Priority Programming Methodology for Rail-Highway Grade Crossings

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The objective was to develop a comprehensive methodology to assist in setting priorities for improvements to rail-highway grade crossings. The objectives of the methodology were as follows: to compute all existing costs at a RHGC, changes in costs that would result from each of a number of improvements for that crossing, and costs of implementing those improvements; to select the set of projects that would maximize expected net benefits, subject to a budget constraint; and to be of practical instead of theoretical use to decision makers. The methodology developed and presented fulfills these objectives, subject to the constraints of existing data bases. Accident costs, delay costs, diversion costs, and costs of delay to emergency vehicles are considered, and up to five improvement projects per crossing are evaluated. The benefit and cost computations are made in a Fortran computer program developed in the research. The methodology was applied successfully to 1985 conditions at all RHGCs in a particular jurisdiction. The results of the application indicate that, for the same total budget, expected net benefits could have been approximately $7 million higher if the methodology's projects had been implemented.

A rail-highway grade crossing is an at-grade intersection of one or more railroad tracks and a roadway. At such a crossing, railroad vehicles and roadway vehicles must share the right-of-way.

COSTS OF RHGCS

Many costs are associated with operating a RHGC; the most obvious one—particularly to the public and to elected officials—is the cost of accidents. Other costs, however, should be recognized as well.

The most obvious cost of a RHGC accident is that of damage and injury to persons and property. Other costs include the rerouting of railroad and roadway traffic while accident investigation and cleanup are under way.

When a train blocks a RHGC, roadway traffic is delayed. Such delays can be minor, as they are when a short train crosses a little-used roadway during the middle of the night. But they can also be major, as they are when a long train traveling slowly crosses a major arterial roadway during the afternoon peak hour. Delays have obvious costs, such as the time of the delayed motorists and additional fuel consumption, vehicle operation, and air pollution.

Even without accidents or blockages, RHGCs impose costs on society. Because a crossing often disrupts the grade of the roadway, vehicles must reduce speed to traverse the crossing or risk mechanical damage. In some cases the train must stop completely to allow a flagger to disembark and warn roadway traffic. Such reductions in roadway and railroad speed use up time and energy. In addition, there are expenses associated with maintaining the crossing surface and traffic-control devices.

A special type of cost is incurred when an emergency vehicle is delayed by a blockage at a crossing. Delays to emergency vehicles can, in the most extreme cases, result in deaths. In less severe cases, these delays can cause additional property damage—if, for example, fire apparatus is held up in reaching a fire. These costs are not obvious, and they frequently go unnoticed until incurred.

PRIORITY RANKING IMPROVEMENTS

Because it would be impractical to eliminate all RHGCs, and because of limited funding for safety improvements for crossings that cannot be eliminated, a methodology that efficiently allocates available resources for crossing improvements is needed.

One of the earliest efforts to priority rank improvement projects for rail-highway grade crossings was made by Richards and Hooks in 1970 (*1*). In that effort, cost-benefit analyses were proposed to be used to examine the upgrading of traffic-control devices. Only direct accident costs were included. A similar approach was taken by Richards and Lamkin, also in 1970 (*2*). Cost-benefit analyses were also used by Schulte (*3*) to determine, on a single-crossing basis, which type of upgraded traffic-control device to install. Again, only direct accident costs were considered.

A generalized approach to priority programming highway projects was presented by Harness and Sinha (*4*). The approach, called the successive subsetting technique, allows for one set of criteria to be used in establishing a short list of candidate projects and for a second set of criteria to be used in establishing a shorter list from the short list. This approach is continued until a subset is developed that allows a fixed budget constraint to be met. The criteria for each iteration may be subjective. This technique suffers from the deficiency that subjective evaluations (such as a decision without data analysis that delay is more important than safety) may be used throughout and could greatly influence the end result.

In an effort to improve on the cost-effectiveness of improvement decisions, the U.S. Department of Transportation (DOT) formed the Rail-Highway Crossing Resource Allocation Procedure in 1982 (*5*). The measure of effectiveness used in the procedure is the efficiency ratio: the percentage

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reduction in accidents that can be expected as a result of a proposed improvement.

The procedure is certainly a helpful tool, but it suffers from two of the weaknesses of the priority ranking systems: first, it considers only safety (as measured by number of accidents and severity of accidents) to be an important parameter; second, it does not consider all the costs of accidents in its approach.

The inclusion of factors other than direct accident costs has been suggested, in general terms, as being desirable. The *Railroad-Highway Grade Crossing Handbook* (*6*), for example, identifies improvements in operating efficiency in addition to improvements in safety as fundamental objectives of an improvement program.

Tidwell and Humphreys (*7*) suggested that stopping sight distance and highway vehicle speed should be considered at crossings with passive traffic-control devices, but they did not suggest a method of numerically including these factors with a hazard index/accident prediction formula to develop a priority list.

The Colorado Department of Transportation (*8*) has developed a formula for grade-separating RHGCs that considers 12 factors: average daily traffic (ADT), daily train volume, project cost, roadway speed limit, maximum train speed, crossing geometrics, delay, alternate route availability, accident history, hazardous material, people factors, and emergency-vehicle access. Although this technique goes beyond the usual limitation of considering only direct accident costs, it has three major weaknesses: several factors, such as the activity levels of pedestrians and emergency vehicles, need to be determined subjectively; all factors are heuristically weighted; and individual site visits are required to obtain many of the factors.

Ryan and Erdman (*9*) suggested including, in addition to accident costs, costs of delay to roadway vehicles and potential emergency-access problems. The three factors are subjectively weighted, and each RHGC is given a score based on a summation of the values of the three weighted factors. The crossings are then ranked on the basis of their total scores. Though this procedure does broaden the basis of the ranking to include factors other than hazard, it has weaknesses: the weightings are subjectively assigned, the procedure ranks crossings instead of improvement projects, and costs and benefits are not explicitly considered.

NEED FOR RESEARCH

Ideally, a priority programming methodology should determine all costs associated with current conditions at a candidate RHGC, anticipated costs of conditions at the crossing if an improvement is made, costs of making the improvement, and the expected net benefit of the improvement. If such a methodology were used, potential projects could be ranked in terms of their expected net benefits, and only those projects with the greatest expected net benefits would be implemented (herein the terms "net benefits," "expected net benefits," and "expected benefits" are used interchangeably).

As far as it is known, however, such a comprehensive methodology is not used—nor does it even exist. Most of the methodologies in use consider only the direct costs of accidents. Thus, a clear need exists for an improved methodology, one based on sound economic principles, so that crossing improvements can be programmed efficiently and scarce resources can be used optimally.

DEVELOPMENT OF PROPOSED METHODOLOGY

In developing a methodology that can be used for efficiently allocating limited resources among RHGC improvement projects, all costs associated with the operation of a RHGC are identified and quantified insofar as possible; in this manner, a monetary value is determined for current conditions for any crossing chosen for analysis. These costs include safety, delay, and emergency access.

The proposed methodology makes use of the costs thus developed in assessing the effectiveness of potential improvements to a given crossing. Upgrading traffic-control devices, providing grade separations, providing additional travel lanes, and closing RHGCs are all options for improvement; the cost reductions resulting from such improvements are identified and quantified. The costs of implementing such improvements are also identified and quantified. The net benefit (the cost of operation with the proposed improvement minus the cost of operation with existing conditions minus the cost of implementation) is computed for each improvement option, and a list of projects with net benefits greater than zero is compiled. Finally, through the use of zero-one integer programming, the set of improvements that optimize net benefits subject to a budget constraint is selected (zero-one integer programming is a specialized form of linear programming; it is an optimatization technique that yields a go/no go decision for each of a set of discrete options).

A methodology that is theoretically flawless but difficult to use would be of little practical value. When a government agency must choose between using an outstanding and complete methodology that requires data collection and using an inefficient but widely accepted technique that requires no data collection (and thus is faster and less expensive), the agency is likely to use the inefficient technique. For this research, it was decided to address this conflict between perfection in theory and practicality in implementation by developing a methodology as complete and theoretically correct as possible while using only those data known to be easily accessible to most agencies responsible for RHGCs.

The data known to be on file with (or readily available to) those agencies come from only two sources: the DOT Rail-Highway Grade Crossing Inventory (to be referred to as "the Inventory"), which consists of data provided by the individual states, and the FRA accident/incident files (FRAIRS). Because of the expense involved in data collection, responsible agencies generally have no information for most of their RHGCs, except that which is provided by the Inventory and FRAIRS. Thus, to have any chance of being practicable to a responsible agency, a methodology for RHGCs should use only information from these two sources or other easily collectible data, or it must generate additional information itself.

Development of Parameters

A detailed description of the portions of the methodology in which the costs of accidents, diversion, and delays to emergency vehicles are computed is presented elsewhere (*10*); it is not included here for the sake of brevity.

Briefly, the methodology computes the direct costs of accidents through the use of an accident prediction formula developed by the Transportation Systems Center (unpublished data), a severity index developed by the same institution (*5*), and NHTSA cost data. Costs of diverting roadway traffic around a blockage are computed through application of limited field data about bypass routes and cost data produced by FHWA (*11*).

Delay costs are computed through application of a deterministic delay model, limited field data, and the cost data described earlier (*11*). Costs of normal operations and maintenance were omitted from the methodology because of a lack of available data. Emergency-access delay costs were developed through application of historical data and unit costs obtained from the literature (*12–16*).

Potential Improvements

A range of options is available for improving each RHGC. In terms of cost, at one extreme would be the installation of crossbucks signs at a completely unprotected RHGC; at the other, the construction of a grade separation. On the basis of the procedures developed or chosen for use in this methodology, the potential improvements in Table 1 was analyzed for each grade crossing. A *K*-value for each improvement is given in Table 1 as well; the significance of this *K*-value is explained later. Crossbucks, flashing-light signals, and automatic gates are taken to be as defined in the *Manual on Uniform Traffic Control Devices for Streets and Highways* (*17*).

The list of potential improvements is rather short and does not include several traditional improvements, such as increasing sight distance, improving warning signing, adding flashing-light signals for greater conspicuity, installing flashing-light signals with larger lenses, and improving the crossing surface. Though these and other improvements are certainly worthwhile, the methodology has no mechanism for considering them explicitly. The primary reason for this lack of mechanism is the fact that almost all of these traditional improvements are safety-related and would thus need to be considered in the methodology's accident prediction formula to be included in the methodology. However, none of these possible improvements would affect the value of the selected accident prediction formula. The art of predicting accidents at RHGCs is simply not developed enough to allow consideration of such factors, so there is no way to consider them explicitly in the methodology.

TABLE 1 IMPROVEMENT OPTIONS

K	Improvement Option
1	Existing Conditions
2	Flashing Light Signals
3	Automatic Gates
4	Add 2 lanes to approach roadways (one in each direction)
5	Close roadway
6	Grade Separation in Place

PRIPROG

A computer program executing the cost assessment portion of the desired methodology was developed. This program, which is written in Fortran, is called PRIPROG.FOR. It is up and running on the VAX computer system at the University of Maryland, Baltimore County (UMBC). As external input, PRIPROG.FOR requires the Inventory data and FRAIRS data for the RHGCs in question, and it also requires the user to specify the year for which the analyses are to be performed. All other necessary information is included in the program and based on the preceding analyses and discussions. The program follows the simplified flowchart in Figure 1. The iterations based on the value of *K* allow for recomputations of costs assuming that a specific set of improvements is made.

Of course, not all six iterations of PRIPROG.FOR are necessarily run for each RHGC: one already equipped with automatic gates, for example, will skip the second and third iterations.

PRIPROG.FOR generates two output files. The first of these files, PRIPROG.DAT, contains the following information for each iteration for each RHGC: Inventory identification number; start and end dates used for accident history analyses; annual ADT (AADT); total number of trains per day; predicted number of accidents per year; accident costs per year; excess vehicle operating costs per year due to delays; excess gallons of fuel consumed per year due to delays; excess pounds of carbon dioxide, hydrocarbons, and nitrous oxides

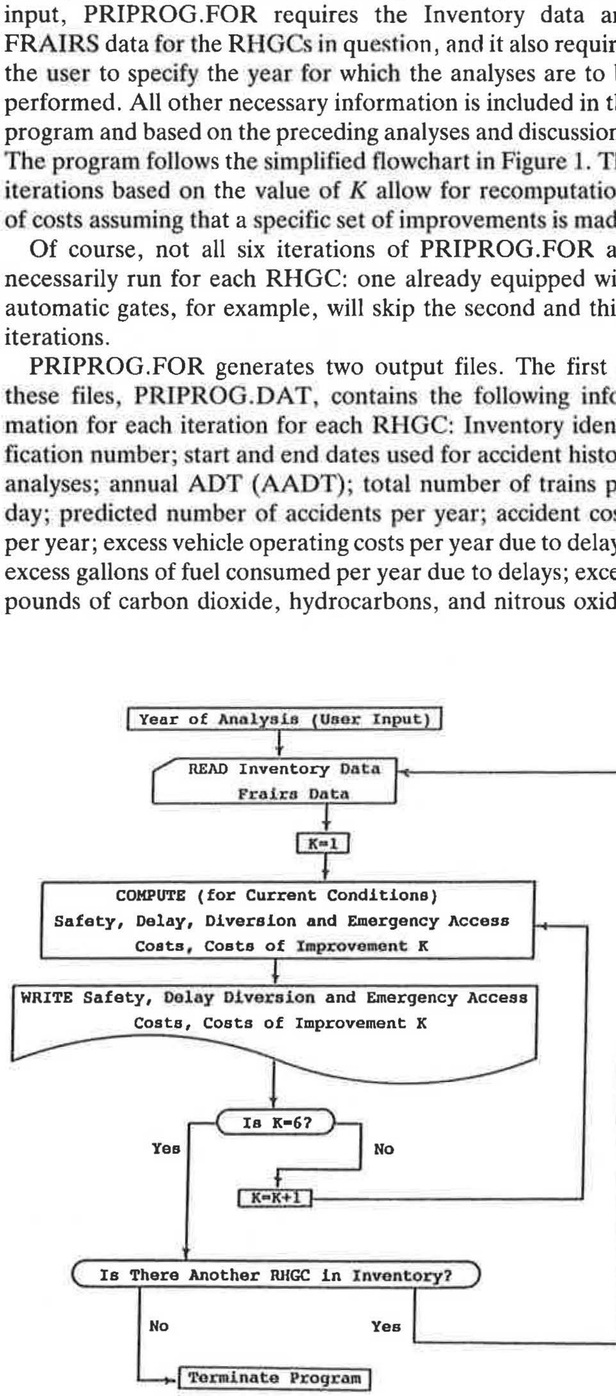

FIGURE 1 PRIPROG.FOR flowchart.

produced per year due to delays; annual delay costs, excess vehicle operating costs, and gallons of fuel consumed on bypass roadways used for diverting traffic; annual pounds of carbon dioxide, hydrocarbons, and nitrous oxides produced on bypass roadways used for diverting traffic; annual costs due to delays to fire equipment; and annual costs due to delays to emergency medical equipment. The reporting of all of this information allows the user to observe the effects of proposed improvements on all key parameters and the relative importance of each parameter to the total costs at each crossing.

The second output file, IMPASS.DAT, contains a summary of the data in PRIPROG.DAT and additional information. For each iteration for each crossing, the following is produced: Inventory identification number; iteration number; total of the monetary costs provided in PRIPROG.DAT (accident, delay, excess operating due to delay, delay on bypass routes, excess operating on bypass routes, and delay to emergency vehicles); the current worth of those costs, assuming an interest rate of 10 percent and a study period of 20 years; installation costs of the proposed improvements; and totals of the fuel consumption and carbon dioxide, hydrocarbon, and nitrous oxides production information in PRIPROG.DAT.

The interest rate of 10 percent appears reasonable in light of current economic conditions (the user can, of course, modify the interest rate as desired). The study period of 20 years was chosen for several reasons, among them that highway projects are typically assumed to have a useful life of about 20 years and that data gathered by FRA indicate that the life expectancy of active warning devices is about 20 years. The signs and barricades that would make up the major portion of the costs of closing a RHGC generally have a useful life of 7 to 10 years. For the purposes of this paper, it was assumed that all signs and barricades would need to be replaced at 10 years. Examination of IMPASS.DAT allows the user to assess, in a six-line format, the conditions at each RHGC and the effects of each potential improvement on that RHGC.

LINDO

LINDO (Linear, Interactive, and Discrete Optimizer) is a software package available on UMBC's VAX system. It is used in this methodology to perform the zero-one integer programming functions described earlier as being desirable for matching potential improvements with particular RHGCs. Of course, other software systems can perform the same functions and can be used in place of LINDO; the decision to use LINDO was based simply on its availability.

Before executing LINDO, some simple arithmetic functions are performed on the IMPASS.DAT file. These functions are performed in PRIPROG.FOR, and the results are written to a file named BENCOMP.DAT. The costs of each RHGC under each option are compared with existing costs; only those options that reduce the costs are analyzed further. The present worth of the reduction in costs is then compared with the implementation cost of the option, and only those options for which the reduction in cost exceeds the implementation cost are written to BENCOMP.DAT. Next, the information in BENCOMP.DAT is written in a format that, with minor adjustments by the user, is directly usable by LINDO. This final file generated by PRIPROG.FOR is called LINDIN.DAT.

LINDO then performs the zero-one integer programming analyses and yields the optimal set of improvements for the RHGCs under study. Strictly speaking, the formulation of the zero-one integer programming problem solved by LINDO in this research is as follows:

Maximize

$$\sum_{i=1}^{n} \sum_{k=1}^{6} x_{ik} AB_{ik}$$

subject to

$$\sum_{i=1}^{n} \sum_{k=1}^{6} x_{ik} C_{ik} \leq B$$

$$X_{ik} = 0 \text{ or } 1 \quad \text{for } k = 1, 2, \ldots, 6 \quad \text{and } i = 1, 2, \ldots, n$$

$$\sum_{k=1}^{6} x_{ik} \leq 1$$

where

i = crossing under consideration,
n = total number of crossings,
k = improvement option under consideration,
AB_{ik} = expected benefit of option k at crossing i,
C_{ik} = implementation cost of option k at crossing i,
B = budget, and
X_{ik} = go/no go variable (limited to the values 0 or 1).

The final constraint ensures that the methodology selects no more than one option per crossing. This is necessary to avoid mathematically correct but physically meaningless selections, such as installing flashing-light signals at a RHGC that is to be closed.

APPLICATION OF METHODOLOGY

It was believed that it would be useful to compare the improvement projects yielded by the methodology with those projects actually implemented by an agency. Data for one jurisdiction's improvement projects for 1985 were obtained, and the methodology was executed, using all the crossings in the jurisdiction and the same budget ($1,232,500).

Data on the agency's projects, as computed by the methodology, are given in Table 2. Examination of Table 2 reveals that 17 improvements projects were implemented and the total expected net benefit was approximately −$880,000.

These negative benefits are caused by two factors. First, the installation of active traffic-control devices can actually increase delays at crossings, thus increasing delay costs. Second, particularly when AADTs on the intersecting roadways are low, the accident prediction formula used in the methodology may forecast an increase in accident rate when active traffic-control devices are installed.

TABLE 2 AGENCY PROJECTS

RHGC	Improvement (See Table 1)	Expected Benefits (1985 Dollars)
A	2	-72,177.13
B	2	-65,312.70
C	2	-68,112.31
D	3	-10,738.97
E	3	-30,052.14
F	2	-75,075.18
G	3	-36,757.87
H	2	-53,689.75
I	2	-72,048.76
J	3	76,752.35
K	2	-76,576.92
L	2	-77,944.89
M	2	-81,154.63
N	2	-79,322.33
O	3	-33,780.83
P	3	-2,800.01
Q	3	-122,560.81

NOTE: RHGC is rail-highway grade crossing.

Data on the methodology-chosen projects are given in Table 3. Examination of Table 3 reveals that 24 improvement projects would be implemented, having a total expected net benefit of approximately $6,600,000. Thus, in terms of costs and benefits as computed by the proposed methodology, the proposed methodology is a major improvement over the technique the agency now uses.

AVAILABILITY AND USAGE

Copies of PRIPROG.FOR are available from the author. Potential users of the program are cautioned that a number of assumptions, which are based on knowledge of local conditions, are incorporated into the program. These assumptions should be reviewed for compatibility with a user's local conditions.

SUMMARY

The objective of this research was to develop a comprehensive methodology to assist in the priority ranking of improvements to rail-highway grade crossings. The methodology developed and presented herein fulfills the stated objectives, subject to the constraints of existing data bases. Accident costs, delay costs, diversion costs, and costs to emergency vehicles are considered, and up to five improvement projects per crossing are evaluated. The benefit and cost computations are made in a Fortran computer program developed in this research; the program requires two common data bases (the Inventory and FRAIRS) for each crossing under consideration. Several sets of intermediate output can be obtained from the program to give the user detailed information about the options under consideration; the final output can be input directly to a preexisting linear programming computer package, after minor clerical adjustments are made.

The methodology was applied successfully to 1985 conditions at all RHGCs in a particular jurisdiction. The results of this application indicate that, for the same total budget, expected net benefits could have been approximately $7 million higher if the methodology's projects had been implemented instead.

In summary, the methodology developed in this research is a major improvement over at least one current technique for priority ranking. The explicit inclusion of delay costs, diversion costs, and costs of delays to emergency vehicles within such a technique is a significant step forward. In addition, the introduction of zero-one integer programming directly into the process greatly improves the cost-effectiveness of the selected projects and thus of the improvements program as a whole.

TABLE 3 METHODOLOGY PROJECTS

RHGC	Improvement (See Table 1)	Expected Benefits (1985 dollars)
R	3	265,407.63
S	3	285,193.88
T	3	213,710.34
U	5	155,979.75
V	3	291,027.88
W	3	286,110.00
X	3	268,465.13
Y	3	268,846.38
Z	3	276,767.19
AA	3	274,237.63
BB	3	293,343.88
CC	3	289,030.63
DD	3	264,602.88
EE	3	281,623.50
FF	4	140,561.56
GG	3	270,139.00
HH	3	265,888.31

TABLE 3 (*continued on next page*)

TABLE 3 (*continued*)

RHGC	Improvement	Expected Benefits (1985 dollars)
II	3	209,220.50
JJ	2	424,242.75
KK	4	251,307.00
LL	4	116,992.13
MM	4	722,403.00
NN	4	346,201.25
OO	4	108,796.38

NOTE: RHGC is rail-highway grade crossing.

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