GradeDec

Reference Manual

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Introduction

Description and Objective

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

GradeDec is a web-based application 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* 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* 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* assists in identifying the investments that will promote accident reduction.

GradeDec facilitates a structured analysis. The analysis process in *GradeDec* is as important as the end result. *GradeDec* can be useful as a tool for managing data and partial analyses and does not require that users take advantage 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* 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. *GradeDec* 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'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* also reports an array of intermediate result metrics that are useful in interpreting the results.

GradeDec'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. *GradeDec* can be used to comply with the Office of Management and Budget's *Guidelines for Benefit Cost Analysis* specified in Circular No. A-94. 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 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.

Accident risk is the number of annual predicted accidents at a crossing (or in a corridor or region) by severity category (fatal, injury or property damage only). Accident risk is measured in *GradeDec* using one of three distinct models:

- The New Accident Prediction and Severity (APS) Model – a recently-developed model that uses advanced statistical methods and recent crash and grade crossing inventory data
- The U.S. Department of Transportation's Accident Prediction and Severity (APS) model – a standard model that was derived in 1986.
- The High-Speed Rail (HSR) model for high-speed rail corridors, developed by Volpe Center researchers specifically for high speed rail corridors.

GradeDec users may select the model best suited for their analyses.

Both the corridor and the regional analysis modules of *GradeDec* include the New Accident Prediction and Severity Model and 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 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*, 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* includes a graphical interface that facilitates data entry and the visualization of probability distributions. *GradeDec* 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 represents a major upgrade from *GradeDec.Net*, the previous release of GradeDec. It incorporates additional analytic algorithms and handles many more grade crossings simultaneously. *GradeDec* 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* easy to use for conducting an analysis.

GradeDec has been available to the public since January 2003, and was recently upgraded. Since its initial release, *GradeDec* has undergone refinements that reflect experience gained from hundreds of analyses and feedback from the community of over 500 registered users and training workshop participants.

The main refinements to the *GradeDec* model since it was introduced include:

- Ability to develop a capital program of improvements with two-phased investment at each crossing (and not just assuming that all investment occurs prior to the period of analysis).
- Explicit segmentation of time-of-day distributions for passenger, freight and switch train movements (in the corridor schema, and for through and switch train movements in the regional schema).
- Increasing from one to three the number of placeholder “new technology” options for grade crossing devices.
- Creating three placeholder options for “other supplementary safety devices” at crossings.
- New APS was added to the upgraded *GradeDec.*

In addition to these modifications, there are a number of refinements to the application interfaces and reporting features that should facilitate the development of analyses with *GradeDec.* These refinements are covered in the revision the companion *GradeDec User's Manual.*

About This Document

This document is the reference for the *GradeDec* 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* application you should refer to the companion volume to this document called "User's Manual for *GradeDec"*.

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 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*

The analysis frame of *GradeDec* 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 major investment) to the costs and benefits in the "base case" (without major investment).

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

Benefits and Costs

The benefits in a *GradeDec* analysis are the public benefits that accrue from grade crossing improvements. These include:

- Safety – the safety benefits are the reduction in predicted accidents and their severity.
- Other user cost savings – other user cost savings result from less queuing at crossing due to grade crossing separations and closures. These benefits are travel time savings, reduced highway vehicle operating costs, reduced emissions and better highway network traffic flow. Closures, without other improvements in a corridor, will typically result in increased user costs and the analysis accounts for these offsetting impacts.

The costs in *GradeDec* are the costs to operate and maintain crossings and the capital outlays for improvements (investment).

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 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 predicted number of accidents and their severity. When proposed investments include grade crossing closures and separations, *GradeDec* evaluates any additional re-allocation of traffic that is likely to occur.

The user has the option of a) allowing all investments at crossings to be implemented in the base year, or, b) developing a capital program by crossing in which one or two phases of improvements can be specified and a year of implementation for each phase (i.e., in year 3 upgrade crossing to gates and in year 15 grade separate the crossing).

This capital programming feature enables the use to develop and evaluate multi-year grade crossing improvement strategies that accommodate the anticipated growth in traffic and the availability of funding.

Base Case and Alternate Case

The Base Case represents the "no major 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 minor improvements. An analysis will typically include a program of modest investments in the Base Case where these investments are part of a minimal fall back position that are most likely to be undertaken in lieu of the more extensive investments.

In the Alternate Case, the analysis evaluates the benefits and costs under the assumption that the proposed investments (in the designated years for cases with capital programming) have been implemented.

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

In *GradeDec* 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)
- Characteristics of rail operations at crossings
- O&M and other lifecycle costs
- Capital investment (alternate case only).

Corridor or Region

GradeDec 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* has a separate analytic model for corridors and for regions. The Corridor Schema provides greater analytic depth than the Regional Schema. The following features are available in the Corridor Schema, but not in the Regional Schema:

- 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 schema. 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 Schema. *GradeDec* 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* 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 16 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.
- Factors for up to three technology improvements. 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* 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 schema 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 schema 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 600 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 (which is accessible from within *GradeDec*).

The Time Horizon

The time horizon of a *GradeDec* 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 2004 and end year 2026 then the model assumes investments in the corridor have been completed by the end of 2003 (the base year) and are fully operational from the beginning of 2004. Benefits from the investment will accrue in the alternate case beginning in year 2004. 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* 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 2004 and the last year is 2026, the last year of near term could be 2007. 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* 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 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, and will likely fluctuate in comparison to other prices. In *GradeDec*, 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* Computational Model

GradeDec includes the following analytic components:

- Re-assignment of highway traffic due to closures and grade separation (corridor schema 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* employs one of three different computational models depending upon the user's selections. These are:

- The New Accident Prediction and Severity Model (developed for FRA in 2020)
- U.S. Department of Transportation (DOT) Accident Prediction and Severity Model (APS) and Resource Allocation Method (from 1986)
- Volpe National Transportation System Center (VNTSC) High-Speed Rail (HSR) Accident Severity Model

When using the corridor schema, the user can choose which of the three models to use. For the regional schema, the HSR model is not 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*.

The New Accident Prediction and Severity Model (APS20)

This model is described in the document: *New Model for Highway-Rail Grade Crossing Accident Prediction and Severity*, DOT/FRA/ORD-20/40, October 2020 (the document can be downloaded at https://railroads.dot.gov/elibrary/new-model-highway-rail-grade-crossing-accident-prediction-and-severity). The model uses new safety analysis regression methods and was derived using recent data. APS20 is applied in *GradeDec* as described in the above document with correction for the correlation between time-of-day distribution between rail and highway traffic.

The DOT Accident Prediction and Severity Model (APS86) 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* as described in the above document with one modification: *GradeDec* 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* uses the resource allocation method in the corridor schema (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 VNTSC High Speed Rail Accident Severity Formulas

The HSR model is an optional feature of the corridor schema in *GradeDec*. 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.

Data and Data Organization in *GradeDec*

This section provides a brief overview of data and their organization in *GradeDec*. 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 three technology parameters that represent the effectiveness of new technology at a 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 model parameter and default 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*.

Accident Prediction and Severity

The accident prediction and severity formulas in *GradeDec* are based upon the three alternatives cited in the introduction, namely:

- The USDOT APS (APS86)
- The New APS (APS20)
- The HSR APS (APSHSR)

These equations are applied in accordance with the mode of usage (corridor or Regional Schema). In the Corridor Schema, the user can specify whether to use the HSR formulas or the DOT formulas. In the Corridor Schema, the user can specify any of the three methods, and while in the Regional Schema, the user can only specify one of the two APS models. Moreover, in the Corridor Schema 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 following sections describe the accident prediction and severity equations in *GradeDec*.

Forecast Highway and Rail Traffic

GradeDec 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 crossing is:

Equation 1 Average Annual Daily Traffic (Highway) at Crossing

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

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

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

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

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

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

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

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

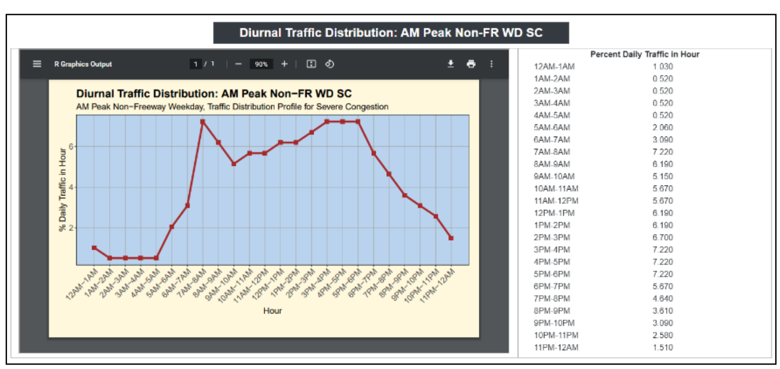
Exposure and Correlation of Diurnal Distributions by Highway and Rail

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* do not account for the correlation between the diurnal distributions of rail and highway traffic. *GradeDec* 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 Schema, 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 diurnal distributions in *GradeDec* divide the daily traffic into twenty-four hourly periods. The user interface of *GradeDec* lets the user select from among the twenty-one pre-set traffic distributions. Five of these are labeled: Uniform, Peak AM, Peak PM, Day Flat and Night Flat. These five distributions are stylized diurnal distributions that are not representative of a particular facility type or traffic pattern. The remaining sixteen are representative traffic distributions for a range of facility types in both urban and rural locales.

Figure 2 Traffic Distribution Profiles



The diurnal distributions provided in *GradeDec* are for convenience, and the user can modify these values or create new distributions 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

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

where:

i an index designating the hour of the day

j an index of highway vehicle type (auto, truck, bus)

k an index of train types (passenger, freight, switch in the Corridor Schema or through and switch in the Regional Schema)

a_{ik} the share of daily trains of train type k at the crossing in the ith time-of-day period

b_{ij} the share of daily traffic of vehicle type j in the ith hour of the day

α_k the share of train type k of total trains

β_j the share of vehicle type j in daily highway traffic

Note: $\sum_i a_{ik} = 1, \quad \sum_i b_{ij} = 1, \quad \sum_k \alpha_k = 1, \quad \sum_j \beta_j = 1$

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

GradeDec 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 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 was equal to the national average[2]. *GradeDec* calculates the daily exposure with time-of-day correlation for each crossing and year of the evaluation.

The New Accident Prediction and Severity Model (APS20)

The new accident prediction and severity model (APS20)[3] is intended for use as a replacement to the USDOT Accident Prediction and Severity model (APS86). The new model was estimated with newer statistical methods that have been widely applied to safety analysis. Recent data were used in the model estimation. APS86 was published in 1986. Methods and data used in developing APS86 were from years preceding its publication. Multiple validations show that APS20 is a better predictor than APS86.

Accident Prediction

The accident prediction component of APS20 has two principal steps:

- A statistical model that explains accident risk as a function of grade crossing characteristics, and
- An adjustment process that accounts for accident history at the grade crossing.

The statistical model employs a method called zero-inflated negative binomial (ZINB). The model has two linked sub-models:

- a count model that predicts an initial estimate of accidents at a grade crossing, and
- an inflated zero model, that predicts the probability that accident risk at a crossing is an "inflated zero" (i.e., effectively has no accident risk).

The ZINB predicted accidents value is then adjusted using a process called Empirical Bayes (EB) to account for the accident history at the crossing.

Table 1 shows the equations for accident prediction using ZINB and EB.

The numerical values in Table 1 are estimated coefficients from the ZINB regression analysis. The bolded expressions in Equations 1 and 2

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

[3] A full exposition of APS20 can be found at: https://railroads.dot.gov/elibrary/new-model-highway-rail-grade-crossing-accident-prediction-and-severity "New Model for Highway-Rail Grade Crossing Accident Prediction and Severity", DOT/FRA/ORD-20/40, October 2020.

represent grade crossing characteristics and are explained in Table 2. The 5-year accident history is shown in Eq. 4 as ***AccCount***.

Table 1 The New Accident Prediction Model

Eq. ID	**Equation**
1	Calculation of predicted accidents using the ZINB count model
	$N_{CountZINB} = e^{L}$, $L = -8.01314 + 0.16952 \cdot \boldsymbol{lExpo} - 0.09801 \cdot \boldsymbol{Dx3} + 0.13392 \cdot \boldsymbol{Dx3} - 0.2283 \cdot \boldsymbol{D2} - 0.81117 \cdot \boldsymbol{D3} + 0.38484 \cdot \boldsymbol{RurUrb} + 0.1352 \cdot \boldsymbol{XSurfaceID2s} + 0.67161 \cdot \boldsymbol{lMaxTtSpd} + 0.11483 \cdot \boldsymbol{lAadt}$
2	Calculation of the probability of an inflated zero using the ZINB inflated zero model
	$P_{ZeroZINB} = z/(1+z)$, $z = e^{M}$, $M = 1.24505 - 1.05711 \cdot \boldsymbol{lTotalTrains}$
3	Calculation of predicted accidents with the combined ZINB count and inflated zero models
	$N_{ZINB} = N_{CountZINB} \cdot (1 - P_{ZeroZINB})$
4	Calculation of the adjusted predicted accidents using the EB process
	$N_{ZINB+EB} = w \cdot N_{ZINB} + (1 - w) \cdot \boldsymbol{AccCount}$
5	Calculation of the weight value used in Eq. 4
	$w = 1/(1 + V[N_{ZINB}]/N_{ZINB})$
6	Calculation of the variance of the ZINB predicted accidents used in Eq. 5
	$V[N_{ZINB}] = N_{ZINB} \cdot [1 + N_{CountZINB} \cdot (P_{ZeroZINB} + 1.2932)]$

Table 2 shows a description of the variables used the new accident prediction model.

Table 2 Description of New Accident Prediction Model Variables

Variable	**Description**
AccCount	Count of accidents at grade crossing for period 2014-2018
lExpo[1]	Exposure, equal to average annual daily traffic times daily trains
Dx3	$\begin{cases} 0, \text{when the } gx's \text{ } lExpo \text{ value is not in region III} \\ 1, \text{when the } gx's \text{ } lExpo \text{ value is in region III} \end{cases}$ $Region\ III: 14.54 \le lExpo < 18.96$

Variable	Description
Dx4	$\begin{cases} 0, when\ the\ gx's\ lExpo\ value\ is\ not\ in\ region\ IV \\ 1, when\ the\ gx's\ lExpo\ value\ is\ in\ region\ IV \end{cases}$ $Region\ IV: 18.96 \leq lExpo < 20.31$
D2	If warning device type is lights =1, 0 otherwise
D3	If warning device type is gates =1, 0 otherwise
RurUrb	If Rural = 0, if Urban = 1
XSurfID2s	Grade crossing surface material: Timber = 1, Asphalt = 2, Asphalt and Timber OR Concrete OR Rubber = 3, Concrete and Rubber = 4
lMaxTtSpd[1]	Maximum timetable speed (integer value between 0 and 99)
lAadt[1]	Average annual daily traffic
lTotalTrains[1]	Total number of daily trains

[1]These variables have been transformed as follows: lx = log(1+αx), where x is the original variable and α is a factor. The factor α was selected so that for the median value of x, ln(1+αx) = ln(x)

In the calculation of the alternate case predicted accidents, the following formula is used:

$$N_{ZINB+EB(ALT)} = N_{ZINB+EB(BASE)} \cdot N_{ZINB(ALT)}/N_{ZINB(BASE)}$$

New Accident Severity Model

The accident severity component of APS20 was derived

from regression analysis. The analysis used the ordinal logistic statistical method. The method is one that is suited for classification, that is, the model classifies accidents into one of three severity types: Property Damage Only (PDO), injury and fatal. The statistical method also uses the information that the severity types are ordered, that is: PDO severity < Injury severity < Fatal severity.

The numerical values in Table 3 are estimated coefficients from the ordinal logistic regression analysis. The bolded expressions in Equation 1 represent grade crossing characteristics and are explained in Table 4.

Table 3 The New Accident Severity Model

Eq. ID	**Equation**
1	Calculation of common element used in Equations 2, 3 and 4
	$Z = -0.29043 \cdot \boldsymbol{lMaxTtSpdSq} - 0.10696 \cdot \boldsymbol{lThru} + 0.13847 \cdot \boldsymbol{lSwitch} - 0.03317 \cdot \boldsymbol{lAadt} - .14500 \cdot \boldsymbol{RuralUrban} - .20471 \cdot \boldsymbol{D1}$
2	Calculation of probability that an accident is of severity PDO
	$P_{PDO} = 1/(1 + e^{-3.05946-Z})$
3	Calculation of probability that an accident is of severity Injury
	$P_{INJ} = 1/(1 + e^{-4.60832-Z}) - 1/(1 + e^{-3.05946-Z})$
4	Calculation of probability that an accident is of severity Fatal
	$P_{FATAL} = 1 - 1/(1 + e^{-4.60832-Z})$

Table 4 Description of New Accident Severity Model Variables

Variable	**Description**
P_{PDO}	The probability that an accident is of severity type PDO
P_{INJ}	The probability that an accident is of severity type Injury
P_{FATAL}	The probability that an accident is of severity type Fatal

Variable	Description
lMaxTtSpdSq[1]	the square of maximum time table speed (mtts) at a grade crossing (transformed as shown in the next equation). The rationale for linking severity to the square of mtts is that accident severity is largely a function of the kinetic energy generated by an accident. The kinetic energy is proportional to the square of the speed. The mtts variable is capped at 70 mph, that is, for mtts exceeding 70 the variable is fixed at 70.
lThru[1]	the number of daily through trains at the crossing, transformed as shown in the next equation.
lSwitch[1]	the number of daily switch trains at the crossing, transformed as shown in the next equation.
lAadt[1]	average annual daily highway traffic
RuralUrban	1 if grade crossing is in a rural area, 0 otherwise.
D1	1 if grade crossing has no lights or gates, 0 otherwise.

[1]These variables have been transformed as follows: $lx = \log(1+\alpha x)$, where x is the original variable and α is a factor. The factor α was selected so that for the median value of x, $\ln(1+\alpha x) = \ln(x)$. (The median value for the variable lSwitch is 0. For this variable, the mean value was used for α.)

Accident Prediction And Severity Model (APS86)

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

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

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

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

where:

	Type of Grade Crossing			
	Passive	Flashing Lights	Lights and Gates	New Technology
K	.0006938	.0003351	.0005745	.0001915
EI	$\left[\frac{Expose + 0.2}{0.2}\right]^{0.37}$	$\left[\frac{Expose + 0.2}{0.2}\right]^{0.4106}$	$\left[\frac{Expose + 0.2}{0.2}\right]^{0.2942}$	$\left[\frac{Expose + 0.2}{0.2}\right]^{0.2942}$
DT	$\left[\frac{dthru + 0.2}{0.2}\right]^{0.1781}$	$\left[\frac{dthru + 0.2}{0.2}\right]^{0.1131}$	$\left[\frac{dthru + 0.2}{0.2}\right]^{0.1781}$	$\left[\frac{dthru + 0.2}{0.2}\right]^{0.1781}$
MS	$e^{0.0077 \cdot ms}$	1	1	1
MT	1	$e^{0.1917 \cdot tracks}$	$e^{0.1512 \cdot tracks}$	$e^{0.1512 \cdot tracks}$
HL	1	$e^{0.1826 \cdot (lanes - 1)}$	$e^{0.142 \cdot (lanes - 1)}$	$e^{0.142 \cdot (lanes - 1)}$
HP	$e^{-0.5966 \cdot (paved - 1)}$	1	1	1
Adj	0.5086	0.3106	0.4846	0.4846 · 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 regression coefficient

Adj Coefficient to normalize predicted accidents in year with actual counts (current values are normalize for year 2013)

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* 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 Crossing 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

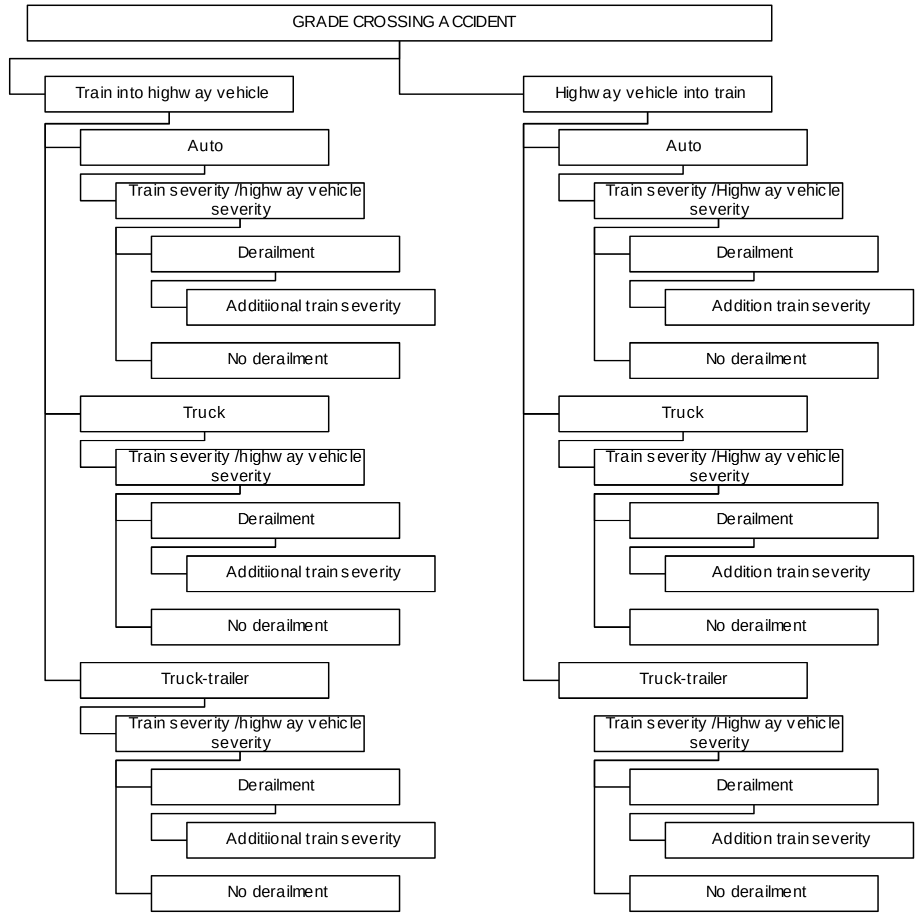
PA predicted number of PDO accidents per year at the grade crossing

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. Using the HSR formulas, accident history is not taken into consideration. *GradeDec* 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,

$$\overline{sp}_{ttype} = \begin{cases} sp_{ttype}, \; sp_{ttype} \le sp^{\max} \\ sp^{\max}, \; sp_{ttype} > sp^{\max} \end{cases}, \; for \; occ = Highwayvehicleoccupants$$

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

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)

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.

If a device is upgraded to one of the new technology types, then the upgrade effectiveness factor is equal to 1 minus the “upgrade to gates” effectiveness factor, times 1 minus the corresponding technology effectiveness factor.

Table 2 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 “Rule for the Use of Locomotive Horns at Highway-Rail 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 3 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

Supplemental Safety Measures	Effectiveness Rate
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 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 differs from time-in-queue because it captures the total time impact of a closure, including the time it takes for vehicles to return to regular traffic flow.

GradeDec employs techniques from recent research[4] 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 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.

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.

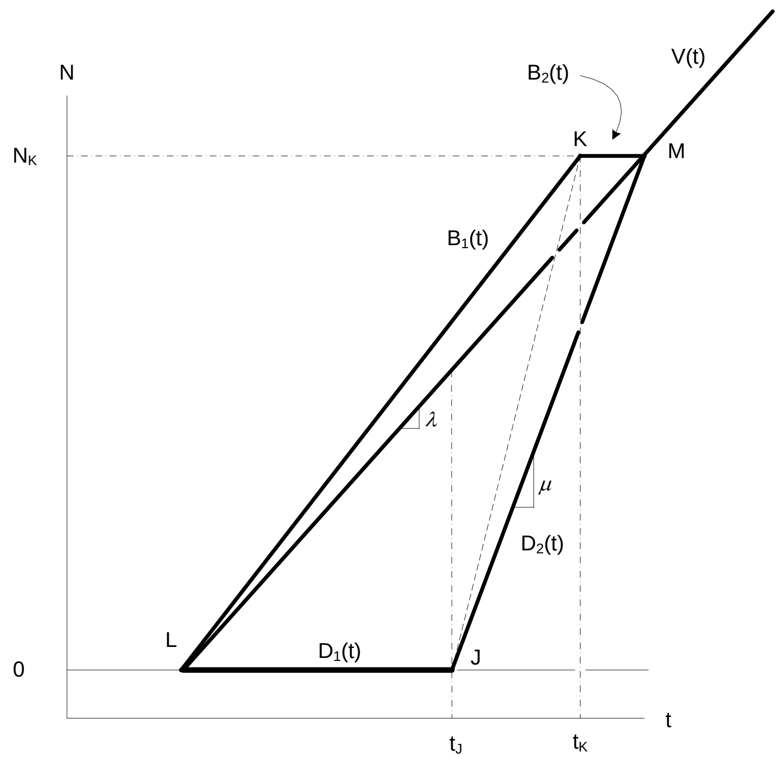
[4] *Using Input-Output Diagram to Determine Spatial and Temporal Extents of Queue Upstream of a Bottleneck*, Tim Lawson, David J. Lovell, and Carlos F. Daganza, Transportation Research Record 1572. pp. 140-147.

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

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

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

Figure 4 Analysis of Delay and Time-in-Queue



Equation 11 Average Crossing Closure Time (minutes)

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

$$ACBT = \frac{\sum_i \delta_i \cdot CBT_i}{\sum_i \delta_i}$$

where:

i	index indicating the type of train: passenger, freight or switch
CBT_i	crossing block 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

ACBT average crossing block 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 number of crossing blocks in each time-of-day period equals the number of trains in the period and is calculated as follows:

Equation 12 Number of Blocks in Time-of-Day Period

$$blocks_{per} = \sum_{trtype} Tr_{trtype} \cdot trtod_{trtype,per}$$

where:

Tr_{trtype} average number of daily trains of type (passenger, freight, switch)

$trtod_{trtype,per}$ Share of average daily trains of type in time-of-day period

Equation 13 Shares of Directional Traffic Weighted by Passenger Car Equivalent

$$d1_{per} = \frac{\sum_{\alpha}\left(d1_{\alpha,per} \cdot veh_{\alpha,per} \cdot PCE_{\alpha}\right)}{AADT}$$

$$d2_{per} = 1 - d1_{per}$$

where:

$d1_{per}$ share of traffic weighted by PCE in principal direction in period

$d2_{per}$ share of traffic weighted by PCE in non-principal direction in period

$veh_{\alpha,per}$ number of vehicles in traffic segment α in period

PCE_{α} Passenger car equivalent by traffic segment (1 for autos, 1.8 for trucks and 2.73 for busses)

$d1_{\alpha,per}$ Percentage of vehicles in traffic segment α in period in principal direction

AADT Average annual daily traffic

Equation 14 Lanes of Traffic in Each Direction in Hourly Period

$$lanes_{d1} = \begin{cases} lanes\ is\ even, & \dfrac{lanes}{2} \\ lanes\ is\ odd\ and\ d1 > d2, & ceiling\left(\dfrac{lanes}{2}\right) \\ lanes\ is\ odd\ and\ d1 \le d2, & floor\left(\dfrac{lanes}{2}\right) \end{cases}$$

$$lanes_{d2} = lanes - lanes_{d1}$$

where:

$lanes_{d1}$	lanes bearing traffic in the principal direction in hourly period
$lanes_{d2}$	lanes bearing traffic in the non-principal direction in hourly period
lanes	total number of lanes at the crossing
d1	share of traffic weighted by PCE in principal direction in period equivalent
d2	share of traffic weighted by PCE in non-principal direction in period

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

Equation 15 Arrival Rate of Vehicles (vehicles per second per lane in traffic direction)

$$\lambda = \frac{AADT \cdot \sum_{\alpha}(\alpha \cdot d_{\alpha,per,i} \cdot PCE_{\alpha})}{3600 \cdot lanes_{di}}$$

where:

AADT	average annual daily traffic at crossing
A	share of highway traffic for traffic segment (auto, truck, bus)
$d_{\alpha,per,i}$	share of highway traffic by segment in hour by direction (i=principal, non-principal direction)
PCE_{α}	Passenger car equivalent (auto=1, truck=1.8 and bus=2.72)
3600	seconds per hour
$lanes_{di}$	highway lanes in direction i

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

Equation 16 The Number of Affected Highway Vehicles per Block per Lane

$$N_K = \frac{\lambda \cdot \mu \cdot ACBT \cdot 60}{\mu - \lambda}$$

where:

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

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

Equation 17 Total Vehicle Delay per Period by Traffic Direction (vehicle-hours)

$$w = N_K \cdot \left[ACBT \cdot 60 + \left(\frac{1}{\mu} - \frac{1}{\lambda} \right) \cdot \left(\frac{N_k + 1}{2} \right) \right] \cdot \frac{lanes}{3600} \cdot blocks_{per}$$

where:

λ	arrival rate of vehicles, vehicles per second
μ	dispersal rate of vehicles, vehicles per second (constant value of 0.5)
ABCT	average crossing block time in minutes
N_K	the number of affected vehicles at closure
lanes	number of highway lanes by direction
$blocks_{per}$	number of crossing blocks per period

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

Equation 18 Slope of the Back-of-Queue Function

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

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 time-of-day period is given by:

Equation 19 Time-in-queue per Time-of-Day Period by Direction (vehicle-hours)

$$t_q = N_K \cdot \left[ACBT \cdot 60 + \left(\frac{1}{\mu} - \frac{1}{z} \right) \cdot \left(\frac{N_k + 1}{2} \right) \right] \cdot \frac{lanes}{3600} \cdot blocks_{per}$$

where:

z slope of the back-of-queue function

μ dispersal rate of vehicles, vehicles per second (constant value of 0.5)

ACBT average crossing closure time in minutes

N_K the number of affected vehicles at closure

lanes number of highway lanes

$blocks_{per}$ number of crossing blocks per period

GradeDec 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 time-of-day period is given by:

Equation 20 Delay for Traffic Segment in Time-of-Day Period (vehicle-hours)

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

where:

w total vehicle-hours delay in time-of-day period

$veh_{\alpha,per}$ number of vehicles of type α (auto, truck, bus) in period

Equation 21 Time-in-Queue for Traffic Segment in Time-of-Day Period (vehicle-hours)

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

where:

t_q 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

The average daily delay for each traffic segment is the sum of the delay for the traffic segment in the four time-of day periods. The average daily time-in-queue for each traffic segment is the sum in the four time-of day periods.

Highway Traffic Re-Assignment (Corridor Schema Only)

With the corridor schema, *GradeDec* 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* model prior to the calculation of all benefit categories.

Grade Closures

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

Equation 22 Diversion from Closure to Lower Adjacent Crossing

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

where:

$aadt_{i-1}$ average annual daily traffic at the crossing adjacent and below the closure, after re-assignment

$aadt_i$ average annual daily traffic at the closed crossing before re-assignment

$aadtb_{i-1}$ average annual daily traffic at the crossing adjacent and below the closure, before re-assignment

mp_i the milepost value of the ith crossing, the closed crossing from which traffic is diverted

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

Equation 23 Diversion from Closure to Upper Adjacent crossing

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

where:

$aadt_{i+1}$ AADT at the crossing adjacent and above the closure, after re-assignment

$aadt_i$ AADT at the closed crossing before re-assignment

$aadtb_{i+1}$ AADT at the crossing 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* 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 24 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 crossing due to a grade separation at an adjacent crossing (a function of the distance to the nearest major highway intersection)

min PD minimum percent of potential AADT diverting from the crossing due to a grade separation at an adjacent crossing (independent of the distance to the nearest highway intersection). This value is set to 5.

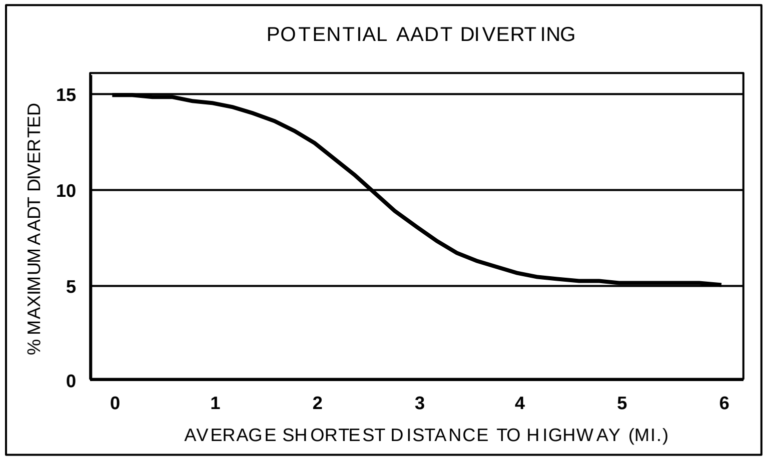
max PD maximum percent of potential AADT diverting from the crossing due to a grade separation at an adjacent crossing (independent of the distance to the nearest highway intersection). This value is set to 15.

α equation parameter set to 4.783. This parameter and the following one are set to meet two conditions: 1) if distance of crossing 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 crossing 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 crossing due to a grade separation at an adjacent crossing

Figure 5 Potential Diversion due to Grade Separation



Equation 25 Percent AADT Diverted from Crossing to adjacent Grade Separated Crossing

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

where:

pcAADTdivert percent of diversion of AADT from the traffic at the crossing to the adjacent, grade separated crossing

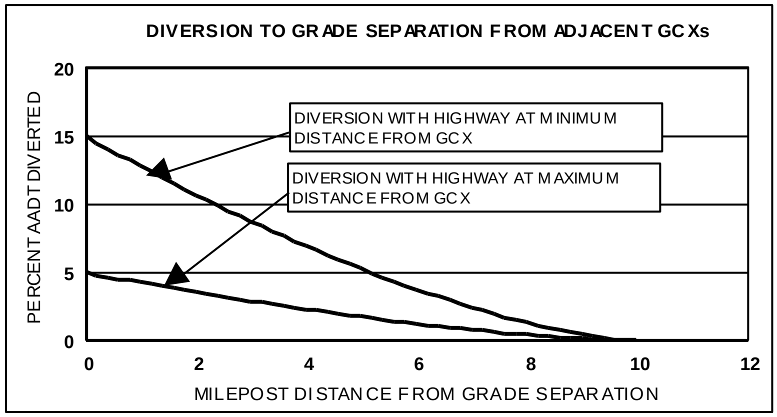
pAADTd percent of potential AADT diverting from the crossing due to a grade separation at an adjacent crossing (see above equation)

ΔMP distance between the adjacent crossing and the grade separated crossing

max MP the maximum distance between adjacent crossings, 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 crossing 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 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.*

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* calculates the safety benefits as:

Equation 26 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 27 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 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 28 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 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 crossing 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 six emission types: carbon monoxide, volatile organic compounds, nitrous oxide, articulate matter, sulfur oxide, and carbon dioxide. 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 29 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: VOC, CO, NOx, PM, SOx, CO_2

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 30 Environmental Benefits (for each year and crossing)

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

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 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 31 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 32 Vehicle Operating Cost Benefits (for each year and crossing)

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

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

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

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

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 crossing

AF annualization factor

VOCB vehicle operating cost benefit

Network Benefits (Corridor Schema Only)

GradeDec 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 crossing in each year is as follows:

Equation 33 Network Delay (for crossing, year)

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

$$VAPB = VAPH \cdot \frac{ACBT}{60}$$

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

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

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

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

$$ND = \sum_{per} ND_{per}$$

where:

ACBT average crossing block time, minutes (see Equation 11)

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

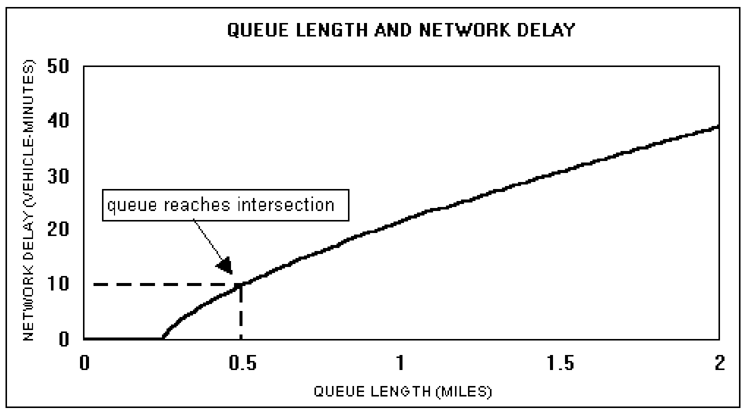
β elasticity of network delay with respect to queue length, set to 0.7

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 34 Network Benefits (for each crossing and year)

$$NDPC = ND \cdot (1 - strucks - sbus) \cdot avgocc \cdot votpx$$
$$NDBC = ND \cdot sbus \cdot (vottr + avgoccbus \cdot votpx)$$
$$NDTC = ND \cdot strucks \cdot vottr$$
$$NDCA = (NDPC + NDBC + NDTC) \cdot AF$$
$$NDSB = NDCA_{base} - NDCA_{alt}$$

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 35 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 36 Total and Net Project Costs (for each year)

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

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

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

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

Salvage Value

In an analysis of the benefits and costs of infrastructure investments, it is customary to “add back” the residual or salvage value of the investments at the end of the time horizon of the analysis. In principle, this represents the value of the remaining useful life of the capital improvements.

In *GradeDec* the analysis assumes that the value of the invested capital declines by 5% per year. The salvage value is calculated at the end of the analysis period. In the benefit-cost summary it is discounted to present value terms.

$$IVal_{InvYr} = CapCost$$

$$IVal_t = IVal_{t-1} \cdot (1-\delta)$$

$$Salvage = \sum_{cr} IVal_{lyr+1}$$

where:

$IVal_{Invyr}$ Value of the improvement in the year of its implementation

CapCost capital cost of the improvement

$IVal_t$ Value of the improvement in year t

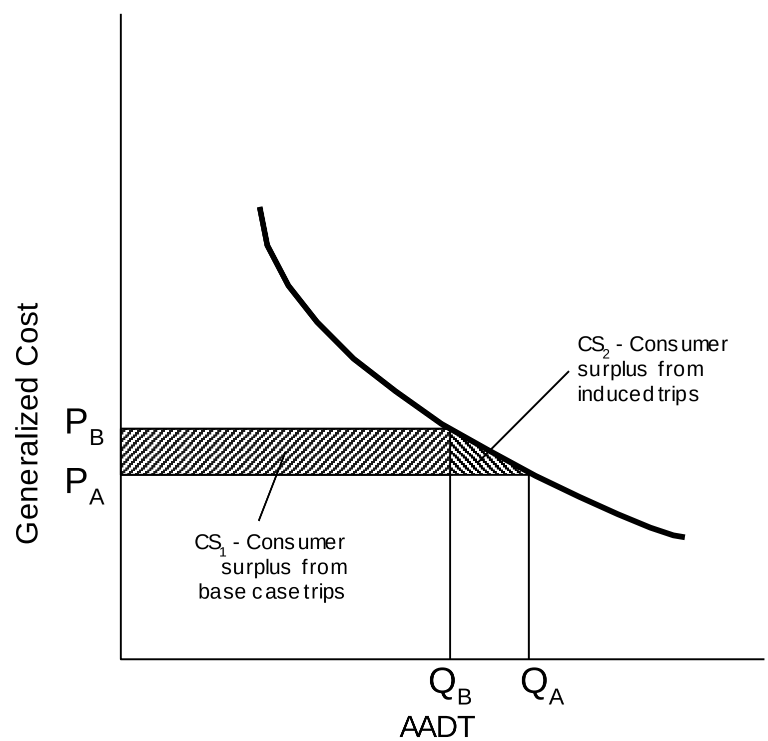
$IVal_{t-1}$ Value of the improvement in year t-1

δ rate of depreciation, set at 5 percent per year

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* 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 37 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 38 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 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 39 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 40 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 39.

Equation 41 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 function

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 42 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 function 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 43 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 44 Consumer Surplus from Induced Trips

$$CS_2 = CS - CS_1$$

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 45 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 46 Total benefits (excluding local) in corridor (for each year)

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

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

Salvage Salvage value of investments (last year only)

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

Equation 47 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 48 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 49 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 50 Net Present Value

$$NPV = PVB - PVC$$

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 51 Benefit-Cost Ratio

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

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 52 Project Rate of Return

$$PRR = IRR(TB_{year} - NC_{year})$$

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.

TB_{year} Total benefits, dollars

NC_{year} Net project costs, dollars

Data and Data Organization

Introduction

There are four principal data elements in *GradeDec* 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 16 daily traffic distributions corresponding to different patterns of diurnal traffic distributions. These distributions of traffic divide the daily traffic into 24 hourly periods. The traffic distributions are each represented as a vector of 24 values that sum to 1. For example, the uniform distribution is given by .01467 (1/24) as the share of daily traffic in each hourly period. The *GradeDec* 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 Schema, unlike the corridor schema, 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 crossing and specifies its geographic location within the rail corridor. The difference between the mileposts of two consecutive crossings 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 crossing 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*: 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* maps these types into the types used by its model as follows:

Table 4 Mapping of Crossing Types

National Inventory Crossing Type	*GradeDec* 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 schema.

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 16 daily traffic distributions corresponding to different patterns of diurnal traffic distributions. These distributions of traffic divide the daily traffic into 24 hourly periods. The traffic distributions are each represented as a vector of 24 values that sum to 1. For example, the uniform distribution is given by .01467 (1/24) as the share of daily traffic in each hourly period. The *GradeDec* 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 schema differs slightly from that of the Regional Schema. In the descriptions below, the variables belonging to each model are shown.

A simulation engine solves the *GradeDec* 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 default data included in the scenarios provided with *GradeDec* for the values of time, crash costs and emissions costs were derived from:

TIGER Benefit-Cost Analysis (BCA) Resource Guide, updated 4/18/2014, U.S. Department of Transportation, http://www.dot.gov/tiger

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 4 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 5 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	244	3.5	0.0
4-quadarnt gates with detection	260	5	0.0
4-quadarnt gates with 60' medians	255	25	0.0
Mountable curbs	15	3.5	0.0
Barrier curbs	15	3.5	0.0
One-way street	5	3.5	0.0
Photo enforcement	65	25	0.0

Based on FRA internal data

Table 6 Emission Rates by Type of Vehicle, Grams per Minute

VehType ID	VEH	VOC	CO	NOX	PM	SOX	CO_2
1	Cars	0.0447	1.1871	0.0586	0	0	31.0652
2	Buses	0.1083	2.5317	0.0888	0	0	87.5789
3	Tucks	0.0576	0.4271	0.5627	0.0383	6.9937	107.4107

Sources: CO_2 emissions per gallon of fuel consumed EPA Emission Facts, Calculating Emissions of Greenhouse Gases: Key Facts and Figures (February 2005)

Non-carbon emission rates per hour EPA, Idling Vehicle Emissions for Passenger Cars, Light-Duty Trucks, and Heavy-Duty Trucks (October 2008)

Table 7 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 8 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 9 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 10 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

Table 11 Default Values for Diurnal Traffic Distribution

Diurnal Distributions (Share of daily traffic in hour)												
Name/Description	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Uniform / Uniform												
AM	4.167	4.167	4.167	4.167	4.167	4.167	4.167	4.167	4.167	4.167	4.167	4.167
PM	4.167	4.167	4.167	4.167	4.167	4.167	4.167	4.167	4.167	4.167	4.167	4.159
AM Peak / AM Peak												
AM	1.667	1.667	1.667	1.667	1.667	8.333	8.333	8.333	8.333	8.333	8.333	8.333
PM	5.833	5.833	5.833	5.834	5.834	0.833	0.833	0.833	0.833	0.833	0.834	0.834
PM Peak / PM Peak												
AM	0.833	0.833	0.833	0.833	0.833	5.833	5.833	5.833	5.833	5.833	5.833	5.833
PM	8.333	8.333	8.333	8.333	8.334	8.334	1.667	1.667	1.667	1.667	1.668	1.668
Day Flat / Day Flat												
AM	1.667	1.667	1.667	1.667	1.666	1.666	6.667	6.667	6.667	6.667	6.666	6.666
PM	6.667	6.667	6.667	6.667	6.666	6.666	1.667	1.667	1.667	1.667	1.666	1.666
Night Flat / Night Flat												

Diurnal Distributions (Share of daily traffic in hour)												
Name/Description	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
AM	6.667	6.667	6.667	6.667	6.666	6.666	1.667	1.667	1.667	1.667	1.666	1.666
PM	1.667	1.667	1.667	1.667	1.666	1.666	6.667	6.667	6.667	6.667	6.666	6.666
AM Peak FR WD LC / AM Peak, Freeway Weekday, Traffic Distribution Profile for Low Congestion												
AM	1.000	0.500	0.500	0.500	1.000	2.490	6.470	9.450	6.970	4.980	4.980	4.480
PM	4.980	5.470	5.970	6.470	6.970	6.970	5.470	3.980	3.480	2.990	2.490	1.440
AM Peak Non-FR WD LC / AM Peak, Non-Freeway Weekday, Traffic Distribution Profile for Low Congestion												
AM	0.990	0.490	0.490	0.490	2.990	2.460	4.430	8.370	6.900	4.930	4.930	5.420
PM	6.400	6.400	6.400	6.900	6.900	6.400	4.930	4.430	3.450	2.960	2.460	1.480
PM Peak FR WD LC / PM Peak, Weekday, Traffic Distribution Profile for Low Congestion												
AM	1.000	.500	.500	.500	1.000	1.500	3.500	5.500	5.000	4.500	4.500	5.000
PM	5.500	5.500	6.500	8.000	9.500	9.500	6.500	4.500	3.500	3.000	3.000	2.000
PM Peak Non-FR WD LC / PM Peak, Non-Freeway, Traffic Distribution Profile for Low Congestion												
AM	0.980	0.490	0.490	0.490	0.490	0.980	2.450	4.410	4.410	4.410	4.900	5.880
PM	6.860	6.370	6.860	8.330	9.310	9.310	6.370	4.900	3.920	2.940	2.450	2.000
AM Peak FR WD MC / AM Peak. Freeway Weekday, Traffic Distribution Profile for Moderate Congestion												
AM	1.010	0.500	0.500	0.500	1.010	2.510	6.530	9.050	7.540	5.530	5.030	5.030
PM	5.030	5.530	5.530	6.530	7.040	6.530	5.030	4.020	3.020	3.020	2.510	1.470
AM Peak Non-FR WD MC/ AM Peak, Non-Freeway Weekday, Traffic Distribution Profile for Moderate Congestion												
AM	1.010	0.500	0.500	0.500	1.010	1.510	4.520	7.540	7.040	5.030	5.030	5.030
PM	6.530	6.530	5.53-	7.040	7.040	7.040	5.530	4.520	3.520	3.020	2.510	1.470
PM Peak FR WD MC / PM Peak, Freeway Weekday, Traffic Distribution Profile for Moderate Congestion												
AM	1.010	0.500	0.500	0.500	0.500	1.500	4.000	6.000	5.500	4.500	4.500	5.000
PM	5.500	5.500	6.500	7.500	9.000	9.000	6.500	4.500	3.500	3.500	3.000	2.000
PM Peak Non-FR WD MC / PM Peak, Non-Freeway, Traffic Distribution Profile for Moderate Congestion												
AM	1.020	0.510	0.510	0.510	0.510	1.020	1.520	4.570	4.570	4.570	5.080	6.090
PM	6.600	6.600	6.600	7.610	9.140	9.140	6.600	5.080	4.570	3.550	2.540	1.490
AM Peak FR WD SC / AM Peak, Freeway Weekday, Traffic Distribution Profile for Severe Congestion												
AM	1.020	0.510	0.510	0.510	0.510	2.030	5.580	7.610	7.110	6.090	5.580	5.580
PM	5.580	5.580	6.090	6.600	6.600	6.600	5.580	4.570	3.050	3.050	2.540	1.520
AM Peak Non-FR WD SC / AM Peak, Non-Freeway Weekday, Traffic Distribution Profile for Severe Congestion												
AM	1.030	0.520	0.520	0.520	0.520	2.060	3.090	7.220	6.190	5.150	5.670	5.680

Diurnal Distributions (Share of daily traffic in hour)												
Name/Description	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
PM	6.190	6.190	6.700	7.220	7.220	7.220	5.670	4.640	3.610	3.090	2.580	1.510
PM Peak FR WD SC / PM Peak, Freeway Weekday, Traffic Distribution Profile for Severe Congestion												
AM	1.000	0.500	0.500	0.500	0.500	1.500	4.500	6.500	6.000	5.000	5.000	5.500
PM	5.500	5.500	6.500	7.000	7.500	7.500	6.500	5.000	3.500	3.500	3.000	2.000
PM Peak Non-FR WD SC / PM Peak, Non-Freeway Weekday, Traffic Distribution Profile for Severe Congestion												
AM	0.990	0.500	0.500	0.500	0.500	1.490	3.470	5.450	5.450	4.950	4.950	5.450
PM	6.440	6.440	6.930	7.430	7.430	7.430	6.440	4.950	4.460	3.470	2.480	1.900
FR WE / Freeway Weekend Traffic Distribution Profile												
AM	2.000	1.500	1.000	0.500	0.500	1.000	2.000	3.000	3.500	5.000	5.500	6.500
PM	7.000	7.000	8.000	7.000	7.500	7.000	6.500	5.000	4.500	3.500	3.500	2.500
Non-FR WE / Non- Freeway Weekend Traffic Distribution Profile												
AM	1.980	1.490	0.990	0.500	0.500	0.990	1.490	2.480	3.470	4.950	5.940	6.930
PM	7.430	7.430	7.430	7.430	7.430	6.930	5.940	4.950	4.460	3.470	2.970	2.420
FR WD SC SS / Freeway Weekday Traffic Distribution Profile for Severe Congestion and Similar Speeds												
AM	1.490	0.990	0.990	0.500	0.500	1.490	5.450	6.930	6.440	5.450	5.450	5.450
PM	5.450	5.940	5.940	6.440	6.930	6.440	5.450	4.460	3.470	3.470	2.970	1.910
Non-FR WD SC SS / Non-Freeway Weekday Traffic Distribution Profile for Severe Congestion and Similar Speeds												
AM	1.460	0.980	0.980	0.490	0.980	2.930	5.370	6.340	5.370	4.880	4.880	5.370
PM	5.370	5.370	5.370	5.850	6.340	6.340	5.850	4.880	4.390	4.390	3.410	2.410

Source: *TTI's 2012 Urban Mobility Report*, David Schrank, Bill Eisele and Tim Lomax, Texas A&M Transportation Institute, Texas A&M University System, December 2012

Table 11 Default Values for Diurnal Shares of Highway Traffic in Principal Direction at Crossing (Principal Direction of Highway Traffic is where the Lower Railroad Milepost is to Highway Vehicle Traffic's Left)

Traffic Direction (Share of hourly traffic in principal direction in hour)												
Name/Description	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Balanced /												
AM	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
PM	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
AM Peak / AM Peak												
AM	50.0	50.0	50.0	50.0	50.0	50.0	60.0	60.0	60.0	60.0	50.0	50.0
PM	50.0	50.0	50.0	50.0	50.0	50.0	40.0	40.0	40.0	40.0	50.0	50.0
PM Peak / PM Peak												
AM	50.0	50.0	50.0	50.0	50.0	50.0	40.0	40.0	40.0	40.0	50.0	50.0
PM	50.0	50.0	50.0	50.0	50.0	50.0	60.0	60.0	60.0	60.0	50.0	50.0

Data in table are illustrative, and may or may not be representative of traffic direction at a specific crossing

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