SELECTING RAILROAD CROSSING SAFETY PROJECTS using PREDICTED ACCIDENT RATES AND BENEFIT COST ANALYSIS

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INTRODUCTION

Indiana is the "Crossroads of America". It is a nickname we got around the turn of the century from the many railroads that crisscross our state. The problem with lots of railroads is that it also means we have a lot of highway-railroad crossings, about 6500 of them. This in turn leads to the potential for a lot of crossing accidents. In fact, we rank fifth nationwide in number of crossings, and typically rank about third in number of crossing accidents.

In 1978 we had 720 motor vehicle / train accidents at rail crossings. Since then we have had a steady decline, dropping to 172 accidents in 1998 with 21 fatalities and 72 injuries. While this is a tremendous improvement, especially considering the higher traffic today compared to twenty years ago, and while our accident rank of third is not unexpected considering our number of crossings, we continue to look for ways to improve our rail crossing safety program.

In a world of limited resources, the key to our continued success will be to make the most cost-effective use of the funds that are available. To accomplish this, we have in the past few years made a number of changes to our processes for selecting rail crossing safety projects.

Our innovation is not that we have a better highway-railroad grade crossing crash model than anyone else, but how we use the results from a well established model along with a benefit / cost analysis to make better project selections. Our mission, in so far as practical, is to squeeze as much accident reduction as possible out of the available funds, and we do so on a statewide basis without regard to who owns the railroad or has jurisdiction of the roadway at the crossing.

GRADE CROSSING PROJECT SELECTION

The key elements of our process for cost effective selection of grade crossing safety improvement projects are as follows:

- Crossing inventory data
- Crossing accident history
- Predicted accident rates
- Diagnostic field review
- Benefit / cost analysis

With nearly 6500 rail crossings and sufficient funding for perhaps 60 to 70 projects per year, it is not practical to do a field review of every crossing. Our first step is use the inventory data, accident history and predicted future accident rates to narrow the list down to candidates with
the most potential for further accident reduction. Those candidates then receive a diagnostic field review to confirm the data and to review any special concerns not evident in the data, followed by analysis of estimated costs and benefits of each potential project.

INVENTORY and ACCIDENT DATA

Grade crossing Inventory data is reported by railroads and state agencies to the Federal Rail Administration (FRA) for inclusion in the national rail crossing inventory database. At the Indiana Department of Transportation (INDOT), we also rely on local agencies to help us update the data for crossings on local roads. The inventory contains key data needed for later use in accident prediction formulas, along with a multitude of other useful data about the physical and operational characteristics of each rail crossing. Update of the database is done on a voluntary basis by both railroads and state agencies.

Accident data is reported by railroads to the FRA for inclusion in the national database. By federal regulation, railroads must report every accident. Accident data for the past five years is generally the most useful in predicting future accident rates, although older data can be helpful at times to confirm long term trends or to help provide clues to possible problems at a crossing.

Both the inventory and accident data files can now be accessed on the internet. This data can be found by starting at the FRA home page, www.fra.dot.gov, and following the links to the office of safety and safety data online.

PREDICTED ACCIDENT RATES

Benefit / cost analysis of potential warning device improvements would not be possible without knowing the "before" and "after" predicted accident rates for each crossing. At INDOT we use the U.S. Department of Transportation (DOT) formulas. The formulas were developed by the FRA and Federal Highway Administration (FHWA) from a statistical analysis of nationwide 1981-1985 crossing accident data and 1986 crossing inventory data. The formulas are periodically adjusted to fit current accident experience. These formulas allow calculating the predicted number of accidents, injury accidents and fatality accidents per crossing per year.

A comprehensive discussion of prediction formulas is beyond the scope of this report. However, the basic DOT equations are included at the end for convenience, along with some general discussion on their use and limitations. For additional information, see the DOT "Rail-Highway Crossing Resource Allocation Procedure Users Guide", third Edition, August, 1987. Also see the DOT "Rail-Highway Crossing Accident/Incident and Inventory Bulletin" (published annually) and the DOT "Railroad-Highway Grade Crossing Handbook", second edition, September, 1986.

While these formulas are widely accepted, no formula is perfect. The equations do not include every factor that could influence the number of accidents at a crossing, nor is completely accurate data always available. Further, accidents at most crossings are such statistically rare events that the equations are at best a general indicator of long term probability of an accident. No formula, or any other tool, can predict where or when the next accident will happen.

Further, while fatal accidents are certainly a tragic event, and can generate considerable public interest and concern, all accidents are considered equal when it comes to calculating the probability of future accidents. Other than train speed, whether or not an accident results in a
fatality is largely a random event depending on the exact point and angle of impact between the train and vehicle, the type of vehicle, and how many people were in the vehicle.

Predictions are a tool to help narrow down the list of potential project candidates by identifying the crossings that are potentially the most hazardous. They are also needed to evaluate the benefit / cost ratio of various alternatives for improvements at a crossing, such as installing stop signs, flashers, gates, grade separation or closure. Benefit / cost analysis along with a diagnostic site review, actual accident history and other pertinent factors, forms the basis for selecting and prioritizing rail crossing safety improvement projects.

DIAGNOSTIC FIELD REVIEW

Diagnostic field review is a valuable tool for reviewing potential project candidates. It provides an opportunity to confirm the data used up to that point in the selection process. It also provides an opportunity to compare accident reports with actual field conditions and look for any sight distance obstructions or other features that may be contributing to accident potential but are not readily apparent from the inventory or accident reports. It is also the proper time to consider the general scope and estimated cost of potential improvements for benefit cost analysis later. One or two qualified people may be all that are needed for most preliminary diagnostics, but in complex situations a multidisciplinary team approach may be useful.

EFFECTIVENESS of UPGRADES

As part of developing the accident prediction formulas, the DOT also developed effectiveness factors for various types of improvements. The basic values for accident reduction are:

- Upgrade from Crossbuck to Stop Signs 35% Accident reduction
- Upgrade from Crossbuck to Flashing Lights 70% Accident reduction
- Upgrade from Crossbuck to Gates 83% Accident reduction
- Upgrade from Flashing Lights to Gates 69% Accident reduction

In addition to the basic values, there is a more comprehensive set of "extended" effectiveness factors which can be used, which depend on the number of trains per day and number of tracks.

Note that there are no factors for modernizing the control circuitry at crossings that already have flashing lights or gates. However, there are times when a diagnostic review will determine that newer equipment or modernized control circuitry may help reduce future accident rates, and that such crossings may on occasion also make cost effective projects.

ACCIDENT COSTS

Accidents have costs, including such things as property damage, medical bills, lost wages, continuing disabilities, etc. For rail crossing projects, we use accident costs derived from information in the National Safety Council "Manual of Classification of Motor Vehicle Accidents" (5th Edition - 1990) in conjunction with data from the FHWA report "Costs of Highway Crashes" (FHWA-RD-91-055, June 1991) plus work on severity of rail crossing accidents by Jim Palmer, in 1992, at the Indiana University School of Public and Environmental Affairs.
Those costs, expressed in terms of 1998 dollars per accident, are as follows:

- Property Damage $6,600
- Injury Accident $260,000
- Fatality Accident $4,000,000

Knowing the predicted accident rate and injury and fatality accident rates for an existing crossing, and the effectiveness of proposed improvements, allows calculating the potential accident reduction cost savings. Further, FHWA annual reports on highway safety improvement programs suggests that the useful life of a grade crossing warning device improvement is about 10 years. Cost savings should thus be calculated assuming a 10 year useful life.

PROJECT COSTS

Project costs can vary widely depending on the complexity and circumstances of each individual crossing. Our average cost to install lights in gates in recent years has been around $140,000 to $150,000 per crossing, with a typical range from $100,000 to $200,000. However, in a few complex situations, costs have been as high as $600,000 to $800,000 for a single project.

With such wide variation, the best solution is to have preliminary cost estimates provided by someone, either highway or railroad, with substantial experience in such work. Where this is not feasible, the following can be used as a very rough approximate guide to estimated costs:

- Basic flashing lights, $80,000 to $100,000 per crossing.
- Additional cost for gates, $20,000 per crossing.
- Cost for additional tracks, $30,000 each.
- Additional cost for complex features, $30,000 each.

Basic means a single track with the most simple train detection circuit, and no overlaps with other circuits or intersections with other railroads. Complex features means motion sensor or speed predictor train detection circuitry, overlaps with control circuits for other crossings, and intersections with other railroads. Keep in mind that for a train at 60 miles per hour, the circuits may extend a half mile each way from the crossing with many complicating factors.

BENEFIT / COST ANALYSIS

The next step in selecting projects is the benefit / cost analysis. It is a concept familiar to anyone who has every compared unit prices when looking for the best buy while out shopping. The goal is to eliminate as many potential accidents as possible with the available funds. The benefit / cost ratio is calculated by dividing the potential accident cost savings by the estimated project cost. Higher B / C ratios are more cost effective than lower values.

The crossing with the highest predicted accident rates, or the most accidents or fatalities, or the most traffic or trains, or the least effective existing warning devices, or the lowest project cost is not always the most cost effective project. To show the importance of benefit / cost analysis in weighing all these variables, consider the following examples:
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<tr>
<th>Xing</th>
<th>Accds A / F</th>
<th>AADT</th>
<th>TPD</th>
<th>WD Old New</th>
<th>PA</th>
<th>PF</th>
<th>EF</th>
<th>Est.$ Ben.</th>
<th>Est.$ Cost</th>
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</tr>
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<td>1.00</td>
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</tr>
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</table>

Where Accds = 5 year data for number of Accidents and Fatalities
AADT = average annual daily traffic count
TPD = average number of trains per day
Train Speed = maximum expected train speed, miles per hour
WD = Warning device, both old (existing) and new (proposed), XB = crossbucks
SS = stop signs w/ XB, FL = flashing lights, GT = gates w/ FL, XX = closed xing
PA = predicted accident rate
PF = predicted fatal accident rate
EF = effectiveness factor for upgrades
Est. $ Ben. = estimated 10 year accident cost savings by doing the project
Est. $ Cost = estimated initial cost of doing the project
B / C = benefit cost ratio, higher values are more cost effective

These are not nice, clean, simple examples. They are generally based on examples of real crossings and projects. For the most part, they are examples of crossings at the higher end of predicted accident rates, as would be expected in selecting real projects. However, a couple more moderate examples show that even such simple things as a pair of stop signs (where appropriate) with other minor improvements, or closing a crossing to traffic, at minimal cost compared to installing lights and gates, can be very cost effective. No single factor other than B/C ratio can be used to identify the most cost effective projects, but collectively they provide a way to get more effective use of the limited funds that are available.

The benefit / cost analysis method presented here works reasonably well for comparing one crossing project with another, although it omits maintenance costs, inflation costs, etc. While not perfect, it provides generally satisfactory results and is now our primary tool for evaluating the relative merits of potential grade crossing improvement projects.

However, a more sophisticated analysis with additional factors could certainly be used, particularly for comparing warning device projects with closures or grade separations where such things as detour costs, congestion and delay costs, or tradeoffs between crossing accidents and other highway accidents may be important. It may also be useful for comparison with other types of highway projects that may compete for the same funds, or in situations with unusual risk factors that may not be adequately represented in the predicted accident rates or accident cost estimates.
DOT ACCIDENT PREDICTION FORMULAS

The United States Department of Transportation (DOT) formulas were developed by the Federal Rail Administration (FRA) and Federal Highway Administration (FHWA) from a statistical analysis of nationwide 1981-1985 crossing accident data and 1986 crossing inventory data. The formulas are periodically adjusted to fit current accident experience. These formulas allow calculating the predicted number of accidents, predicted number of injury accidents and predicted number of fatality accidents per crossing per year.

A comprehensive discussion of prediction formulas is beyond the scope of this report. Following are the basic DOT equations, along with some general discussion on their use and limitations. For more information, see the DOT "Rail-Highway Crossing Resource Allocation Procedure Users Guide", third Edition, August, 1987. Also see the DOT "Rail-Highway Crossing Accident/Incident and Inventory Bulletin" (published annually) and the DOT "Railroad-Highway Grade Crossing Handbook", second edition, September, 1986.

The total number of predicted accidents (PA) at a crossing per year is dependent on the type of warning device as shown below. The numeric constants in these three equations are "normalizing coefficients", and were last adjusted in 1998.

\[
PA = 0.7159 \, B \quad \text{PASSIVE} \quad \text{crossbucks, stop sign, yield sign, or no signs}
\]

\[
PA = 0.5292 \, B \quad \text{ACTIVE} \quad \text{flashers, traffic light, wigwag, bell, or flagman}
\]

\[
PA = 0.4921 \, B \quad \text{GATES} \quad \text{automatic gates with flashing lights}
\]

where \( B = (a)(T_o/(T_o+T)) + (N/T)(T/(T_o+T)) \)

\( N/T = \) accident history, \( N \) accidents in \( T \) years

\( T_o = 1.0/(0.05+a) \), an accident history weighting factor

\( a = K \times E \times D \times M \times M \times H \times L \), the basic prediction

and \( K, E, D, M, M, H \) and \( L \) are as follows:

<table>
<thead>
<tr>
<th>FACTOR</th>
<th>PASSIVE</th>
<th>ACTIVE</th>
<th>GATES</th>
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</thead>
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<tr>
<td>( K )</td>
<td>0.0006938</td>
<td>0.0003351</td>
<td>0.0005745</td>
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<tr>
<td>( E )</td>
<td>((c+d)/(0.2)^{0.37})</td>
<td>((c+d)/(0.2)^{0.4106})</td>
<td>((c+d)/(0.2)^{0.2942})</td>
</tr>
<tr>
<td>( D )</td>
<td>((d)/(0.2)^{0.178})</td>
<td>((d)/(0.2)^{0.1131})</td>
<td>((d)/(0.2)^{0.1781})</td>
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<tr>
<td>( \text{MS} )</td>
<td>(e^{0.0077ms})</td>
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<td>1.0</td>
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<tr>
<td>( \text{MT} )</td>
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<td>(e^{0.1512mt})</td>
<td>(e^{0.1420(hl-1)})</td>
</tr>
<tr>
<td>( \text{HP} )</td>
<td>(e^{-0.5966(hp-1)})</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>( \text{HL} )</td>
<td>1.0</td>
<td>(e^{0.1826(hl-1)})</td>
<td>(e^{0.1420(hl-1)})</td>
</tr>
</tbody>
</table>

where \( K = \) a formula constant

\( c+d = \) the exposure factor, consisting of the number of highway vehicles \( c \), per day, times the number of trains \( d \), per day
\(d\) = the number of daytime through trains per day

\(ms\) = the maximum timetable speed of the train, miles per hour

\(mt\) = the number of main tracks on the railroad

\(hp\) = a factor for type of highway surface (paved = 1, not paved = 2)

\(hl\) = the number of highway lanes

The "normalizing coefficients are periodically adjusted by the FRA to reflect recent actual nationwide accident experience. For example, the coefficients for 1992 were developed using accident data from the years 1986 thru 1990 for the top 20% of the crossings in each category (passive, flasher, gates) so that the sum of predicted accidents using inventory data at the end of 1991 was equal to the actual number of accidents in 1991 at those crossings. Coefficients for 1998 and prior years are as follows:

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</tr>
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</table>

**PREDICTED FATAL ACCIDENTS**

The number of predicted fatal accidents (PF) per year is shown below:

\[
PF = \frac{PA}{1 + KF \times MS \times TT \times TS \times UR}
\]

where \(PA\) = Number of predicted total accidents per year

\(KF = 440.9\), a formula constant

\(MS = ms^{-0.9981}\) where \(ms\) = maximum timetable speed, miles per hour

\(TT = (tt+1)^{-0.0872}\) where \(tt\) = number of through trains per day

\(TS = (ts+1)^{0.0872}\) where \(ts\) = number of switch trains per day

\(UR = e^{0.3571ur}\) where \(ur = 1\) (urban crossing) or \(ur = 0\) (rural)

note that through and switch train counts include both day and night movements.

**PREDICTED INJURY ACCIDENTS**

The formula for the number of predicted injury accidents (PI) per year is:

\[
PI = \frac{PA}{1 + KC \times MS \times TK \times UR} - PF
\]

where \(PA\) = Number of predicted total accidents per year

\(PF\) = Number of predicted fatal accidents per year

\(KC = 4.481\), a formula constant

\(MS = ms^{-0.343}\) where \(ms\) = maximum timetable speed, miles per hour
Note that the FRA provides a formula to predict the number of casualty accidents (hence the factor KC) per year, which includes both injury and fatal accidents. The injury formula shown above is thus the number of casualty accidents minus the number of fatal accidents. Also note that PF plus PI does not equal PA, because not every accident involves a fatality or injury.

**INTERPRETING ACCIDENT PREDICTIONS**

Accident predictions are NOT the end of the process for selecting projects, rather just a beginning. Further, predictions are not absolute and cannot tell when or where the next accident will happen. Predictions are an indicator of long term accident potential, and certainly no better than the quality of the data or the limitations inherent to the formulas.

Generally, a crossing with a high predicted accident rate is probably more hazardous than a crossing with a much lower rate. However, two crossings with similar predicted accident rates are not necessarily equally hazardous. Factors which could potentially make one more hazardous than the other include errors in the data, factors not included in the prediction formulas (such as school bus or hazardous cargo traffic, sight distance restrictions, passenger trains, etc.), and accidents which are due more to driver error or weather conditions rather than due to any inherent problems with the crossing.

There are no hard and fast rules in how to evaluate all the different factors which may make a prediction higher or lower or less reliable than it should be. Interpreting predictions requires a measure of common sense plus engineering judgement after collecting as much information as reasonably possible at each crossing.

**CHANGES in PHYSICAL or OPERATIONAL CHARACTERISTICS**

Changes to data for any factor used in the formulas will result in changes to the predicted accident rates. The physical and operational factors considered by the predictions include roadway AADT, train counts, number of tracks, number of main tracks, train timetable speed, number of roadway lanes, whether the roadway is paved or not and whether the crossing is in an urban or rural setting. The type of warning device used at the crossing also falls into this category, but is discussed in a separate section below.

However, it is difficult to assess the effect of such changes on predicted accident rates at a crossing. For example, if the number of trains per day doubles, then predicted accident rates should increase. However, simply plugging the new data into the prediction formula may yield flawed results. This is because the prediction will still be heavily weighted for accident history under the old train counts, and could thus be somewhat lower than it actually should be.

Accident predictions immediately after a change to physical or operational characteristics may thus require some scrutiny until enough experience accumulates under the new parameters for a more reliable prediction. At best, some common sense can be applied to the results, along with engineering judgement and experimentation to determine the relative importance of various types of changes on predicted accident rates.

Aside from the type of warning device, changes to train counts and highway AADT generally have the most significance in predicted accidents rates, along with changes in train speed for predicted accidents.
accident severity. Even so, the formulas are relatively insensitive to changes in such data. For example, doubling the train count or highway traffic count typically yields only about a 20 percent increase in predicted accident rates.

**CHANGES in ACCIDENT HISTORY**

Accidents generally have a much greater effect on predicted accident rates than changes to train counts or traffic counts. This is because the predictions are strongly weighted for actual accident history at the crossing. On the one hand, this is good because accident weighting becomes a surrogate for factors which could affect accident rates but which are otherwise not part of the prediction formulas. On the other hand, it is a concern where recent accidents may not truly be representative of the long term accident potential at a crossing. However, it is not always easy to distinguish between these two possibilities.

Predictions are generally done using accident history for the past five years. This helps minimize the effects of changes in physical features and operational data at a crossing which may occur over a longer time span. For crossings with relatively high predicted accident rates, which should be the primary focus in selecting crossing safety projects, this generally yields fairly good results.

However, for crossings moderate to low train counts and traffic counts, and which should generally have moderate to low predicted accident rates, even one accident in five years can significantly affect the results. For example, the average predicted accident rate for all crossings in Indiana is about 0.025 accidents per crossing per year. For crossings with rates between 0.02 and 0.03 and no accidents in the past five years, adding even one accident can double or triple the future predicted accident rate, and substantially change its rank relative to other crossings.

Where there is only one accident in five years, it is important to decide whether that accident is truly representative of the crossing, or perhaps simply the one accident in 10 or 20 years (or even longer) which could be expected at the crossing. There are no clear rules on how to make this determination. One option, if train and traffic counts have remained fairly constant, is to look at actual accident history over the past 10 or 20 years. Another is to look at how much the predicted accident rate increased when changing from no accidents to one. Another option may be to ignore all accident effects entirely and simply use the theoretical accident prediction (which is done by using $T = 0$ years in the prediction equations).

Another problem with accident history weighting of predictions is that the formulas cannot distinguish between accidents due largely to physical and operational characteristics of the crossing and those primarily caused by driver error or weather factors. Because the predicted accident rates are so sensitive to actual accident history, it is always prudent to review the apparent causes of those accidents where possible. Where one or more accidents are clearly due to factors not related to the crossing, it may make sense to ignore those accidents when calculating the predicted accident rates.

**CHANGES to TYPE of WARNING DEVICE**

Changes to physical and operational characteristics and accident history thus require careful evaluation when interpreting the predictions. However, the FRA does provide a simple method to estimate the predicted accident rate after an upgrade to an improved warning device type.

They do this by providing an "effectiveness" factor for the new device relative to the old device. This helps eliminate the problem of using the prediction formulas with new physical/operational data but old accident history data. The effectiveness factors were developed using nationwide
data from 1975 to 1980 for the before and after performance of upgrades to crossing warning devices. In a separate study by FHWA, an effectiveness factor was developed for adding stop signs (where appropriate) to existing passive warning devices at crossings.

The resulting effectiveness factors from these studies are summarized in the DOT "Rail-Highway Crossing Resource Allocation Procedure Users Guide", Third Edition, August, 1987, as shown in the following table:

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<td>Trains per day</td>
<td>N/A</td>
<td>&lt;=10</td>
<td>&gt; 10</td>
<td>&lt;=10</td>
<td>&gt; 10</td>
</tr>
<tr>
<td>Upgrade passive to flashers</td>
<td>0.70</td>
<td>0.75</td>
<td>0.61</td>
<td>0.65</td>
<td>0.57</td>
</tr>
<tr>
<td>Upgrade passive to gates</td>
<td>0.83</td>
<td>0.90</td>
<td>0.80</td>
<td>0.86</td>
<td>0.78</td>
</tr>
<tr>
<td>Upgrade flashers to gates</td>
<td>0.69</td>
<td>0.89</td>
<td>0.69</td>
<td>0.65</td>
<td>0.63</td>
</tr>
<tr>
<td>FHWA EFFECTIVENESS FACTORS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Add stop signs to crossbucks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.35</td>
</tr>
</tbody>
</table>

The FRA suggests that any set of effectiveness factors may be used which accurately reflects the situation being evaluated. If better data is not available, both the Standard and Extended values are acceptable, but FRA suggests a preference for the Extended values because they incorporate more variables. What the above factors indicate is the fraction of predicted accidents which would be eliminated by doing the proposed upgrade.

Using these factors is a simple process calculating the predicted accident rate for the old warning device, then multiplying the answer by the effectiveness factor for the upgrade. Note that the prediction yielded by this method is NOT the same as would result from using the prediction formulas with the new type of warning device.

For the period immediately after the upgrade, the old prediction combined with the effectiveness factors should yield a reliable result. As time passes and experience accumulates under the new device, it eventually becomes more accurate to instead use the prediction formulas with the new warning device. Effectiveness factors should certainly be used to evaluate the cost-effectiveness of potential upgrades. After five years, the prediction formula should probably be used instead of the effectiveness factors. During the interim, it is probably not critical which method is used, since a crossing would seldom be a candidate for a second upgrade project within five years after the previous upgrade.

Occasionally, it might be useful to consider the effect of downgrading the type of warning device at a crossing. For example, a former main line track with high train counts might be converted to a siding with very limited use. Repair and maintenance of gates and lights along that siding might eventually require a decision to make high cost repairs or to downgrade to crossbucks. Keep in mind that in many states, including Indiana, downgrading of warning devices is a regulatory matter that can only be done with the written consent of the proper state authorities.

The FRA does not report on any studies of the effect of downgrading the type of warning device at a crossing. Lacking any other criteria, one possibility might be to use the prediction formulas with the revised data, another might be to assume that the downgrade has the opposite effect of an upgrade. Neither method may be entirely correct and the results should be used with caution.