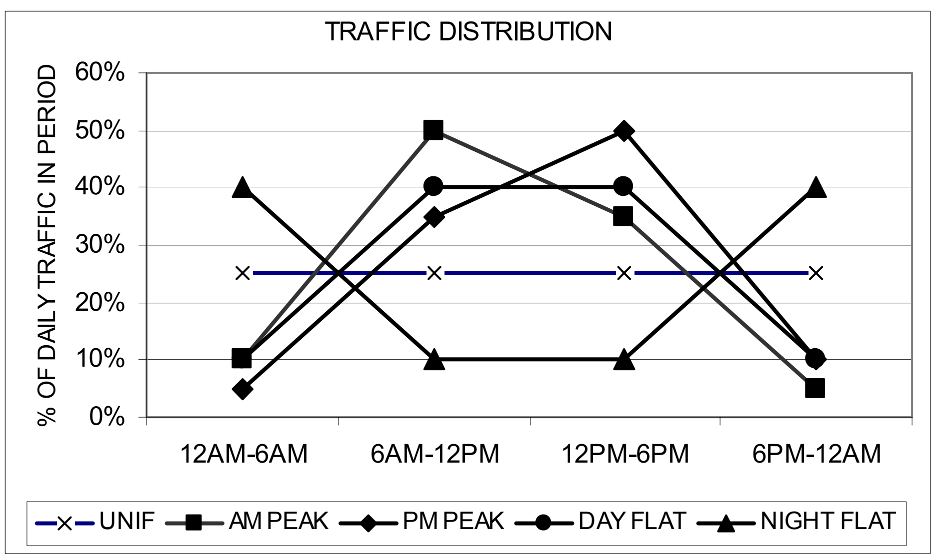


Table 2 Traffic Distribution Profiles (Share of Daily Traffic in Period)

	Uniform	AM Peak	PM Peak	Day Flat	Night Flat
12AM-6AM	**0.25**	**0.10**	**0.05**	**0.10**	**0.40**
6AM-12PM	**0.25**	**0.50**	**0.35**	**0.40**	**0.10**
12PM-6PM	**0.25**	**0.35**	**0.50**	**0.40**	**0.10**
6PM-12AM	**0.25**	**0.05**	**0.10**	**0.10**	**0.40**

The above time-of-day distributions are default values. These values can be changed by the analyst so as to more accurately correspond to time-of-day travel patterns in the corridor or region under consideration.

The degree of exposure is captured in the benefits evaluation by the exposure correlation factor that is given by the following equation:

Equation 3 Time-of-Day Exposure Correlation Factor

$$EF = \frac{\sum_i \left(a_i \sum_j \beta_j b_{ij} \right)}{Max\left(\sum_i a_i^2 \ , \sum_i \sum_j \left(\beta_j b_{ij}\right)^2 \right)}$$

where:

i	an index designating the time-of-day periods (early AM, late AM, early PM, late PM)
j	an index of highway vehicle type (auto, truck, bus)
a_i	the share of daily trains at the crossing in the ith time-of-day period
b_{ij}	the share of daily traffic of vehicle type j in the ith time-of-day period
β_j	the share of vehicle type j in daily highway traffic
Note:	$\sum_i a_i = 1, \quad \sum_i b_{ij} = 1, \quad \sum_j \beta_j = 1,$

GradeDec 2000 calculates the exposure correlation factor for each crossing and year of the evaluation.

GradeDec 2000 integrates with the DOT Accident Prediction formula by calculating the daily exposure equivalent that would be realized if the time-of-day correlation of traffic at the grade crossing equaled the national average. That "national average" is the average correlation that is reflected in the sample that served as the basis for the estimation of parameters in the DOT model. *GradeDec 2000* calculates the exposure correlation factor for each crossing and year of the evaluation.

Equation 4 Daily Exposure with Time-of-Day Correlation

$$Expose = 1.35 \cdot EF \cdot AADT_{year} \cdot TV_{year}$$

where:

Expose	base year daily exposure with time-of-day correlation, effective daily exposures
EF	time-of-day exposure correlation factor (see equation 3 above)
AADT	average annual daily traffic on the highway at the crossing

TV average daily trains at the crossing

The value 1.35 in the above equation means that if there was full time-of-day correlation between the rail and highway modes at the crossing, then there would 35 percent more exposure than if the correlation were equal to the national average[2]. *GradeDec 2000* calculates the daily exposure with time-of-day correlation for each crossing and year of the evaluation.

Predicted Number of Accidents

The predicted number of accidents at a crossing is based upon the DOT Accident Prediction and Severity formulas. The predicted number of accidents is calculated for each crossing in each year (for the base case and sometimes for both base and alternate cases – see Figure 1 above). Note that when using the DOT Accident Prediction and Severity model, the predicted number of accidents is normalized to account for the accident history at the crossing (N is the number of accidents at the crossing in the previous five years). However, when using the HSR model, the accident history is not included as part of the formula.

Equation 5 Predicted Number of Accidents at the Crossing

$$a = k \cdot EI \cdot DT \cdot MS \cdot MT \cdot HL \cdot HP$$

$$T_0 = \frac{1}{0.05 + a}$$

$$NA = \begin{cases} \dfrac{(a \cdot T_0) + N}{T_0 + 5} \cdot Adj & \text{, for DOT formulas} \\ a \cdot Adj & \text{, for HSR formulas} \end{cases}$$

[2] **35% is the opinion of a surveyed expert regarding this factor's likely value.**

where:

	Type of Grade Crossing			
	Passive	Flashing Lights	Lights and Gates	New Technology
K	.0006938	.0003351	.0005745	.0001915
EI	$\left[\frac{\text{Expose}+0.2}{0.2}\right]^{0.37}$	$\left[\frac{\text{Expose}+0.2}{0.2}\right]^{0.4106}$	$\left[\frac{\text{Expose}+0.2}{0.2}\right]^{0.2942}$	$\left[\frac{\text{Expose}+0.2}{0.2}\right]^{0.2942}$
DT	$\left[\frac{\text{dthru}+0.2}{0.2}\right]^{0.1781}$	$\left[\frac{\text{dthru}+0.2}{0.2}\right]^{0.1131}$	$\left[\frac{\text{dthru}+0.2}{0.2}\right]^{0.1781}$	$\left[\frac{\text{dthru}+0.2}{0.2}\right]^{0.1781}$
MS	$e^{0.0077 \cdot \text{ms}}$	1	1	1
MT	1	$e^{0.1917 \cdot \text{tracks}}$	$e^{0.1512 \cdot \text{tracks}}$	$e^{0.1512 \cdot \text{tracks}}$
HL	1	$e^{0.1826 \cdot (\text{lanes}-1)}$	$e^{0.142 \cdot (\text{lanes}-1)}$	$e^{0.142 \cdot (\text{lanes}-1)}$
HP	$e^{-0.5966 \cdot (\text{paved}-1)}$	1	1	1
Adj	0.7159	0.5292	0.4921	0.4921*Tech Factor

and,

N	number of accidents in previous five years at grade crossing
Expose	daily exposure with time of day correlation, see equation 4 above
dthru	number of day through trains per day
ms	maximum timetable speed at crossing, miles per hour
tracks	number of main tracks
lanes	number of highway lanes
paved	if highway is paved, Paved =1, if unpaved then Paved=2
k, Adj	regression coefficients
NA	predicted number of accidents per year at the grade crossing

Number of Accidents by Severity Category – DOT Formulas

The DOT Accident Severity formulas predict the number of fatal accidents (accidents with at least one fatality) and the number of casualty accidents (accidents with at least one fatality or injury). *GradeDec 2000* calculates the number of injury accidents (accidents with at least one injury, but no fatality) as the number of casualty accidents less the number of fatal accidents. Property damage only accidents are calculated as predicted accidents less casualty accidents.

The numbers of accidents by severity category are calculated from the following equation:

Equation 6 Predicted Number of Accidents at GCX by Severity Category (DOT Formulas)

$$KF = 440.9$$

$$MS = ms^{-0.9981}$$

$$TT = (thru + 1)^{-0.0872}$$

$$TS = (switch + 1)^{0.0872}$$

$$UR = e^{0.3571 \cdot urban}$$

$$KC = 4.481$$

$$MS_{CA} = ms^{-0.343}$$

$$TK = e^{0.1153 \cdot tracks}$$

$$UR_{CA} = e^{0.2960 \cdot urban}$$

$$FA = \frac{NA}{1 + KF \cdot MS \cdot TT \cdot TS \cdot UR}$$

$$CA = \frac{NA}{1 + KC \cdot MS_{CA} \cdot TK \cdot UR_{CA}}$$

$$IA = CA - FA$$

$$PA = NA - FA - IA$$

where:

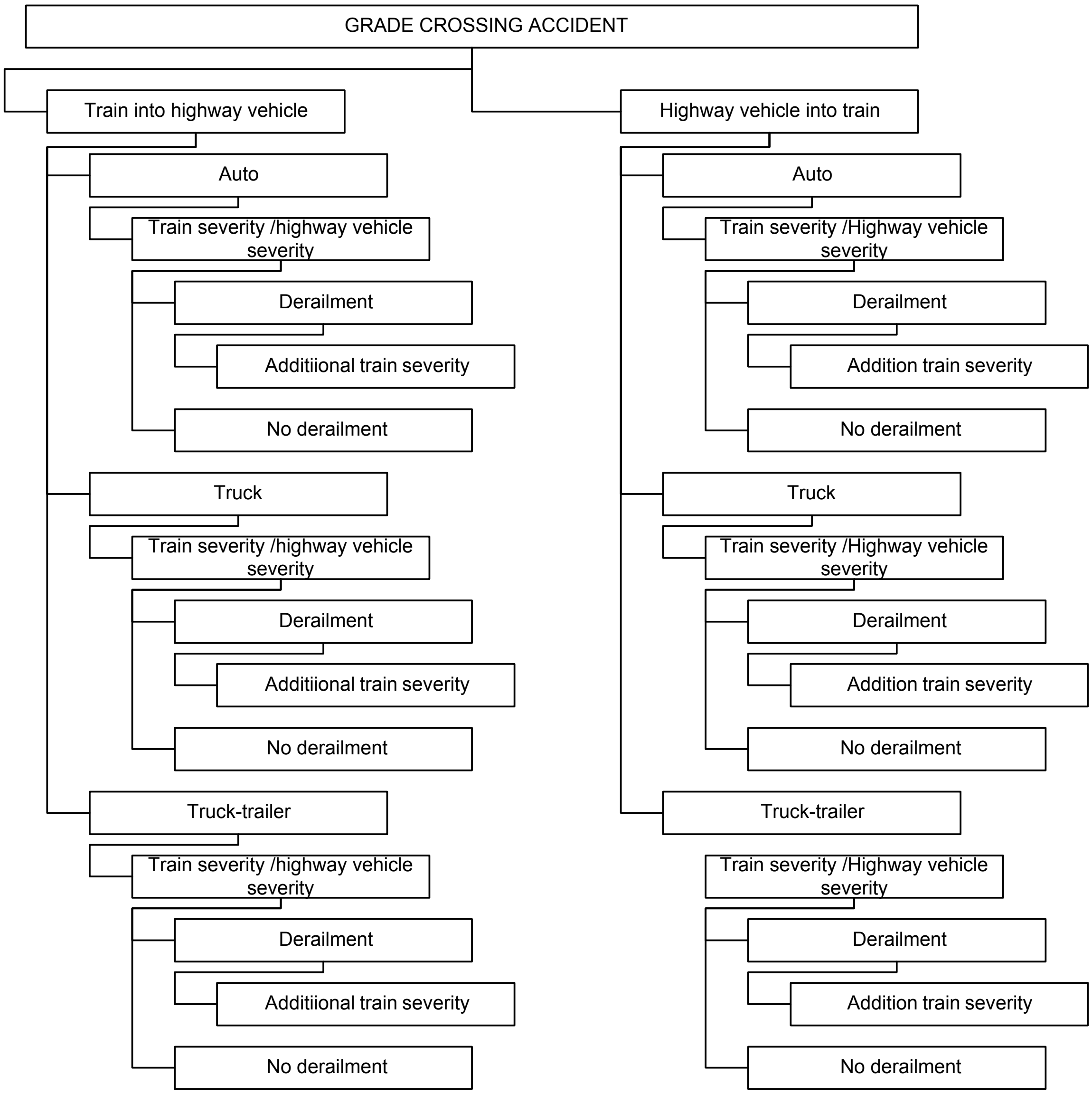
ms	maximum timetable train speed, miles per hour
thru	through trains per day
switch	switch trains per day
urban	if crossing is urban, Urban=1, else Urban=0
tracks	number of railroad tracks
NA	predicted number of accidents per year at the grade crossing
FA	predicted number of fatal accidents per year at the grade crossing
CA	predicted number of casualty accidents per year at the grade crossing
IA	predicted number of injury accidents per year at the grade crossing
PA	predicted number of PDO accidents per year at the grade crossing

Number of Accidents by Severity Category – HSR formulas

While the DOT formulas calculate the predicted accidents by severity, the high speed rail model calculates the predicted number of fatalities among highway vehicle and train occupants. *GradeDec 2000* calculates the number of injuries as a fixed ratio to the number of fatalities.

The following figure shows the calculation flow for the high-speed rail accident severity formulas. The following equations show the calculation of fatalities at grade crossing accidents based upon: accident type (train strikes vehicle or vehicle strikes train), vehicle type (auto, truck or truck trailer), and occupants by mode (rail or highway).

Figure 3 Accident Severity with High Speed Rail Formulas



Equation 7 Predicted fatalities by mode of occupancy for accident given train strikes highway vehicle (HSR)

$$Ftsv_{occ} = \sum_{ttype} \left[\alpha_{ttype} \cdot \overline{sp}^{2}_{ttype} \cdot \sum_{vtype} \beta_{vtype} \cdot \left(\gamma_{atype,vtype,occ} + P(sd)_{vtype} \cdot s_{vtype,occ} \right) \right]$$

and,

$$\overline{sp}_{ttype} = \begin{cases} sp_{ttype}, & sp_{ttype} \le sp^{max} \\ sp^{max}, & sp_{ttype} > sp^{max} \end{cases}, \text{for occ} = \text{Highway vehicle occupants}$$

$$\overline{sp}_{ttype} = sp_{ttype}, \text{for occ} = \text{Train occupants}$$

Equation 8 Predicted fatalities for accident given highway vehicle strikes train (HSR)

$$Fvst_{occ} = \sum_{ttype} \alpha_{ttype} \cdot \sum_{vtype} \beta_{vtype} \cdot \gamma_{atype,vtype,occ}$$

where:

$Ftsv_{occ}$	predicted fatalities when train strikes vehicle, by occupancy mode
$Fvst_{occ}$	predicted fatalities when vehicle strikes train, by occupancy mode
occ	occupancy mode of fatality (e.g., train occupants, highway vehicle occupants)
atype	accident type (e.g., train strikes vehicle, vehicle strikes train)
vtype	vehicle type (e.g., auto, truck, truck trailer)
ttype	train type (passenger, freight, switch)
$\gamma_{atype,vtype,occ}$	model coefficient by accident type, highway vehicle type and occupancy mode of casualties
β_{vtype}	share of vehicle type in highway traffic
α_{ttype}	share of train type in total rail traffic
sp_{ttype}	average train speed, for train type
sp^{max}	train speed of maximum impact on highway fatalities
$P(sd)_{vtype}$	probability of severe derailment
sd	added severity with severe derailment (model coefficient – assumed 0 for highway vehicle strikes train type accidents)

Equation 9 Total Predicted Fatalities (HSR)

$$F = Ptsv \cdot \sum_{occ} Ftsv_{occ} + (1 - Ptsv) \cdot \sum_{occ} Fvst_{occ}$$

where:

F	total predicted fatalities
$Ftsv_{occ}$	predicted fatalities when train strikes vehicle, by occupancy mode
$Fvst_{occ}$	predicted fatalities when vehicle strikes train, by occupancy mode
Ptsv	probability that accident is of type train strikes highway vehicle

Equation 10 Total Predicted Injuries (HSR)

$$I = u \cdot F$$

where:

I	total predicted injuries
F	total predicted fatalities
u	ratio of predicted injuries to fatalities

Effectiveness Multipliers

The DOT resource allocation method recommends that the following effectiveness multipliers be applied to predicted accidents in the base case in order to arrive at the estimate for safety risk at the grade crossing with the proposed improvements.

Note that in using the effectiveness multipliers, predicted accidents in the alternate case equal the base case predicted accidents times one minus the effectiveness multiplier.

Table 3 Effectiveness Values for Crossing Warning Devices

	Total trains per day			
	10 or less		More than 10	
Improvement Action	**Single Track**	**Multiple Track**	**Single Track**	**Multiple Track**
Passive to Flashing Lights	0.75	0.65	0.61	0.57
Passive to Lights and Gates	0.9	0.86	0.8	0.78
Flashing Lights to Gates	0.89	0.65	0.69	0.63

Supplementary Safety Measures

The proposed rule 49 CFR Parts 222 and 229 "Use of Locomotive Horns at Highway-Rail Grade Crossings" seeks to require the sounding of a horn at every crossing and provides detailed provisions for the establishment of "quiet zones" that are exempt from the requirement. As part of its provisions, the proposed rule allows for jurisdictions to add supplementary measures to crossings that have the equivalent effect on predicted accidents as the use of a locomotive horn. The rule incorporates a number of research findings that allow for the evaluation of estimated impacts from a range of improvements at grade crossings.

The table below shows the estimated effectiveness of supplementary measures at gated crossings (where the effectiveness rate is the rate of reduction in the number of predicted accidents with the supplementary device as opposed to a gated crossing).

Supplementary measures are applied to gated crossings only. In the alternate case, if a crossing is upgraded from a non-gated crossing to a gated crossing with supplementary measures, then the two effectiveness multipliers are applied serially.

Table 4 Effectiveness Multipliers for Supplementary Safety Measures

Supplemental Safety Measures	Effectiveness Rate
4 quadrant - no detection	0.82
4 quadrant – with detection	0.77
4 quadrant – with 60' medians	0.92
Mountable curbs-with channelized devices	0.75
Barrier curbs-with or without channelized devices	0.8
One-way street with gate	0.82
Photo enforcement	0.78

Source: Federal Register, January 13 , 2000, 49 CFR Parts 222 and 229, Use of Locomotive Horns at Highway-Rail Grade Crossings; Proposed Rule. Appendix A, pp. 2251-2255.

GradeDec 2000 allows for the re-routing of highway traffic in the corridor via changes in signage and signals, which can be effective in directing traffic away from high-risk/high-exposure crossings in the corridor. If the user has entered data indicating changes in AADT by traffic segment or changes in the time-of-day distribution of traffic segments, these changes will be reflected in the calculations of exposure.

Delay and Time-in-Queue

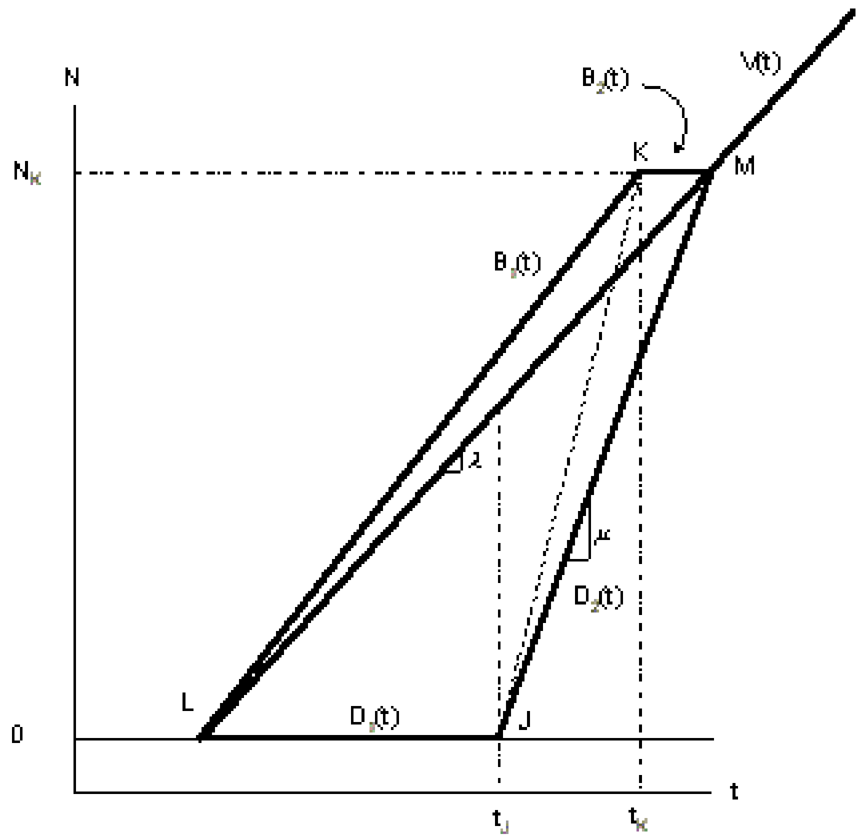
Accurate estimates of the non-safety benefits due to grade crossing investments depend upon properly quantifying the time that highway vehicles spend queued behind closed gates (or, waiting for a train to pass at ungated crossings). While the time-in-queue measure is the basis for the non-safety benefits (incremental emissions and vehicle operating costs while idling), the measure of time savings benefit is best measured as a function of highway vehicle delay. Delay measures the total time impact due to crossing blockages, and delay per blockage is the difference in travel time in a blockage scenario less the travel time in a non-blockage scenario. Time-in-queue measures the vehicle time spent waiting in queues behind blocked crossings.

GradeDec 2000 employs techniques from recent research[3] that have remapped the conventional time-space queuing model into a graphical construct plotting the cumulative vehicles in queue against time. With some relatively unrestrictive

[3] *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.

simplifying assumptions, time-in-queue is derived as a multiple of delay. Both highway delay and time in queue are readily calculated using easy-to-obtain data. The analysis framework is shown in the figure below.

Figure 4 Analysis of Delay and Time-in-Queue



The figure shows the blockage of highway traffic flow that occurs at a blocked grade crossing. 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 describe the calculation of delay and time-in-queue in *GradeDec 2000.*

The crossing blockage time is calculated from the train speed and the train length. The model calculates the average crossing closure time as follows:

Equation 11 Average Crossing Closure Time (minutes)

$$CCT_i = \frac{cl_i \cdot nc_i + el}{spd_i \cdot cf} + \frac{36}{60}$$

$$ACCT = \frac{\sum_i \delta_i \cdot CCT_i}{\sum_i \delta_i}$$

where:

i	index indicating the type of train: passenger, freight or switch
CCT_i	crossing closure time for train of type i , minutes
cl_i	average car length for train of type i, feet
nc	average number of cars for train of type i
el	engine length (set at 50 feet)
cf	factor for converting mph to feet per minute, equal to 5280/60
spd_i	average speed at the crossing of train of type i, mph
δ_i	trains per day of type i
ACCT	average crossing closure time, minutes

Time per train is calculated in minutes. 36 seconds are added to the time per train to account for the lead time of warning or closure prior to the arrival of a train (the model assumes that the lead time applies to passive crossings also, i.e., 36 seconds prior to the arrival of a train, highway motorists will not venture a crossing).

The arrival rate of vehicles is given by the following equation:

Equation 12 Arrival Rate of Vehicles (vehicles per second per lane)

$$\lambda = \frac{TotalVeh_{per}}{6 \cdot 3600 \cdot lanes}$$

where:

$TotalVeh_{per}$	total number of vehicles in period
lanes	number of highway lanes at the crossing
6	the number of hours in the period
3600	the number of seconds per hour

The number of vehicles that are affected by a closure is given by:

Equation 13 The Number of Affected Highway Vehicles at Closure

$$N_K = \frac{\lambda \cdot \mu \cdot ACCT}{60 \cdot (\mu - \lambda)}$$

where:

λ	arrival rate of vehicles, vehicles per second
μ	dispersal rate of vehicles, vehicles per second (constant value of 0.5)
ACCT	average crossing closure time in minutes

The total vehicle delay in the time-of-day period is given by:

Equation 14 Total Vehicle Delay per Closure (vehicle-seconds)

$$w = N_K \cdot \left[\frac{ACCT}{60} + \left(\frac{1}{\mu} - \frac{1}{\lambda} \right) \cdot \left(\frac{N_k + 1}{2} \right) \right]$$

where:

λ	arrival rate of vehicles, vehicles per second
μ	dispersal rate of vehicles, vehicles per second (constant value of 0.5)
ACCT	average crossing closure time in minutes
N_K	the number of affected vehicles at closure

The line $B_1(t)$ in the above figure represents the back of the queue. Its slope is given by:

Equation 15 Slope of the Back-of-Queue Equation

$$z = \frac{\lambda \cdot v_f \cdot k_j}{v_f \cdot k_j - \lambda}$$

where:

λ	arrival rate of vehicles, vehicles per second
v_f	freeflow speed of highway vehicles (constant value of 45 mph converted to feet per second)
k_j	traffic density in vehicles per feet at speed 0 (set to constant 0.05)

The above equation was derived from the flow-density relationship.

The time-in-queue per closure is given by:

Equation 16 Time-in-queue per Closure (vehicle-seconds)

$$t_q = N_K \cdot \left[\frac{ACCT}{60} + \left(\frac{1}{\mu} - \frac{1}{z} \right) \cdot \left(\frac{N_k + 1}{2} \right) \right]$$

where:

z	slope of the back-of-queue equation
μ	dispersal rate of vehicles, vehicles per second (constant value of 0.5)
ACCT	average crossing closure time in minutes
N_K	the number of affected vehicles at closure

GradeDec 2000 allocates delay and time-in-queue to each of the three traffic segments (auto, truck, bus) according to the shares of each traffic segment in total traffic for the time-of-day period. Delay and time-in-queue are summed for each traffic segment over the four daily periods to arrive at average daily delay and time-in-queue (for each segment). These metrics are used in the calculation of non-safety benefits.

Delay and time-in-queue per traffic segment per period is given by:

Equation 17 Delay for Traffic Segment in Time-of-Day Period (vehicle-minutes)

$$w_{\alpha,per} = w_{per} \cdot \frac{veh_{\alpha,per}}{\sum_{\alpha} veh_{\alpha,per}} \cdot 60$$

where:

w_{per}	total delay in time-of-day period
$veh_{\alpha,per}$	number of vehicles of type α (auto, truck, bus) in period

Equation 18 Time-in-Queue for Traffic Segment in Time-of-Day Period (vehicle-minutes)

$$t_{q\ \alpha,per} = t_{q\ per} \cdot \frac{veh_{\alpha,per}}{\sum_{\alpha} veh_{\alpha,per}} \cdot 60$$

where:

$t_{q\ per}$	total time-in-queue in time-of-day period (vehicle-seconds)
$veh_{\alpha,per}$	number of vehicles of type α (auto, bus, truck) in period

Average daily delay and time-in-queue for each traffic segment is given by:

Equation 19 Average Daily Delay per Traffic Segment (vehicle-minutes)

$$w_{\alpha} = \sum_{per} w_{\alpha,per}$$

where:

$w_{\alpha,per}$	total delay in time-of-day period

Average time-in-queue for each traffic segment is given by:

Equation 20 Average Daily Delay per Traffic Segment (vehicle-minutes)

$$w_{\alpha} = \sum_{per} w_{\alpha,per}$$

where:

$w_{\alpha,per}$	total delay in time-of-day period

Highway Traffic Re-Assignment (Corridor Model Only)

With the corridor model, *GradeDec 2000* re-assigns highway traffic at the grade crossing in two instances: 1) a grade crossing closure and, 2) a grade separation. The rationale for the re-assignment is that with closure forecast traffic will take alternate routes and will cross the rail lines at other points of crossing in the corridor in order to reach their destination. With grade separation, the grade-separated route will have less traffic impedance than it would have had without the improvement. Travelers will have a greater propensity to choose the route with less impedance and, therefore, some diversion of traffic to the grade-separated route is anticipated. Re-assignment of traffic at grade separated crossings is a feature that the user can turn on or off when running a simulation.

Highway traffic is re-assigned in *GradeDec 2000* model prior to the calculation of all benefit categories.

Grade Closures

The re-assigned AADT for the GCX adjacent below (i.e., lower milepost number) to the closed GCX is given by:

Equation 21 Diversion from Closure to Lower Adjacent GCX

$$aadt_{i-1} = aadtb_{i-1} + aadt_i \cdot \left[1 - \frac{mp_i - mp_{i-1}}{mp_{i+1} - mp_{i-1}}\right]$$

where:

$aadt_{i-1}$	average annual daily traffic at the GCX adjacent and below the closure, after re-assignment
$aadt_i$	average annual daily traffic at the closed GCX before re-assignment
$aadtb_{i-1}$	average annual daily traffic at the GCX adjacent and below the closure, before re-assignment
mp_i	the milepost value of the ith GCX, the closed crossing from which traffic is diverted

The re-assigned AADT for the GCX adjacent above (i.e., higher milepost number) to the closed GCX is given by:

Equation 22 Diversion from Closure to Upper Adjacent GCX

$$aadt_{i+1} = aadtb_{i+1} + aadt_i \cdot \left[1 - \frac{mp_{i+1} - mp_i}{mp_{i+1} - mp_{i-1}}\right]$$

where:

$aadt_{i+1}$	AADT at the GCX adjacent and above the closure, after re-assignment
$aadt_i$	AADT at the closed GCX before re-assignment
$aadtb_{i+1}$	AADT at the GCX adjacent and above the closure, before re-assignment
mp_i	the milepost value of the ith grade crossing

Grade Separation

After re-assigning traffic due to closures *GradeDec 2000* looks for grade separations and re-assigns traffic to account for the reduced traffic impedance at separated crossings. The model can be run without re-assigning traffic due to grade separations. On the simulation screen of the model, uncheck the box that says "Re-assign traffic if grade separated".

The potential AADT diverting from an adjacent crossing to a grade separated crossing is given by:

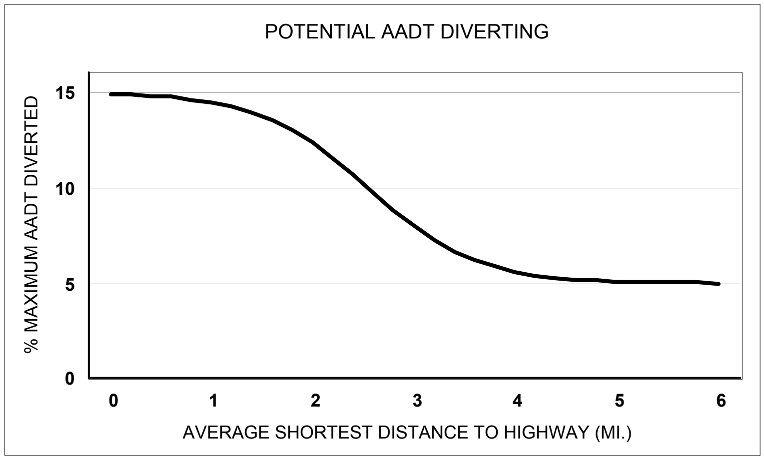
Equation 23 Potential AADT Diverted from Adjacent Crossing to Grade Separated Crossing

$$pAADTd = \min PD + (\max PD - \min PD) \cdot \frac{1}{1 + e^{-(\alpha + \beta \cdot D)}}$$

where:

pAADTd	percent of potential AADT diverting from the GCX due to a grade separation at an adjacent GCX (a function of the distance to the nearest major highway intersection)
min PD	minimum percent of potential AADT diverting from the GCX due to a grade separation at an adjacent GCX (independent of the distance to the nearest highway intersection). This value is set to 5.
max PD	maximum percent of potential AADT diverting from the GCX due to a grade separation at an adjacent GCX (independent of the distance to the nearest highway intersection). This value is set to 15.
α	equation parameter set to 4.783. This parameter and the following one are set to meet two conditions: 1) if distance of GCX is .1 miles from closest major highway intersection then the value of F in the above equation is 0.99, and 2) if distance of GCX is 5 miles from closest major highway intersection then the value of F in the above equation is 0.01.
β	equation parameter set to -1.876 and meeting the conditions described above.
D	percent of potential AADT diverting from the GCX due to a grade separation at an adjacent crossing

Figure 5 Potential Diversion due to Grade Separation



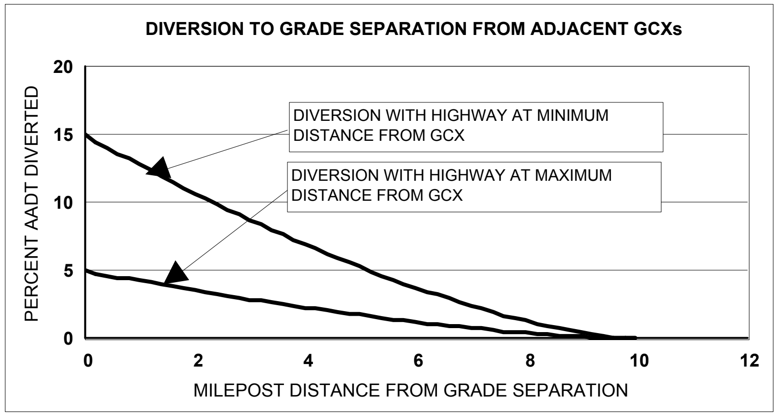
Equation 24 Percent AADT Diverted from Crossing to adjacent Grade Separated Crossing

$$\text{pcAADTdivert} = \text{pAADTd} \cdot \left(1 - \frac{\Delta\text{MP}}{\max\text{MP}}\right)^{\gamma}$$

where:

pcAADTdivert	percent of diversion of AADT from the traffic at the GCX to the adjacent, grade separated GCX
pAADTd	percent of potential AADT diverting from the GCX due to a grade separation at an adjacent GCX (see above equation)
ΔMP	distance between the adjacent GCX and the grade separated GCX
max MP	the maximum distance between adjacent GCXs, beyond which there is no diversion due to grade separation. This value is set to 10 miles in the model.
γ	an equation parameter reflecting the diminishing impact of grade separation on the route choice as the position of the adjacent GCX is further from the grade separated crossing. The parameter determines the concavity and the pace at which the impact diminishes with distance from grade separation. In the model and in Figure 6 below the parameter is set at 1.5.

Figure 6 Diversion due to Grade Separation



Benefits and Costs

The following sections describe the calculation of benefits and costs in *GradeDec 2000.*

Safety Benefits

The accident prediction and severity sections above describe the procedures for calculating predictions by severity type, with the DOT formulas, and fatalities and injuries, with the HSR formulas. *GradeDec 2000* calculates the safety benefits as:

Equation 25 Safety Benefits (for each year and crossing – with DOT formulas)

$$SB = \sum_{i} (AccB_i - AccA_i) \cdot CPAcc_i$$

where:

SB	safety benefit, constant dollars
i	accident severity type (fatal, injury, PDO)
$AccB_i$	number of accidents in base case, type i
$AccA_i$	number of accidents in alternate case, type i
$CPAcc_i$	cost per accident, type I

Equation 26 Safety Benefits (for each year and crossing – with HSR formulas)

$$SB = \sum_{i} [(CasB_i - CasA_i) \cdot CPCas_i] + (NAB - NAA) \cdot OPCAcc$$

where:

SB	safety benefit, constant dollars
i	casualty severity type (fatal, injury)
$CasB_i$	number of accidents in base case, type i
$CasA_i$	number of accidents in alternate case, type i
$CPCas_i$	cost per casualty, type I

NAB	predicted number of accident, base case
NAA	predicted number accidents, alternate case
OPCAcc	average out-of-pocket cost, dollars

Travel Time Savings

GradeDec 2000 computes travel time benefits based on the delay experienced by the highway vehicles at the highway-rail grade crossings. See the section on delay for a complete discussion.

The model calculates the probability that an individual highway vehicle will be blocked at a highway-rail grade crossing and the minutes of delay per vehicle. The product of these two quantities provides the average delay that each highway vehicle endures. This quantity is then multiplied by the total number of highway vehicles that arrive at the blocked grade crossing to obtain the total vehicle hours of delay. The highway vehicle delay hours are divided into passenger vehicles and trucks based upon the percentage of trucks data entry for the crossing.

The delay per blocked vehicle is equal to the time per train converted to hours. The probability that a vehicle is blocked equals the total daily block time (time per train times number of trains per day) times the exposure correlation factor (a number between 0 and 1 representing the correlation between the time-of-day distributions of rail and highway traffic).

The vehicle hours of delay are calculated at each crossing and for each year of the evaluation.

Equation 27 Time Savings Benefits (for each year and crossing)

$$PVDC = \frac{W_{auto}}{60} \cdot avgocc \cdot votpx$$

$$TDC = \frac{W_{truck}}{60} \cdot vottr$$

$$BDC = \frac{W_{bus}}{60} \cdot (vottr + avgoccbus \cdot votpx)$$

$$DCA = (PVDC + TDC + BDC) \cdot AF$$

$$TTSB = DCA_{base} - DCA_{alt}$$

where:

PVDC	average daily passenger vehicle delay time cost, dollars
w_{auto}	average daily passenger vehicle delay, vehicle-minutes
avgocc	average passenger vehicle occupancy, passengers per vehicle
votpx	value of passenger time, dollars per hour
BDC	average daily bus delay time cost, dollars
w_{bus}	average daily bus delay, vehicle-minutes
vottr	value of truck time (driver time), dollars per hour
TDC	average daily truck delay time cost, dollars
w_{truck}	average daily truck delay, vehicle-minutes
DCA	annual delay costs, dollars
AF	annualization factor
TTSB	annual travel time savings benefit, dollars

Environmental Benefits

GradeDec 2000 calculates the reduction in highway vehicle emissions due to reduced idle time at the grade crossings. There will be reduced emissions with grade separations and closures. However, the reductions in emissions at the closed GCX will typically be offset by increases in emissions at the crossings that absorb traffic diverted from the closed crossings.

There are emission rate tables for automobiles, transit vehicles, and trucks for three emission types: carbon monoxide, hydrocarbons, and nitrous oxide. The model uses these values to calculate emissions from idling vehicles at grade crossings. Emission costs for highway vehicles are calculated by multiplying the appropriate emission rate (by vehicle type) by the time spent by each vehicle type at the grade crossing. This calculation is performed for the base and alternate cases, the net difference being the change in vehicle emission.

Equation 28 Average Daily Emissions at Crossing by Vehicle Type

$$EM_{Etype} = \sum_{Vtype} ER_{Vtype,Etype} \cdot t_{q\ Vtype} \cdot \frac{60}{907185}$$

where:

Etype	emission type: HC, CO, NOx
Vtype	type of vehicle: car, truck or bus
$ER_{Vtype,\ Etype}$	emission rate (grams per minute)
$t_{q\ Vtype}$	time-in-queue by vehicle type, vehicle-hours
EM_{Etype}	emissions by type (tons per day)

The value 907185 is the number of grams per ton

Equation 29 Environmental Benefits (for each year and GCX)

$$EB = \sum_{Etype} [\left(EM_{Base,Etype} - EM_{Alt,Etype}\right) \cdot VOE_{Etype}] \cdot AF$$

where:

Etype	emission type: HC, CO, NOx

$EM_{Base, Etype}$	emissions by type in base case, tons
$EM_{Alt, Etype}$	emissions by type in alternate case, tons
VOE_{Etype}	emissions cost, dollars per ton
AF	annualization factor
EB	environmental benefit, dollars

Vehicle Operating Cost Savings

GradeDec 2000 computes the vehicle operating cost savings as a result of the improvements at the highway-rail grade crossing. Savings are generated from the reduction in delay at the grade crossing following the grade crossing upgrade. Between the base and alternate cases, a reduction in delay will lead to decreased consumption of fuel and oil by the vehicles operating on the highways. Vehicle consumption of fuel and oil is calculated for each vehicle type using the rates of idling consumption of fuel and oil. The time delay for each vehicle type is multiplied by the consumption rate to derive the fuel or oil consumed by the vehicles at the grade crossing.

Vehicle operating cost savings are then calculated by aggregating the change in gasoline, diesel and oil consumption for the different vehicle types and multiplying by their respective costs.

Equation 30 Average Daily VOC at Crossing by Vehicle Type

$$FCI_{Ftype} = \sum_{Vtype} BR_{Vtype,Ftype} \cdot t_{q\ Vtype} \cdot 60$$

where:

Ftype	fuel or oil type: gasoline, diesel, oil
Vtype	passenger vehicles, buses, trucks
$BR_{Vtype, Ftype}$	fuel burn rate rate - gallons (gas and diesel) or quarts (oil) per minute
$t_{q\ Vtype}$	time-in-queue by vehicle type, vehicle-hours
FCI_{Ftype}	fuel/oil consumed idling during delays , gallons (gas and diesel) or quarts (oil)

Equation 31 Vehicle Operating Cost Benefits (for each year and GCX)

$$FCOST_{Ftype, year} = FCOST_{Ftype, year-1} \cdot \frac{(1 + fpirg_{year})}{(1 + cpirg_{year})}$$

$$FCIC_{Ftype} = FCI_{Ftype} \cdot FCOST_{Ftype}$$

$$FCIC = \sum_{Ftype} FCIC_{Ftype} \cdot AF$$

$$VOCB = FCIC_{Base} - FCIC_{Alt}$$

where:

$FCOST_{Ftype, year}$	the constant dollar price of fuel in forecast year
$fpirg_{year}$	the fuel price index rate of growth
$cpirg_{year}$	the general price rate of growth
$FCIC_{Ftype}$	fuel cost by fuel type
FCI_{Ftype}	average quantity of fuel consumed per day idling at GCX
AF	annualization factor
VOCB	vehicle operating cost benefit

Network Benefits (Corridor Model Only)

GradeDec 2000 computes the estimated impacts of crossing investments on delay reduction on the neighboring highway network. The calculation relies on the average queue length on the approaching highway segments and the distance to the nearest major highway intersection.

The model assumes that network delay is negligible when the queue does not extend to within one-half the distance to the nearest highway. As the queue lengthens beyond the half-way, the network delay increases until it reaches a value of 10 vehicle-minutes at the point where the queue extends to the nearest highway crossing. The network delay will continue to increase at a declining rate as the queue length reaches and extends beyond the intersection. If the grade crossing signal is synchronized with the highway traffic signals, then network delay from the grade crossing is reduced by 50%. The calculation of network delay for each GCX in each year is as follows:

Equation 32 Network Delay (for crossing, year)

$$\text{VAPH} = \frac{\text{AADT} \cdot \sum_j \beta_j b_{per}}{6}$$

$$\text{VAPB} = \text{VAPH} \cdot \frac{\text{ACCT}}{60}$$

$$\text{QL} = \frac{\text{vl} \cdot \text{VAPB}}{5280 \cdot \text{Lanes}}$$

$$\text{BPP} = \text{TV} \cdot a_{per}$$

$$\text{DQL} = \begin{cases} \text{QL} - (\text{dth} - \text{th}), \text{ if QL} > (\text{dth} - \text{th}) \\ 0, \text{ if QL} \le (\text{dth} - \text{th}) \end{cases}$$

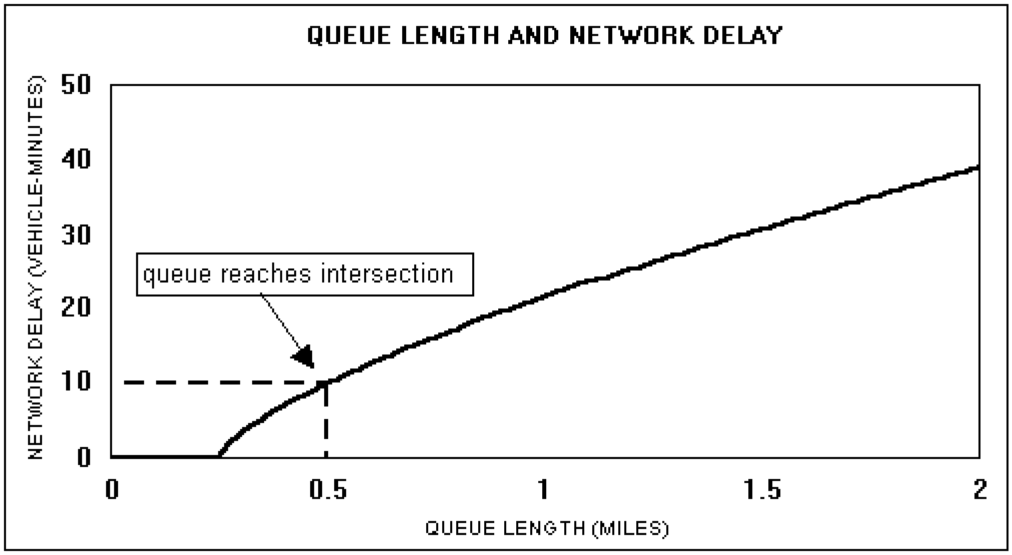
$$\text{ND}_{per} = \begin{cases} \dfrac{A \cdot \text{DQL}^{\beta} \cdot \text{BPP} \cdot \text{ndpfq}}{60}, \text{ if sp false} \\ \dfrac{A \cdot \text{DQL}^{\beta} \cdot \text{BPP} \cdot \text{ndpfq} \cdot 0.5}{60}, \text{ if sp true} \end{cases}$$

$$\text{ND} = \sum_{per} \text{ND}_{per}$$

where:

ACCT	average crossing closure time, minutes (see equation 17)
AADT	average annual daily traffic at crossing
VAPH	average number of vehicles arriving at crossing per hour in time-of-day period
$b_{j,per}$	share of daily highway traffic of vehicle type j in time-of-day period
β_j	share of vehicle type j in daily traffic
VAPB	average number of vehicles arriving at crossing during block
QL	queue length at blocked crossing, miles
vl	average length of vehicle (set at 22 feet)
TV	average number of trains per day
BPP	average number of blocks per period
a_{per}	share of daily trains in time-of-day period
DQL	the portion of the queue length that contributes to network delay, miles
dth	distance of crossing to nearest highway intersection, miles
th	the distance from major intersection such that if queue extends beyond this point network delay begins to accrue. Set at half of dth.
ND_{Per}	network delay in time-of-day period, vehicle-hours
A	a value calibrated so that network delay equals 10 vehicle-minutes when queue reaches the intersection
β	elasticity of network delay with respect to queue length, set to 0.7
sp	true/false flag designating whether grade crossings are synchronized with signal progression on the highway network
ndpfq	the number of vehicle-hours of network delay caused by a queue extending to the nearest major intersection. Set at one-sixth vehicle-hours (equal to 10 vehicle-minutes)
ND	daily network delay in vehicle-hours

Figure 7 Network Delay as a Function of Queue Length (when intersection is 0.5 miles from crossing)



As with the other benefits categories, network delay is calculated in the base and the alternate cases. The savings times the appropriate cost value is the network delay benefit.

Equation 33 Network Benefits (for each GCX and year)

$$\mathrm{NDPC} = \mathrm{ND} \cdot (1 - \mathrm{strucks} - \mathrm{sbus}) \cdot \mathrm{avgocc} \cdot \mathrm{votpx}$$

$$\mathrm{NDBC} = \mathrm{ND} \cdot \mathrm{sbus} \cdot (\mathrm{vottr} + \mathrm{avgoccbus} \cdot \mathrm{votpx})$$

$$\mathrm{NDTC} = \mathrm{ND} \cdot \mathrm{strucks} \cdot \mathrm{vottr}$$

$$\mathrm{NDCA} = (\mathrm{NDPC} + \mathrm{NDBC} + \mathrm{NDTC}) \cdot \mathrm{AF}$$

$$\mathrm{NDSB} = \mathrm{NDCA}_{\mathrm{base}} - \mathrm{NDCA}_{\mathrm{alt}}$$

where:

NDPC	average daily cost of network delay, passenger vehicles, dollars
ND	average daily network delay, vehicle-hours
avgocc	average passenger vehicle occupancy, passengers per vehicle
votpx	value of passenger time, dollars per hour
strucks	share of highway traffic that is trucks
sbus	share of highway traffic that is buses
NDBC	average daily cost of network delay, buses, dollars
avgoccbus	average bus occupancy, passengers per bus
NDTC	average daily cost of network delay, trucks, dollars
vottr	value of truck time, dollars per hour
NDCA	annual network delay costs, dollars
AF	annualization factor
NDSB	annual network delay savings benefit, dollars

Local Benefits

Local benefits in the corridor are calculated as a percentage of the benefits from all the preceding benefits categories summed over all the grade crossings. These benefits represent the value of the grade crossing improvements to the local community or communities. These include benefits not conventionally counted like: improved mobility for residents (due to easier, safer crossings), reduced noise, economic benefits from improved access, etc. The local benefits are equal to the sum of all the previously discussed benefits times the local benefits factor.

Equation 34 Local benefits (for each year)

$$LB = \left(\sum_{GCX} SB + \sum_{GCX} TTSB + \sum_{GCX} VOCB + \sum_{GCX} EB + \sum_{GCX} NDB \right) \cdot lbf$$

where:

LB	Annual local benefits in the corridor, dollars
SB	Annual safety benefits, dollars
TTSB	Travel time savings benefits, dollars
VOCB	Vehicle operating cost savings benefits, dollars
EB	Environmental benefits, dollars
NDB	Network delay savings benefits, dollars
lbf	Local benefits factor (exogenously determined factor)

Project Costs

There are three components of project costs. First, there are capital outlays that are incurred in the alternative case. Second, annual operating and maintenance costs for each crossing. Third, other lifecycle costs for each of the grade crossings in the corridor. The following is the formula for costs:

Equation 35 Total and Net Project Costs (for each year)

$$TC_{Base} = OM_{Base} + LC_{Base} + OMss_{Base} + LCss_{Base}$$

$$TC_{Alt} = \begin{cases} OM_{Alt} + LC_{Alt} + OMss_{Alt} + LCss_{Alt} & \text{, if year} > 1 \\ OM_{Alt} + LC_{Alt} + CC_{Alt} \cdot (1 + dr) & \\ + OMss_{Alt} + LCss_{Alt} + CCss_{Alt} \cdot (1 + dr) & \text{, if year} = 1 \end{cases}$$

$$NC = TC_{Alt} - TC_{Base}$$

where:

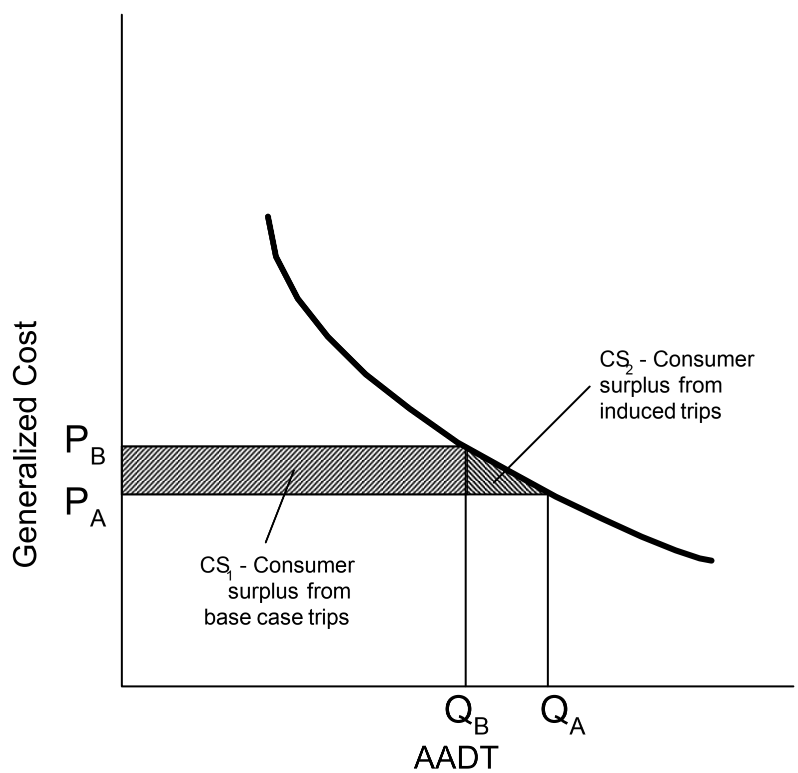
TC	total project costs in year (for each case, base and alternate), dollars
OM	operating and maintenance costs (for each case, base and alternate), dollars
LC	other life-cycle costs (for each case, base and alternate), dollars
CC	capital costs (alternate case only, presumed executed in year 0 - the base year), dollars
OMss	operating and maintenance costs (for each case, base and alternate) for supplementary safety measure (for gated crossings only), dollars

LCss	other life-cycle costs (for each case, base and alternate) for supplementary safety measure (for gated crossings only), dollars
CCss	capital costs (alternate case only, presumed executed in year 0 - the base year), for supplementary safety measure (for gated crossings only) dollars
dr	discount rate
NC	net project costs, dollars

Consumer Surplus

The benefit components described above include only the benefits accruing to current users of the roadway network. With grade crossing improvements, the generalized cost of travel by car in the corridor or region will decline. As a result, we expect that grade crossing improvements will induce some additional highway traffic. The consumer surplus includes both the consumer surplus from the base case auto trips as well as from the induced trips (see Figure 7 below). The model assumes that bus and truck traffic in the corridor or region are not sensitive to the changes in generalized cost from grade crossing improvements.

Figure 8 Consumer Surplus



In addition to incremental consumer surplus, induced trips will also generate external costs. *GradeDec 2000* calculates these external costs and deducts them from the total benefits. The following are the model equations for the calculation of consumer surplus and the external costs from induced trips.

Equation 36 Base Case Auto Travel Demand in the Corridor or Region

$$Q_B = \sum_i \alpha_i \cdot AADT_i$$

where:

i	index of the crossing (i.e., each of n crossings in the corridor or region is indexed from 1 to n)
α_i	auto share of traffic at the crossing
$AADT_i$	average annual daily traffic at crossing i

The costs that influence the traveler's decision to make additional trips are the internal costs, namely: safety risk, travel time and vehicle operating cost.

Equation 37 Base case Generalized Cost of Auto Trips

$$P_B = \frac{\sum_i (\alpha_i \cdot sr_{Bi} + tt_{Bi} + voc_{Bi})}{(pTC/100) \cdot Q_B}$$

where:

P_B	imputed average generalized trip cost in the corridor
α_i	auto share of traffic at the crossing
sr_{Bi}	auto cost of accidents at crossing i, dollars
tt_{Bi}	auto travel time delay costs at crossing i, dollars
voc_{Bi}	auto vehicle operating cost at crossing i, dollars
pTC	percent share of trip costs at the crossing
Q_B	auto AADT at crossings in the corridor or region

GradeDec 2000 represents highway auto travel demand with a standard, Cobb-Douglas functional form, which has a fixed elasticity of demand with respect to generalized cost.

Equation 38 Auto Highway Travel Demand as a Function of Generalized Cost

$$Q = A \cdot P^{\beta}$$

where:

Q	daily trips that traverse the crossings in the corridor or region as measured by AADT at the grade crossings
P	the generalized average cost of auto trips traversing crossings in the region or corridor
β	elasticity of demand for auto trips with respect to generalized cost
A	a constant, derived by substituting Q_B, P_B and solving

The alternate case generalized cost is based on the imputed cost in the base case and the change in cost at the crossing.

Equation 39 Alternate Case Generalized Cost of Auto Trips

$$P_A = P_B + \left[\frac{\sum_i (\alpha_i \cdot sr_{Ai} + tt_{Ai} + voc_{Ai}) - \sum_i (\alpha_i \cdot sr_{Bi} + tt_{Bi} + voc_{Bi})}{Q_B} \right]$$

where:

P_B	the imputed average generalized trip cost in the corridor in the base case
α_i	auto share of traffic at the crossing
sr_{Ai}	cost of accidents at crossing, alternate case, dollars
tt_{Ai}	travel time delay at crossing i, alternate case, dollars
voc_{Ai}	the auto vehicle operating cost at crossing i, alternate case, dollars
sr_{Bi}	the cost of accidents at crossing i, base case, dollars
tt_{Bi}	travel time delay at crossing i, base case, dollars
voc_{Bi}	the auto vehicle operating cost at crossing i, base case, dollars
Q_B	auto AADT at crossings in the base case

The travel demand in the alternate case is derived by applying the auto travel demand function from equation 30.

Equation 40 Alternate case auto travel demand

$$Q_A = AP_A^{\beta}$$

where:

P_A	alternate case average generalized cost of travel in the corridor or region elasticity of auto travel demand with respect to generalized cost
A	constant of demand equation

Consumer surplus is estimated in the conventional way as the area beneath the demand curve. Since the demand curve is based on daily traffic, the result is annualized.

Equation 41 Total Consumer Surplus (in each year)

$$CS = A\int_{P_A}^{P_B} P^{\beta} dP \cdot AF = \frac{A}{1+\beta}\left[P_B^{\beta+1} - P_A^{\beta+1}\right] \cdot AF$$

where:

P_A	alternate case average generalized cost of travel in the corridor or region
P_A	base case average generalized cost of travel in the corridor or region
A	demand equation constant
β	elasticity of demand with respect to generalized cost
AF	annualization factor

The consumer surplus from base case trips, and which is already included in the calculation of the benefit components, is given by:

Equation 42 Consumer Surplus from Base Case Trips (in each year)

$$CS_1 = Q_B \cdot (P_B - P_A) \cdot AF$$

where:

Q_B	auto AADT at crossings in the base case
P_B	imputed average generalized trip cost in the corridor in the base case
P_A	imputed average generalized trip cost in the corridor in the alternate case
AF	annualization factor

The consumer surplus from the induced trips is the difference between the total consumer surplus and the consumer surplus from base case trips.

Equation 43 Consumer Surplus from Induced Trips

$$\mathrm{CS}_2 = \mathrm{CS} - \mathrm{CS}_1$$

The disbenefit that is generated by induced trips is equal to the external costs (congestion and emissions) that each induced trip generates. This disbenefit is estimated by the following equation.

Equation 44 Disbenefit from Induced Trips

$$DisBen = \left[\sum_i (ec_{Ai} + ndc_{Ai})\right] \cdot \left[\frac{AF}{pTC/100}\right] \cdot \left[\frac{Q_A - Q_B}{Q_A}\right]$$

where:

ec_i	emission costs at crossing i, alternate case, dollars
ndc_i	network delay costs due to queuing at crossing i, alternate case dollars
pTC	percent share of trip costs at the crossing
Q_B	auto AADT at crossings in the base case
Q_A	auto AADT at crossings in the alternate case
AF	annualization factor

Total Benefits and Benefit-Cost Indicators

GradeDec computes the corridor (or regional) level benefits from grade crossing improvements by aggregating the benefits estimated for each individual crossing and then adding the consumer surplus from induced trips and subtracting the disbenefit (in the form of external costs) from these trips. A simple sum is used to aggregate the safety benefits, travel time benefits, vehicle operating cost benefits, environmental benefits and network delay benefits.

Equation 45 Total benefits (excluding local) in corridor (for each year)

$$TB = \sum_{GCX} SB + \sum_{GCX} TTSB + \sum_{GCX} VOCB + \sum_{GCX} EB + \sum_{GCX} NDB + CS_2 - DisBen$$

where:

TB	total annual local benefits in the corridor, dollars
SB	annual safety benefits, dollars
TTSB	travel time savings benefits, dollars
VOCB	vehicle operating cost savings benefits, dollars
EB	environmental benefits, dollars
NDB	network delay savings benefits, dollars
CS2	consumer surplus from induced trips
DisBen	disbenefit from induced trips

The net benefits for the corridor or region are calculated as follows:

Equation 46 Net benefits (excluding local) in corridor (for each year)

$$NB = TB - NC$$

where:

NB	net benefits, dollars
TB	total benefits, dollars
NC	net project costs, dollars

The following formulas give the present value calculations of benefits, costs and net benefits.

Equation 47 Present value benefits

$$PVB = \sum_{year} \frac{TB_{year}}{(1+dr)^{year}}$$

where:

PVB	present value of benefits, dollars
TB	total benefits, dollars
dr	discount rate

Equation 48 Present Value Costs

$$PVC = \sum_{year} \frac{NC_{year}}{(1+dr)^{year}}$$

where:

PVC	present value of project costs, dollars
NC	net costs, dollars
dr	discount rate

Equation 49 Net Present Value

$$\mathrm{NPV} = \mathrm{PVB} - \mathrm{PVC}$$

where:

NB	net present value, dollars
PVB	present value benefits, dollars
PVC	present value costs, dollars

The following is the benefit-cost ratio calculation.

Equation 50 Benefit-Cost Ratio

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

where:

BCR	benefit-cost ratio
PVB	present value benefits, dollars
PVC	present value costs, dollars

The following is the project rate of return calculation.

Equation 51 Project Rate of Return

$$\mathrm{PRR} = \mathrm{IRR}(\mathrm{TB}_{\mathrm{year}} - \mathrm{NC}_{\mathrm{year}})$$

where:

PRR	project rate of return
IRR	designates a function that returns the discount rate for which the present value of the net benefit stream is equal to zero.
$\mathrm{TB}_{\mathrm{year}}$	Total benefits, dollars
$\mathrm{NC}_{\mathrm{year}}$	Net project costs, dollars

Data and Data Organization

Introduction

There are four principal data elements in *GradeDec 2000* and these were described in the Model Overview section above. The following sections include detailed descriptions of the data in each of the data elements.

Corridor Data

The following are the corridor data variables. Except where noted, the variable descriptions are self-explanatory.

Number of Passenger Trains per Day

Number of Freight Trains per Day

Number of Switch Trains per Day

Rail Traffic Daily Distribution

The user can choose from one of five daily traffic distributions: uniform, AM peak, PM peak, day flat, night flat. These distributions of traffic divide the daily traffic into four six-hour periods. These are early AM (12AM-6AM), late AM (6AM- 12PM), early PM, (12PM-6PM), and late PM (6PM-12AM). The traffic distributions are each represented as a vector of four values that sum to 1. For example, the uniform distribution is given by (.25,.25,.25,.25). The *GradeDec 2000* default distributions are given in the "Time-of-Day Distributions" section of "Model Components". The user can modify these distributions to reflect conditions in the corridor under evaluation.

Signal Synchronization with the Highway Network (yes/no)

This yes/no variable indicates whether the grade crossing signaling is synchronized with the signaling system of the adjacent highway network.

Technology Impact Factor

The accident incidence of the "new technology" crossing type will be determined by the Technology Impact Factor. This factor determines the safety risk of new technology relative to conventional lights and gates crossing barriers, i.e., a value of 0.5 for this factor will yield safety risk half that of a lights and gates crossing.

Region Data

Besides its description, the following are the two parameters associated with a region:

Technology Impact Factor

See the description above under Corridor Data.

Percent Benefit from Closure

The regional model, unlike the corridor model, does not reassign traffic at the crossing when the crossing is closed. When a crossing is closed, there are no longer highway user costs at the crossing. However, the trips of highway users who used the route with the crossing in the base case did not simply disappear. Most likely, the highway trips at the crossing will divert to another crossing and new user costs will be realized at that crossing. This "percent benefits" parameter determines the percent of base case user costs that will be realized as a benefit. For instance, if the parameter is set to 0 this is equivalent to all highway users finding alternate routes that have exactly the same user costs as the base case. If this parameter is set to a value greater than 0 (say, 10) this implies that users find lower cost alternatives in the alternate case when the crossing is closed and 10 percent of the base case cost is realized as benefit. Conversely, if the parameter is set to –10 then users find alternatives that are 10% more costly than the base case and there is a net disbenefit from the closure.

Grade Crossing Data

The following are the crossing data variables. The variables noted below are either common to both corridors and regions, or are unique to one or the other as noted. Except where noted, the variable descriptions are self-explanatory.

Milepost (corridor and region)

The Milepost is a decimal number (i.e., 153.7) that identifies the GCX and specifies its geographic location within the rail corridor. The difference between the mileposts of two consecutive GCXs should equal the distance between them in miles. The data for crossings in a corridor should be entered in a linear sequence (i.e., with mileposts in either ascending or descending order). This order has no significance for a region and the milepost only serves as an additional identifier of the crossing.

Crossing ID (region only)

This is the unique crossing ID corresponding to the 7-character crossing identifier in the National Inventory of Grade Crossings.

Paved/Unpaved (corridor and region)

This yes/no variable designates whether the highway at the crossing is paved or unpaved.

Urban/Rural (corridor and region)

A yes/no variable that designates whether the GCX is in an urban or rural

Grade Crossing Base Type (corridor and region)

This variable designates the type of crossing in the base case.

There are six types of grade crossings used in *GradeDec 2000*: passive, flashing lights only, flashing lights and gates, closure, grade separation and new technology. The "new technology" type of grade crossing is a hypothetical type of crossing that may involve advanced traffic management and information systems and/or new kinds of barriers.

The crossing types correspond to the crossing types in the National Inventory of Grade Crossings database. *GradeDec 2000* maps these types into the types used by its model as follows:

National Inventory Crossing Type	GradeDec 2000 Crossing Type
No Device Stand Stop Crossbucks Special Procedure	Passive
Flashing Lights	Flashing Lights
Wigwags Gates	Lights and Gates

Region crossing types also include closure, grade separation and new technology. These are the same types as in the corridor model.

Grade Crossing Alternate Type (corridor and region)

This variable designates the type of crossings in the alternate case. See the descriptions for crossing types in the base case.

Safety Supplement Base Type (corridor and region, only available for gated crossings)

This variable specifies whether a supplementary safety measure is deployed at the crossing in the base case. Supplementary safety measures include the following: four quadrant gates – no detection, four quadrant gates with detection, four quadrant gates with 60 foot medians, mountable curbs, barrier curbs, one-way streets, and, photo enforcement.

Safety Supplement Base Type (corridor and region, only available for gated crossings)

This variable specifies whether a supplementary safety measure is deployed at the crossing in the base case. Supplementary safety measures include the following: four quadrant gates – no detection, four quadrant gates with detection, four quadrant gates with 60 foot medians, mountable curbs, barrier curbs, one-way streets, and, photo enforcement.

Safety Supplement Alternates Type (corridor and region, only available for gated crossings)

This variable specifies whether a supplementary safety measure is deployed at the crossing in the alternate case. See the Base Type description above.

Number of Highway Lanes (corridor and region)

Highway Traffic (AADT) (corridor and region)

This is the bi-directional average annual daily highway traffic at the crossing.

Of the Highway Traffic, the Percent of Vehicles that are Trucks (corridor and region)

Of Trucks, the Percent that are Truck Trailers (corridor)

Of the Highway Traffic, the Percent of Vehicles that are Buses (corridor and region)

Auto Time-of-Day Traffic Distribution (corridor and region)

This variable represents the distribution of auto traffic at the crossing in a typical 24-hour period.

The user can choose from one of five daily traffic distributions: uniform, AM peak, PM peak, day flat, night flat. These distributions of traffic divide the daily traffic into four six-hour periods. These are early AM (12AM-6AM), late AM (6AM- 12PM), early PM, (12PM-6PM), and late PM (6PM-12AM). The traffic distributions are each represented as a vector of four values that sum to 1. For example, the uniform distribution is given by (.25,.25,.25,.25). The *GradeDec 2000* default distributions are given in the "Exposure and Correlation of Time-of-Day Distributions by Highway and Rail" subsection of "The Model" section. The user can modify these distributions to reflect conditions in the corridor or region under evaluation.

Truck Time-of-Day Traffic Distribution (corridor and region)

This variable represents the distribution of truck traffic at the crossing in a typical 24-hour period. See the discussion under auto time-of-day traffic distribution.

Bus Time-of-Day Traffic Distribution (corridor and region)

This variable represents the distribution of bus traffic at the crossing in a typical 24-hour period. See the discussion under auto time-of-day traffic distribution.

Yes/No Flag Indicating whether Alternate Case includes Traffic Management Measures for Re-assigning Traffic at the Crossing (corridor and region)

This flag determines that the user specifies alternate case values for AADT by traffic segment and the time-of-day distribution of traffic segments. These new values represent the projected impact of proposed traffic management measure on highway traffic at the crossing.

Highway Traffic (AADT), Of the Highway Traffic, the Percent of Vehicles that are Trucks, Of the Highway Traffic, the Percent of Vehicles that are Buses, Auto Time-of-Day Traffic Distribution, Truck Time-of-Day Traffic Distribution, Bus Time-of-Day Traffic Distribution – Alternate Case (corridor and region)

These data are entered in the Alternate Case only if the flag indicating the presence of traffic management measures is set.

Number of Railroad Tracks (corridor)

This is the number of traffic-bearing tracks at the crossing.

Number of Main Railroad Tracks (region)

This is the number of daily traffic-bearing tracks at the crossing.

Number of Other Railroad Tracks (region)

Other tracks at the crossing are special use tracks.

Maximum Schedule Train Speed (corridor and region)

Average Number of Day Through Trains (region)

This includes both passenger and freight trains.

Average Number of Night Through Trains (region)

This includes both passenger and freight trains.

Average Number of Day Switch Trains (region)

Average Number of Night Switch Trains (region)

Distance from Highway (corridor only)

This is the distance, measured in miles, from the crossing to the nearest major highway intersection.

Number of Accidents at Crossing in Past Five Years

Crossing Costs

The cost data for the crossing include O&M costs and other lifecycle costs for the base and alternate cases and capital costs for the alternate case. O&M and other lifecycle costs are annual outlays that are repeated every year. Capital costs (i.e. the cost of improving the crossing) is a one-time outlay that is expended in the year prior to the start year of the analysis

Scenario Data

The scenario data include those variables to which probability distributions can be assigned. There are distinct scenarios for the two models, as the set of variables for the corridor model differs slightly from that of the regional model. In the descriptions below, the variables belonging to each model are shown.

A simulation engine solves the *GradeDec 2000* model for a specified number of trials. For each trial, a randomly sampled value is selected from each of the probability distributions as its input value. The collection of model solutions represents a probability distribution of the model's result variables.

The scenario variables are divided into four data sets, namely: Rail Operations, Highway, Social Costs and Price Indexes. For each of the variables in the scenario data the user can specify whether the value is fixed or, is one of four types of probability distributions. These distributions types are:

- uniform probability distribution, which requires the specification of two end points of an interval to define the distribution.
- normal probability distribution, which requires that the user specify the mean value and the standard deviation of the distribution, and
- a skewed-bell distribution that is normal when symmetric, but allows for skew and which requires three defining points corresponding to its 10, 50 and 90 percentiles.
- A triangle distribution, where the user specifies a minimum value, maximum value and the most likely value.

Rail Operations

These variables are used to define the rail operations in the corridor. The variables are:

Annual Rate of Growth in Train Traffic, Near Term, Percent (corridor and region)

Annual Rate of Growth in Train Traffic, Far Term, Percent (corridor and region)

Number of Rail Cars per Freight Train (corridor)

Number of Rail Cars per Passenger Train (corridor)

Number of Rail Cars per Switch Train (corridor and region)

Average Length of Freight Rail Cars, Feet (corridor)

Average Length of Passenger Rail Cars, Feet (corridor)

Average Length of Switch Train Cars, Feet (corridor and region)

Number of Rail Cars per Through Train (region)

Average Length of Through Train Rail Cars, Feet (region)

Highway

The following variables define the corridor-level highway characteristics. The highway data are required for the forecasting of highway-related benefits.

Annual Rate of Growth of Highway Traffic, Near Term, Percent (corridor and region)

Annual Rate of Growth of Highway Traffic, Far Term, Percent (corridor and region)

Annualization Factor (corridor and region)

This is a factor for converting daily benefits to annual benefits.

Average Auto Vehicle Occupancy (corridor and region)

This is the average number of occupants per vehicle.

Average Bus Vehicle Occupancy (corridor and region)

This is the average number of passenger occupants on a bus.

Elasticity of Auto Travel Demand with respect to Generalized Cost of Travel (corridor and region)

This variable is the percent change in corridor or region AADT per percent change in generalized cost. For instance, if a 10% increase in travel cost results in a 1% decrease in AADT then the elasticity of demand with respect to cost is –0.1. Many travel demand studies show that the value for the variable is many cases about –0.1. The "generalized cost of travel" includes all of the internal costs of auto travel that are perceived by users including: vehicle operating costs, travel time and safety risk.

Average Percent of Auto Trip Costs that are Crossing-Related, Percent

This is the corridor or region average of the percent of total trip costs at the crossing. For instance, if an average trip has a generalized cost of $8.00 and $0.80 are the average trips costs at the crossing, then the value for this variable should be 10. This factor is used in the consumer surplus calculation.

Social and Other Costs

The variables represent the monetized value of social costs and the market value of other costs.

The Discount Rate

This variable is the real discount rate for the analysis. This rate is applied to future constant dollar cost and benefit streams (i.e., the benefits and costs have been adjusted to account for forecast inflation).

Cost of a Fatal Accident, $’000 (corridor and region)

Cost of an Injury Accident, $’000 (corridor and region)

Cost of a Property Damage Accident, $’000 (corridor and region)

Cost per Fatality, $'000 (HSR formulas)

Cost per Injury, $'000 (HSR formulas)

Average Out-of-Pocket Cost per Accident, $"000 (HSR formulas)

Value of Time (auto) ($/person-hr.)

Value of Time (truck – driver time)) ($/truck-hr.) (corridor and region)

Cost of HC Emissions, $'000/Ton

Cost of NOx Emissions, $'000/Ton

Cost of CO Emissions, $'000/ Ton

Base Fuel Cost, $/Gallon

This variable refers to the cost of fuel (dollars per gallon) in the base year.

Base Oil Cost, $/Quart

Fuel Cost, Annual Rate of Change, Percent

Inflation, Annual Rate, Percent

This variable refers to the cost of motor oil (dollars per quart) in the base year.

Sources for social cost data included in the scenarios provided with *GradeDec 2000* were derived from the following sources:

Values of time:

Valuation of Travel-Time Savings and Predictability in Congested Conditions for Highway User-Cost Estimation, Small, Keneth, Xuehau Chu, Robert Noland, et al, National Cooperative Highway Research Program 2-18(2), January 1977

Accident and casualty unit cost values:

The Cost of Highway Crashes, Miller, Ted, John Viner, Nancy Pindus, et al., The Urban Institute, Washington, DC, prepared for the Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1991.

Unit cost values for emissions:

Monetary Values of Air Pollution Emissions in Various U.S. Cities, Wang, M. and D. Santini, Transportation Research Board Paper No. 951046, 74th Annual Meeting, January 1995.

Model Parameters and Default Values

The following parameters and default values are used in the model to calculate: accident costs, capital and maintenance costs, emission rates by vehicle type, railroad emissions by engine type, and the rate fuel and oil are consumed by vehicle type per minute.

Grade crossing types used in the following data tables are:

1. Passive Grade Crossing
2. Flashing Lights

3. Flashing Lights and Gates
4. Grade Closure
5. Grade Separation
6. New Technology

Table 5 Project Costs

Crossing Type	Initial Capital Cost (thous. of $)	O and M Costs (thous. of $)	Other Life Cycle Costs (thous. of $)
Passive	1.6	.2	0.0
Lights	74.80	1.8	0.0
Gates	106.10	2.5	0.0
Closure	20.00	0.0	0.0
Separation	1,500.00	.5	0.0
New Technology	180.00	.5	0.0

Based on FRA internal data

Table 6 Costs for Supplementary Safety Measures

Measure Type	Initial Capital Cost (thous. of $)	O and M Costs (thous. of $)	Other Life Cycle Costs (thous. of $)
4-quadarnt gates without detection	150	25	0.0
4-quadarnt gates with detection	150	25	0.0
4-quadarnt gates with 60' medians	150	25	0.0
Mountable curbs	150	25	0.0
Barrier curbs	150	25	0.0
One-way street	150	25	0.0
Photo enformcement			

Based on FRA internal data

Table 7 Emission Rates by Type of Vehicle, Grams per Minute

Type of Vehicle	Hydro Carbons (HC)	Carbon Monoxide (CO)	Nitrogen Oxides (NOx)
1-car	0.3030	4.86	0.0915
2-bus	0.6655	11.85	0.183
3-truck	0.2559	3.144	0.2754

Derived from EPA Idling Emissions Table, Reference Document: EPA420-F-98-014

Table 8 Rates of Fuel and Oil Consumption

Type of Vehicle	Fuel gallons/minute	Oil quarts/minute
1-car	.00969	0.000626
2-bus	0.0184	0.000119
3-truck	0.02067	0.00134

Sources: "Passenger Car Fuel Economy - A Report to Congress", January 1980, EPA

HERS Technical Report v3.26 Appendix H: A Numerical Example, FHWA, June 2000

"Technology Options to Reduce Truck Idling", F. Stodolsky, L. Gaines, A. Vyas, Transportation Technology, R&D Center - Argonne National Laboratory

Table 9 High Speed Rail Model Parameters – Accident Breakout by Type

Percent Breakout of accidents by type	
Train Strike Highway Vehicle	84
Highway Vehicle Strikes Train	16

Table 10 High Speed Rail Model Parameters – Coefficients for Train Strikes Highway Vehicle Accident

Name	Auto	Truck	Trailer
Highway Fatalities	0.000127	0.000111	0.00004
Train Fatalities	0.000005	0.00001	0.000044
% Accidents with Severe Derailment	0.0001	0.001	0.007
Added Severity with Severe Derailment	0.00022	0.00022	0.00022
Speeds of maximum severity (highway)	70	70	65

Table 11 High Speed Rail Model Parameters – Coefficients for Highway Vehicle Strikes Train Accident

Name	Auto	Truck	Trailer
Highway Fatalities	0.000127	0.000111	0.00004
Train Fatalities	0.000005	0.00001	0.000044
% Accidents with Severe Derailment	0.0001	0.001	0.007
Added Severity with Severe Derailment	0.00022	0.00022	0.00022
Speeds of maximum severity (highway)	70	70	65
Highway Fatalities	0.217	0.16	0.091
Train Fatalities	0.01	0.01	0.01

Source: *Assessment of Risks for High Speed Rail Grade Crossings on the Empire Corridor*, Mark Mironer and Michael Coltman, High Speed Ground Transportation Division, VNTSC, April 1998

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