Appendix J

Delay Cost Calculations and
Grade Separation Priority Ranking of Crossings

GRADE SEPARATION PRIORITY RANKING OF CROSSINGS

January 2022

NDOT assesses the at-grade railroad crossings and, in cooperation with Railroad companies, strives to eliminate at-grade crossings which may contribute to significant vehicular delay or potential crashes. It is understood that constructing grade separations at rail crossings provides enhanced safety for the traveling public. Such projects, however, require careful consideration and extensive planning efforts. The Grade Separation Priority Ranking of Crossings guidance document establishes the criteria NDOT will use to evaluate at-grade rail crossings for potential conversion to a grade separation. This analysis will screen potential locations based on the amount of traffic (vehicular and rail) and establish priority among locations across the state based on certain criteria, such as the number of at-grade crossings that may be closed as part of the constructed grade separation, the delay costs associated with the existing at-grade crossing, and the potential to minimize crash costs.

NEEDS PLAN

The first step in the process is to consider all single public crossings with a minimum exposure factor of 50,000. A group of crossings that will be closed as a part of the project may be considered for comparison of locations but in the initial analysis there must be at least one crossing with a minimum exposure of 50,000.

PRIORITY RANKING

The next step will be to complete an initial screening of the locations in the Needs Plan to determine the potential for a grade separation based upon two primary benefits to construction of a grade separation: elimination of vehicular delay and minimizing crash costs.

When comparing locations, the delay costs will be based on all the crossings to be closed as a part of the project, whether an individual crossing or a group of crossings. As an example, Title 415, Nebraska Administrative Code, Chapter 5 requires closure of a minimum of two public at-grade crossings: one at or near the location of the new viaduct and one, or more, as selected and approved by the Department and the political subdivision. Exceptions may be granted only upon a finding of unique or unusual circumstances by the Director or Deputy Director – Engineering.

The vehicle delay and crash cost formulas used will be those developed in NCHRP Report 288 and the *Crash Prediction Model for Highway-Rail Grade Crossings in Nebraska* (Rail Study) that was developed by HNTB in conjunction with Midwest Research Institute, respectively.

DELAY COSTS

The following information describes the basic assumptions used in Nebraska to calculate delay costs.

Societal Crash Costs:

Societal crash costs used will be those developed by the Highway Safety Section of Traffic Engineering Division. Costs are updated every 2-5 years; updates shall be periodically requested from the Highway Safety Section.

Delay Costs:

Delay at a crossing is only estimated for moving trains. Insufficient data exists to estimate delay associated with stopped trains. The delay cost formulas in NCHRP 288 will be used.

Length of Train:

Train lengths shall be assumed to be 110-135 cars, which equates to 8,500 feet, or 1.61 miles

Train speed (mph):

The speed is determined for individual locations. NDOT will typically use the maximum timetable speed found in the Railroad Inventory Management System (RIMS). In areas near rail yards or other locations of high switching movements, the typical minimum speed may be used (generally 1/2 the maximum timetable speed). Coordinate with the Local Assistance Division to determine the appropriate train speed.

ADT:

In most instances, the average daily traffic shall be provided by the Strategic Planning Division. For crossings off the state system where traffic counts are unknown, traffic counts from RIMS shall be used. During an analysis of a potential project location with multiple crossings , estimates of the following will be made for use in the analysis: 1) the percent of traffic at each crossing that will move to the new grade separation, and 2) the total ADT from all crossings closed.

Average minutes for activation/deactivation of warning devices

This value shall equal 0.6 minutes

Average minutes for motorist to react and start up after train has passed

This value shall equal 0.05 minutes

Annual Crash Costs ($)

This value is calculated using the following formula:

Crash Prediction factor x *Crash Cost*, where:

Crash Prediction Factor **=** the raw number predicting the probability of a crash at a grade crossing in a given year based on data from the crossing inventory and crash files. Additional information on the *Crash Prediction Factor* will be provided in the next section.

For example, the crash prediction factor for a rural public crossing is 0.05. Therefore, the Annual Crash Cost would be calculated as follows:

Annual Crash Cost = 0.05 x $1,200,000= $60,000/year

CRASH PREDICTION FACTOR AND COSTS

In 1999, HNTB completed a Rail Study for NDOT. Based on this study, NDOT decided to adopt the US DOT Crash Prediction Model. Due to special circumstances in Nebraska where there are a substantial number of rural at grade crossings that have low vehicular traffic volumes and very high train volumes, the Midwest Research Institute developed a modified crash prediction model specific to the State of Nebraska, as part of HNTB's Rail Study. The model was patterned after the US DOT crash prediction model, but was developed with a Nebraska grade crossing database. Although the modified model provides only a small improvement in predicting crashes at grade crossings in Nebraska, it is a simpler model to use because it requires fewer inputs to develop a crash prediction factor.

To calculate the crash prediction factor, a basic prediction model is used to develop an initial crash prediction factor that is based upon the characteristics of a particular grade crossing. They are as follows:

Initial Crash Prediction Factor - Passive Crossing:

$a = 0.2e^{-6.9006}\ x\ (ct)^{0.5606}\ x\ e^{0.0142ms}$, where

a = initial crash prediction factor (crashes per year at a particular crossing)

c = annual average number of highway vehicles per day (total for both directions)

t = average total of train movements per day

ms = maximum timetable speed for trains, mph

Initial Crash Prediction Factor - Crossing with Flashing Lights:

$a = 0.2e^{-9.9968}\ x\ (ct)^{0.7355}\ x\ e^{0.0275ms}$, where

a = initial crash prediction factor (crashes per year at a particular crossing)

c = annual average number of highway vehicles per day (total for both directions)

t = average total of train movements per day.

ms = maximum timetable speed for trains, mph

Crossing with Gates:

$a = 0.2e^{-7.1516}\ x\ (ct)^{0.3490}\ x\ e^{0.0162ms}\ x\ e^{0.5375mt}$, where

a = initial crash prediction factor (crashes per year at a particular crossings)

c = annual average number of highway vehicles per day (total for both directions)

t = average total of train movements per day.

ms = maximum timetable speed for trains, mph

mt = number of main tracks

Once calculated, the initial crash prediction factor is used in the final crash prediction model to calculate the final crash prediction factor. These equations are as follows:

Final Crash Prediction Equation:

$A = \left[\left(\frac{T_0}{T_0+T}\right)(a)\right] + \left[\left(\frac{T_0}{T_0+T}\right)\left(\frac{N}{T}\right)\right]$, where

A = Final Predicted Crash Rate

T_0 = Weighting Factor (see below)

T = Number of years crashes were observed

a = Initial Crash Rate (calculated above)

N = Number of crashes observed at a particular crossing

Weighting Factor:

$T_0 = \frac{1.0}{0.05+a}$, where

T_0 = Weighting Factor (see below)

a = Initial Crash Rate (calculated above)

To establish estimated costs associated with crashes, the Final Crash Prediction Factor is multiped by the societal crash costs discussed in the Nebraska Basic Assumption section of this document.

COST OF VEHICULAR DELAY PER YEAR

To calculate the costs associated with delay, NDOT uses a series formulas derived from NCHRP Report 288, in conjunction with an equation that utilizes the traffic composition (passenger vehicle vs. heavy trucks) and the associated delay costs for each.

NCHRP Report 288 Equation 1 – Minutes of blocked time per day:

$M = \left[\left(\frac{L}{S}\right)(60\ min/hr) + 0.6\ min + 0.05\ min\right] x\ ADTT$, where

M = Minutes of blocked crossing time on average day (min/day)

L = Average train length (miles/train)

S = Average train speed (mph)

0.6 min = Time crossing signals are active before and after the train passes (min/train)

0.05 min = Average time for motorists to react and start up after train passes (min/train)

$ADTT$ = Number of trains per day (trains/day)

NCHRP Report 288 Equation 2 – Proportion of Day Crossing is Blocked:

$P = \frac{M}{1440}$, where

P = Proportion of the day that the crossing is blocked

M = Minutes of blocked crossing time on average day (min/day) (Calculated from Equation 1)

NCHRP Report 288 Equation 3 – Number of vehicles delayed at the crossing on an average day:

$V = P \times AADT$, where

V = Vehicles delayed during an average day (vehicles/day)

P = Proportion of the day that the crossing is blocked (Calculated from Equation 2)

$AADT$ = Number of Vehicles per day at crossing (vehicles/day)

NCHRP Report 288 Equation 4 – Average duration of delay per delayed vehicle:

$D = M/ADTT/2$, where

2 = Assumption of uniform highway vehicle arrivals (2 = ratio of train blocked time to average delayed block time)

D = Duration of delay per delayed vehicle (min/vehicle)

ADDITIONAL EQUATIONS NOT INCLUDED IN NCHRP Report 288

Time for One Train to Pass:

$MT = \frac{M}{ADTT}$, where

MT = Time for one train to pass (min/train)

M = Minutes of blocked crossing time on average day (min/day) (Calculated from Equation 1)

$ADTT$ = Number of trains per day (trains/day)

Total Delay on an Average Day:

$TD = D\ x\ V$, where

TD = Total delay on average day (min/day)

D = Duration of delay for a delayed vehicle (min/vehicle) (Calculated from Equation 4)

V = Vehicles delayed during an average day (vehicles/day) (Calculated from Equation 3)

Average delay per vehicle at crossing:

$Average\ Delay = TD\ x\ AADT$, where

$Average\ Delay$ = Average delay per vehicle at crossing (min/vehicle)

TD = Total delay on average day (min/day) (Additional Equations not in the NCHRP 288)

$AADT$ = Number of vehicles per day at crossing

Annual Delay:

$Annual\ Delay = \frac{(TD)(365\ days/year)}{60\ min/hr}$, where

$Annual\ Delay$ = Total annual delay per year (hours/year)

TD = Total delay on average day (min/day) (Additional Equations not in NCHRP Report 288)

NDOT EQUATIONS FOR COSTS OF VEHICULAR DELAY

NDOT Equation 5 – Cost of Highway Vehicle Delay per Day:

$CD = [(1 - \%T)(\$_{Pass}) + (\%T)(\$_{Trucks})] \times TD$, where

CD = Cost of highway vehicle delay per day (dollars/day)

$\%T$ = Percent Trucks in Decimal Form

$\$_{Pass}$ = Cost of Delay for Passenger Vehicles (dollars/minute) = $0.35 (2021 – Provided by Construction Division)

$\$_{Trucks}$ = Cost of Delay for Trucks (dollars/minute) = $0.58 (2021 – Provided by Construction Division)

TD = Total Delay on average day (minutes/day) (Additional Equations not in the NCHRP 288 Report)

NDOT Equation 6 – Cost of Highway Vehicle Delay per Vehicle:

$CV = \frac{CD}{V}$, where

CV = Cost of highway vehicle delay per vehicle ($/day)

CD = Cost of highway vehicle delay per day (dollars/day) (Calculated from NDOT Equation 5)

V = Vehicles delayed during average day (vehicles/day) (Calculated from NCHRP Report 288 Equation 3)

NDOT Equation 7 – Annual Cost of Highway Vehicle Delay:

$C = (CV)(V)(365\ days/year)$, where

C = Cost of delay per year (dollars/day)

CV = Cost of highway vehicle delay per vehicle ($/day) (Calculated from NDOT Equation 6)

V = Vehicles delayed during average day (vehicles/day) (Calculated from NCHRP Report 288 Equation 3)

Summary of Vehicle Delay and Accident Costs at Railroad-Highway At-Grade Crossing

CN 51299, Bridgeport Viaduct

Annual Cost of Delay	**$42,197**		
Annual Accident Cost	**$10,153**	0	0
Total	**$52,350**		

Cost of Vehicle Delay at Railroad-Highway At-Grade Crossing

CN 51299, Bridgeport Viaduct

Inputs: Requires entry of project specific data
Outputs: Results from methodology

Equation 1: Minutes of blocked time per day

$$M = \left[\left(\frac{L}{S}\right)(60min/hr) + 0.6min + .05min\right] \times ADTT$$

L=	1.610	L = Average train length (miles/train) (Default is 1.610 miles)
S=	35	S = Average train speed (miles/hour)
	60	60 min/hour = conversion to change mile/hour to miles/minute
	0.6	0.6 min = Time crossing signals are active before and after the train passes (minutes/train)
	0.05	0.05 min = Average time for motorists to react and start up after train passes (minutes/train)*
ADTT=	16	ADTT = Number of trains per day (trains/day)
		** The start-up time term was in prior NDOR formulas and comes from work in Virginia*
M=	54.6	**M = Minutes of crossing blocked time on an average day (minutes/day)**

Equation 2: Probability of vehicular delay on an average day

$$P = \frac{M}{1440}$$

	1440	Number of minutes in one day (minutes/day)
P=	0.038	**P = Proportion of the day that the crossing is blocked**

Equation 3: Number of vehicles delayed at the crossing on an average day

$$V = P \times AADT$$

AADT=	4440	AADT = Number of vehicles per day at crossing (vehicles/day)
V=	168	**V = Vehicles delayed during an average day (vehicles/day) [rounded to nearest vehicle]**

Equation 4: Average duration of delay per delayed vehicle

$$D = M/ADTT/2$$

	2	Assumption of uniform highway vehicle arrivals (2 = ratio of train blocked time to avg delayed vehicle blocked time)
D=	1.71	**D = Duration of delay <u>for a delayed vehicle</u> (minutes/vehicle)**

Note: NCHRP 288 had a typographic error and called for AADT instead of ADTT in this equation

Additional Equations and Delay Terms not in the Original NCHRP 288

$MT = M/ADTT$	MT=	3.41	**Time for one train to pass (minutes/train)**
$AD = TD \times AADT$	AD=	0.06	**Average delay per vehicle - based on AADT - at crossing (minutes/vehicle)**
$TD = D \times V$	TD=	286.4	**Total delay on an average day (minutes/day)**
$Annual\ Delay = \frac{TD \times (365\frac{day}{year})}{(60min/hr)}$	Annual Delay	1,743	**Total annual delay (hours/year)**

NDOT equations for cost of vehicular delay (these equations are not in NCHRP 288)

Equation 5: Cost of highway vehicle delay per day

$$CD = [(1 - \%T)(\$Pass) + (\%T)(\$Trucks)] \times TD$$

%T=	0.14	Percent trucks for subject crossing in decimal form
$Pass=	$0.37	Cost of delay for passenger cars ($/minute) [2022: $0.37]
$Trucks=	$0.61	Cost of delay for trucks ($/minute) [2022: $0.61]
CD =	$115.61	**Cost of highway vehicle delay per day ($/day) [time only, rounded to nearest $0.01]**

Equation 6: Cost of highway vehicle delay per vehicle

$$CV = {}^{CD}/_{V}$$

CV=	$0.688	**Cost of highway vehicle delay per delayed vehicle ($/vehicle) [time only, rounded to nearest $0.01]**

Equation 7: Annual cost of highway vehicle delay

$$C = CV \times V \times 365$$

C=	$42,197	**Cost of delay per year ($/year) [time only]**

Accident Prediction Model for Highway Rail Crossings

User Defined Variables

Chose Existing Crossing Type	Crossing with Gates	
ADT in both directions - (c)	4440	vehicles
Trains Per Day (NE Inventory) (t)	16	Trains/Day
Speed of Train @ Crossing (ms)	35	MPH
Number of Crossings (mt)	1	Main Tracks
Number of Accidents (N)	0	accidents
Years Observed at Crossing (T)	5	years
Urban or Rural?	Urban	

2021 Accident Costs w/Train (Provided by Traffic Accidents Group)

Urban:	CONFIDENTIAL
Rural:	CONFIDENTIAL

Accident Prediction Equations

Initial Accident Prediction Equations

where,

a = initial accident prediction (accidents per year at a particular crossing)
c = annual average number of highway vehicles per day (total for both directions)
t = average total train movements per day
ms = maximum timetable speed for trains, mph
mt = number of main tracks

Passive Crossing Equation

$$a = 0.2e^{-6.9006} \, x \, (ct)^{0.5606} \, x \, e^{0.0142ms}$$

a = -

Crossing with Flashing Lights Equation

$$a = 0.2e^{-9.9968} \, x \, (ct)^{0.7355} \, x \, e^{0.0275ms}$$

a = -

Crossing with Gates Equation

$$a = 0.2e^{-7.1516} \, x \, (ct)^{0.3490} \, x \, e^{0.0162\,ms} \, x \, e^{0.5375\,x\,mt}$$

a = 0.0233

Final Accident Prediction Equation

where,

To = Weighting Factor
a = Initial Accident Rate (calculated above)
T = number years accidents were observed
N = number accidents observed at particular crossing
A = Final Predicted Accident Rate

Weighting Factor

$$T_o = \frac{1.0}{0.05 + a}$$

T_o = 13.63631

Final Accident Prediction Factor

$$A = \frac{T_o}{T_o + T}(a) + \frac{T}{T_o + T}(\frac{N}{T})$$

A = 0.0171

Total Accident Cost

$10,152.51

Source: Development of An Accident Prediction Model for Highway-Rail Grade Crossings in Nebraska - MRI Global