Establishing Priorities for the Installation of Traffic Control Devices: The Rail-Highway Intersection Example

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From a study of protective device installations at rail-highway intersections, a procedure is developed that establishes priorities for the improvement of safety at these intersections. Techniques are reported for computing installation and maintenance costs, prorated annually, of rail-highway traffic control devices. In addition, the benefit-cost relationship is demonstrated, i.e., the intersections are ranked in descending order on the basis of the relationship between incremental benefits, or the reduction in accident costs, and incremental cost of additional protection. Although the paper does not deal with all factors included in the economic evaluation of safety at intersections, it contains procedures that should be of use to city, county, and state traffic engineers in establishing priority ratings for the installation and improvement of traffic control devices at highway and street intersections as well as for rail-highway intersections.

•THE TWO PURPOSES of this paper are (a) to develop a procedure for the economic evaluation of alternative types and locations of traffic safety devices and (b) to apply this procedure to a rail-highway grade crossing example. The example is derived from a research project recently completed by the Texas Transportation Institute for the Texas Highway Department and the U.S. Bureau of Public Roads, and represents a specific application of the more general procedures discussed in the paper. The authors assume that the rail-highway grade crossing is similar in many respects to highway and street intersections; therefore, the procedure described in this paper should be of use to city, county, and state traffic engineers in establishing priority ratings for the installation of traffic control devices at highway and street intersections as well as at rail-highway intersections.

Economic theory is concerned with the efficient allocation of scarce resources so as to ensure the maximization of social welfare. Although this paper does not discuss the details of the general equilibrium theory, it does emphasize that this concept of economic efficiency requires that the expenditure decisions of all economic units be evaluated at the margin. In other words, the marginal or incremental returns must equal the marginal or incremental costs of the transaction or investment. This will ensure the maximization of net returns.

Ideally, therefore, the investment and expenditure decisions of governments should also be made at the margin with each alternative forced to compete for funds on the basis of its respective costs and returns. Of course, this is often not the case in the real world where economic criteria may be secondary to political criteria. The utilization of the benefit-cost technique in some water resource and navigation projects seems merely to have been a procedure for justifying political decisions rather than a procedure for selecting alternative investments. With regard to alternatives, the same

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criticism may be made of some expenditure decisions of state and local governments. This paper demonstrates the use of the technique in allocating investment funds among competing projects.

In recent years the public has become increasingly concerned with safety, particularly on the highways. Highway accidents, however, are only one of many causes of death, injury, and property loss, and it would seem that the logical objective of society would be to reduce losses of life and property regardless of the cause. Then, limited resources should be allocated among alternative programs concerned with health and safety according to the expected costs and benefits of each.

If all benefits and costs are properly identified and measured, the use of marginal benefit-cost analysis will determine the funds required for maximum return from a specific safety program such as reducing accident losses at rail-highway grade crossings. This program must then compete with others designed to reduce the losses caused by accident and health hazards. Thus, if the objective is to reduce losses of life and property, funds are allocated such that each program is carried out to the point where the extra benefit from further investment equals the extra costs incurred. The net returns from the entire program will be at the maximum when the marginal or incremental values of all programs are equated.

This paper, then, is an application of this scheme to a particular program of accident reduction. (Ideally, all feasible alternatives would be included in the analysis.) Essentially, it consists of ranking competing projects in descending order of their marginal benefit-cost (B-C) ratio values and carrying the program to the point where (a) the marginal benefits and costs are equal or (b) the given funds are exhausted, a situation usually faced by traffic engineers. Such institutional constraints and the assumption that the funds available for the program are given, as used later in the example, are merely a recognition of political reality and not a procedure advocated by the authors. On the contrary, the authors believe that the funds for a specified program, e.g., rail-highway grade crossing safety, should be determined by the more general procedure outlined earlier.

ECONOMIC COST OF TRAFFIC ACCIDENTS

In this paper, economic losses caused by traffic accidents are dealt with as social costs rather than as private costs. The assumption that resources are scarce and that they have alternative uses is fundamental to the costing of accidents, especially those involving injuries and deaths. In essence, such costing attempts to measure the net loss to society of productive resources.

Property damage resulting from traffic accidents presents the least difficulty in that market values are available for repair or replacement of vehicles and equipment. Conceptual and even moral complications arise, however, when attempts are made to estimate the loss caused by injury and death. Direct expenditures for medical services and loss of earnings through fatality or injury are also market values, although the latter are less indicative of the losses they purport to measure. For deaths, consideration should be given to the inclusion of burial costs and the loss of future earnings. One may counter the contention that "everyone must die sometime" with the argument that with premature death both lost earnings and burial costs represent opportunity costs. For example, the money could have been invested during the period. Similarly, the present value of future earnings, including consumption expenditures, must also be added to the estimate of premature losses to society. Consumption expenditures are included because persons are considered members of society and not capital in the usual sense. These categories are often excluded from tabulations of accident cost studies.

The authors contend that the value of earnings lost may be omitted only when the problem is one of allocating a given sum of money among alternative projects designed to serve the same purpose with varying degrees of effectiveness and cost. Furthermore, it must be assumed that fatalities are not expected to vary in proportion among the alternatives and that the income distribution of the population "at risk" is relatively uniform. These costs must not be omitted, however, if the problem includes the

TABLE 1

ACCIDENT COST FACTORS USED IN ESTABLISHING ALTERNATIVE PRIORITY RATINGS

Accident	Average Cost (1)	Composite Accident[c] (2)	Composite Accident Cost (3)
Personal injury			
Fatal injury[a]	$109,807	0.51	$56,001.57
Non-fatal injury[a]	23,864	1.04	24,818.56
Day of disability[b]	12	–	–
Property damage, automobile			
Fatal injury[a]	996	0.34	338.64
Non-fatal injury[a]	427	0.65	277.55
Non-injury[a]	197	–	–
Property damage, railway			
All accidents[b]	771	1.00	771.00
Total			$82,207.32

[a]Includes direct costs incurred by person, e.g., medical, funeral, legal, time lost, and loss of future earnings (2, Tables 9-A, B, and C and 10-A and B).
[b]Data developed in Texas Transportation Institute study from railroad T-Form information on file with the Texas Railroad Commission.
[c]Composite accident computed from actual accident experience of study intersections.

determination of the amount of money to be allocated, especially when there are alternative programs competing for public funds. Although the omission will not affect the relative ranking of alternatives, given these assumptions, it will most certainly affect the total economic loss estimate that is intended to be reflective of the overall accident problem. For these reasons, lost earnings are used in this paper.

Secondary benefits from accident-reduction programs may include reductions in delay time to traffic, in repair and replacement costs of property other than the vehicles, in insurance overhead costs, excluding transfer payments, and in legal and governmental administrative costs.

This discussion has omitted private intangible losses incurred by the persons directly and indirectly involved. Although these losses, such as pain and grief, are not amenable to measurement, it is generally assumed that the sum of private losses exceeds the social economic cost of accidents. Thus, one might consider the social costs outlined to represent a "lower bound on the amount society would spend to prevent accidents" (1).

This paper evaluates rail-highway grade crossing safety devices, but insufficient data for this accident category necessitated the use of general highway accident cost estimates. Only railway equipment and facility property loss resulting from rail-highway accidents occurring during a 3-year period in Texas were developed for specific use in this study. After examining a number of highway accident cost studies, the authors determined that the recent Washington, D.C., study best suited the purposes of this paper (2).

Data extracted include the direct economic cost of fatalities, non-fatal injuries, and vehicle property damage according to accident severity. The estimates include medical, burial, legal, and time costs in addition to the value of loss of future earnings. Additional cost data from railroad sources provided an estimate of the average direct costs incurred by railroads in crossing accidents. No attempt was made to determine the indirect costs suggested earlier such as commercial vehicle delays. It may be assumed, therefore, that the loss estimates used in this paper are understated.

Table 1 gives the accident cost factors used in establishing alternative priority rating procedures developed in this paper. Column 2 gives each accident severity category expressed as a percentage of all grade crossing accidents in Texas over the 3-year period, 1965-1967. The product of columns 1 and 2 gives the estimates in column 3 of accident cost by category of accident severity. The column total then gives an estimate of the cost of the average accident or the composite accident cost. This composite value represents the cost of the average accident experience as recorded in the grade crossing accident statistics for Texas. It may be written

$$CAC = (FR \times CF) + (IR \times CI) + PL$$

where
CAC = composite accident cost,
FR = fatality rate per accident,
IR = injury rate per accident,
CF = cost of a fatality,
CI = cost of an injury, and
PL = property loss.

SOURCE OF DATA FOR PRIORITY RATING ANALYSIS

The rail-highway intersections selected for the application of alternative priority rating procedures developed in this paper are all located in one of the 25 Texas highway districts. The 138 crossings represent all rail-highway intersections within the district under the administrative responsibility of the Texas Highway Department.

A detailed inventory of the physical and operational characteristics of these intersections reveals that 68 of the 138 intersections are not protected by actuated traffic control devices. It is estimated that replacement cost of the actuated devices installed at the 70 protected crossings is approximately $816,000. An analysis of accident records discloses that during the 3-year period, 1965-1967, 27 accidents occurred at these intersections and resulted in 19 fatalities and 30 injuries. Applying accident costs reported in this paper to these 27 accidents indicates that their total costs are $2,563,613.

A determination of which intersections are to be improved and in what order of priority provides the basis for developing a procedure to rank each of the 138 intersections within the highway district. In general, the objective is to obtain maximum benefits from limited funds available for safety improvement at rail-highway intersections.

INSTALLATION COST OF PROTECTIVE DEVICES

Two additional studies were necessary in order to establish current estimates of installation cost for providing either new or additional protection at rail-highway intersections. The objective of the first study was to determine the average number of AAR units required at grade crossings protected by either flashers (single track), flashers (multiple track), or gates. (Railroad signal systems are comprised of more than 60 component parts, each of which, individually or in combination, has been assigned relative unit values by the Signal Division of the Association of American Railroads. These relative unit values, designated as AAR units, were developed for accounting and recording purposes in determining installation, replacement, maintenance, and operating costs on an industry-wide uniform basis.) Ten major Texas railroads provided data for this study.

The objective of the second study was to determine the cost of providing protection at a specific crossing given a specified protective device. In this study, data were obtained from estimates of installation costs for 89 crossings geographically distributed over Texas and involving 14 different railroad companies. Only 4 estimates of installation costs were made at crossings that were located on railroads not included in the first study. In these instances, the average number of AAR units developed for the 10 railroads in the study was applied.

A computer program was developed to apply these costs to both protected and nonprotected intersections according to the railroad involved. In general, the results of this analysis are as follows:

Device	Cost Per AAR Unit	Average Installation Cost
Flashers, single track	$868.32	$11,900
Flashers, multiple track	887.52	16,950
Gates	913.76	21,016

The costs of traffic delay with the installation of gates may vary with types of devices; however, these costs are not included in this paper.

MAINTENANCE COST OF PROTECTIVE DEVICES

The information provided by the 10 railroad companies reveals that, in addition to the use of AAR units to determine the relative amount of equipment necessary to the installation of various types of protective devices at rail-highway intersections, these units are significant in estimating the maintenance cost of these devices. From a descriptive list of AAR units required in the installation and operation of these various devices, annual maintenance costs for each installation may be computed. In general the average cost per AAR unit is estimated by the allocation of each railroad company's total maintenance cost to the total number of AAR units maintained by the company. It was found that these costs differ among railroad companies because of geographic location, labor cost, and operating cost.

Maintenance costs applicable to the alternative priority rating procedures developed in this paper include data from each of the 10 railroads participating in the study. An averaging of these costs provided the following results:

Device	Average AAR Units Per Location	Average Annual Maintenance Cost
Flashers, single track	13.7	$ 571
Flashers, multiple track	19.9	827
Gates	26.0	1,105

INCREMENTAL BENEFIT-COST PROCEDURE

For each incremental improvement in protection at each crossing location, an incremental or marginal B-C ratio is computed for use in the priority index to be described later. The benefits are the expected annual reduction in accident costs attributed to each increment of protection. These accident costs are discussed in an earlier section. Costs include initial installation cost, prorated annually, and annual maintenance expenses incurred for each incremental improvement in protection.

The procedure may be more easily described by the use of several equations. The equation for benefits is

$$EAB_{ijk} = ER_i \times CAC_j \times EAR_k \qquad (1)$$

where

EAB = expected annual accident cost reduction,
ER_i = relative effectiveness rating for an increment of protection,
CAC_j = composite accident cost, and
EAR_k = expected annual accident rate for a given crossing location.

The equation for costs is

$$TAC_{ik} = (CRF \times IC_{ik}) + MC_{ik} \qquad (2)$$

where

TAC = total annual cost of an increment of protection,
CRF = capital recovery factor $[r(1 + r)^m/(1 + r)^m - 1]$,
r = interest rate,
m = useful life of device,
IC = total installation cost of improvement, and
MC = annual maintenance cost.

The incremental benefit-cost is calculated by the equation

$$PI_{ijk} = EAB_{ijk}/TAC_{ik} \qquad (3)$$

In the evaluation procedure the incremental B-C ratio may be thought of as a priority index value to be used in ranking projects. The key point is that the choices of level of protection and location of protection are made simultaneously; thus, the index value or B-C ratio corresponding to each feasible increment of protection for each location is ranked in descending order. The decision rule is to carry the project to the point where incremental benefits equal the incremental costs thereby maximizing net benefits; or, if the level of expenditure is given, until funds are exhausted at some point above this. Additional investment beyond this point will contribute more to costs than to benefits. Wohl and Martin (3, Ch. 8) present an excellent critique of alternative methods of economic evaluation.

PROCEDURES FOR COMPUTING PRIORITY RATINGS

From an inventory of physical and operational characteristics of the 138 rail-highway intersections and the installation and maintenance cost factors reported in this paper, the annual cost of improving protection at each of the intersections may be computed. The following assumptions are made regarding these costs:

1. Protective devices are limited to crossbucks or signs, flashing lights, and gates.
2. Each class of protective device has a 30-year useful life and no salvage value at the end of that period.
3. A 6 percent interest rate is applied to the computation of the annually prorated installation cost.
4. Protective devices may be upgraded by the addition of AAR units.

Equation 2 is applicable to the computation of total annual protection cost, TAC, for both protected and unprotected intersections. The only difference is that two computations are required for unprotected intersections and only one is required for protected intersections. For example, at an unprotected intersection, costs for flashers, gates, and the increment between flashers and gates are estimated by Eq. 2 to be as follows:

Improvement Alternative	Annual Installation Cost	Annual Maintenance Cost	TAC
Crossbucks to flashing lights	$1,066.71	$563.92	$1,630.63
Crossbucks to gates	1,604.98	850.96	2,455.94
Flashing lights to gates	538.27	287.04	825.31

At an intersection protected with flashing lights, on the other hand, costs for the addition of gates (the only improvement alternative necessary) are estimated by Eq. 2 to be as follows:

Improvement Alternative	Annual Installation Cost	Annual Maintenance Cost	TAC
Flashing lights to gates	$456.27	$313.37	$769.64

These examples are representative of the two levels of protection exhibited by the grade crossings included in this study.

The second step is the composite accident cost calculation (Table 1). This cost estimate may computed for the state, for each highway district, for rural and urban intersections, or for any other category warranted by the data. In this example, the composite accident cost estimate of $82,207.32 is based on statewide accident data.

The third step in the procedure is the calculation of the expected reduction in accident costs for a given increment of improvement. The following relative effectiveness ratings for protective devices have been utilized in this paper (4):

Device	Relative Hazard
Crossbucks	1.00
Flashing lights	0.20
Gates and lights	0.11

According to these data, the addition of flashing lights to an unprotected crossing should reduce the hazard by 80 percent, and the addition of gates should contribute an additional 9 percent reduction in the relative hazard rating. The expected accident rate for the existing protection is calculated as follows:

$$EAR_k = 0.02091 + 0.26689(PF) - 0.03996(PD)$$

where

EAR_k = expected accident rate,

PF = probability of conflict = $1 - e^{-am}$,

PD = type of protective device—1 = non-actuated and 2 = actuated,

$$am = ADT\left[\frac{\dfrac{\text{train length in ft}}{\text{train speed in ft per sec}} + 10\text{ sec (trains per day)}}{86{,}400\text{ sec per day}}\right],\text{ and}$$

ADT = average daily vehicular traffic.

This expected accident rate equation was developed as a part of the Texas rail-highway grade crossing research project. Data used in the development of the accident rate equation were collected during a special study of a stratified random sample of 280 accident and non-accident rail-highway intersections. The model for developing the equation was derived by adapting a multiple-regression and correlation analysis program for use on the IBM 7094 computer. Thirteen independent variables were used in the analysis. The computer-programmed statistical procedure has the feature of eliminating the variable with the least non-significant t-value after the calculation of an equation and computing a new equation with the remaining variables. This process is continued until all of the remaining variables are significant at the 5 percent level. A detailed description of the expected accident equation model will be included in the research project report currently being prepared by the Texas Transportation Institute.

Now, Eq. 1 is used to compute the expected annual benefit for installing flashing lights as follows:

$$\begin{aligned} EAB_j &= ER_i \times CAC_j \times EAR_k \\ &= 0.80 \times \$82{,}207.32 \times 0.24784 \\ &= \$16{,}299.41 \end{aligned}$$

Equation 2 is used to compute the total annual cost of protection as follows:

$$TAC_{ik} = \$1{,}630.63$$

The priority index value is, therefore,

$$EAB/TAC = 9.99$$

Similar computations give the priority index value for the addition of gates to the flashing lights:

$$\begin{aligned} EAB &= 0.09 \times \$82{,}207.32 \times 0.24784 = \$1{,}833.68 \\ TAC &= \$825.31 \\ PI &= 2.22 \end{aligned}$$

On the other hand, raising the level of protection from crossbucks to gates initially will produce the following results:

$$EAB = \$18{,}130.64$$

$$TAC = \$\ 2{,}455.94$$

$$PI = 7.38$$

TABLE 2

OPTIMUM ALLOCATION

Crossing No.	Current Protection (1)	Priority Index (2)	Improvement Decisions: Flashers (3)	Improvement Decisions: Gates (4)	Improvement Decisions: Flashers and Gates (5)	Initial Investment[a] (6)
8771	Flasher	22.81	–	X	–	$ 3,396
8666	Flasher	22.81	–	X	–	6,792
50417	Flasher	22.81	–	X	–	10,188
50199	Flasher	22.80	–	X	–	13,584
5820	Flasher	22.72	–	X	–	16,980
5823	Flasher	22.45	–	X	–	20,376
12363	Flasher	21.96	–	X	–	23,986
5826	Flasher	20.13	–	X	–	27,382
5835	Flasher	20.13	–	X	–	30,778
5874	Flasher	20.13	–	X	–	34,174
5880	Flasher	20.13	–	X	–	37,570
5882	Flasher	20.13	–	X	–	40,966
5903	Flasher	20.13	–	X	–	44,362
7804	Flasher	20.13	–	X	–	47,758
8775	Flasher	20.13	–	X	–	51,154
50128	Flasher	20.13	–	X	–	54,550
50414	Flasher	20.13	–	X	–	57,946
50415	Flasher	20.13	–	X	–	61,342
5888	Flasher	20.12	–	X	–	64,738
50413	Flasher	20.12	–	X	–	68,134
7286	Flasher	20.12	–	X	–	71,530
5856	Flasher	20.01	–	X	–	74,926
8669	Flasher	20.01	–	X	–	78,322
8680	Flasher	19.73	–	X	–	81,718
5853	Flasher	19.16	–	X	–	85,114
5851	Flasher	18.11	–	X	–	88,510
5845	Flasher	17.66	–	X	–	91,906
50416	Flasher	17.33	–	X	–	95,302
50402	Flasher	14.52	–	X	–	100,948
143	Flasher	13.46	–	X	–	106,780
151	Flasher	13.45	–	X	–	112,612
152	Flasher	13.44	–	X	–	118,444
12296	X Buck	12.59	–	–	X	134,227
50132	X Buck	12.59	–	–	X	150,010
50270	X Buck	12.59	–	–	X	165,793
50271	X Buck	12.59	–	–	X	181,576
5821	Flasher	12.58	–	X	–	184,972
12305	Flasher	12.21	–	X	–	191,335
50406	Flasher	11.90	–	X	–	196,981
138	Flasher	11.87	–	X	–	202,813
146	Flasher	11.87	–	X	–	208,645
150	Flasher	11.86	–	X	–	214,477
749	Flasher	11.85	–	X	–	220,309
739	Flasher	11.52	–	X	–	226,141
137	Flasher	11.49	–	X	–	231,973
2148	Flasher	11.12	–	X	–	238,854
2179	Flasher	11.12	–	X	–	245,735
2962	Flasher	11.12	–	X	–	252,616
12350	X Buck	11.11	–	–	X	268,399
12389	X Buck	11.11	–	–	X	284,182
12391	X Buck	11.11	–	–	X	299,965
12410	X Buck	11.11	–	–	X	315,748
50124	X Buck	11.11	–	–	X	331,531
50130	X Buck	11.11	–	–	X	347,314
50130	X Buck	11.11	–	–	X	363,097
50268	X Buck	11.11	–	–	X	378,880
12421	X Buck	11.09	–	–	X	394,663
2971	Flasher	11.08	–	X	–	401,544
12298	Flasher	10.99	–	X	–	407,907
12299	Flasher	10.99	–	X	–	414,270
12354	Flasher	10.99	–	X	–	$ 420,633
12367	Flasher	10.99	–	X	–	426,996
50129	Flasher	10.99	–	X	–	433,359
12318	Flasher	10.97	–	X	–	439,722
730	Flasher	10.96	–	X	–	445,554
3732	Flasher	10.87	–	X	–	452,435
12355	Flasher	10.82	–	X	–	458,798
2071	Flasher	10.81	–	X	–	465,679
3720	Flasher	10.80	–	X	–	472,560
50276	X Buck	10.48	–	–	X	486,336
742	Flasher	10.32	–	X	–	492,168
8681	Flasher	10.23	–	X	–	495,564
7287	X Buck	9.87	–	–	X	509,340
8663	X Buck	9.85	–	–	X	523,116
8664	X Buck	9.85	–	–	X	536,892
50266	X Buck	9.85	–	–	X	550,668
50267	X Buck	9.85	–	–	X	564,444
50273	X Buck	9.85	–	–	X	578,220
5881	X Buck	9.84	–	–	X	591,996
157	X Buck	9.49	–	–	X	608,744
159	X Buck	9.49	–	–	X	625,492
160	X Buck	9.49	–	–	X	642,240
708	X Buck	9.49	–	–	X	658,988
5885	X Buck	9.43	–	–	X	672,764
50275	X Buck	9.03	–	–	X	686,540
2986	Flasher	8.63	–	X	–	693,421
2164	Flasher	8.42	–	X	–	700,302
50127	X Buck	8.39	–	–	X	720,816
2069	X Buck	8.39	–	–	X	741,334
2957	X Buck	8.39	–	–	X	761,850
12309	Flasher	8.17	–	X	–	768,213
2982	X Buck	8.02	–	–	X	788,729
2963	Flasher	7.82	–	X	–	795,610
2956	X Buck	7.06	–	–	X	816,126
12314	Flasher	6.76	–	X	–	822,489
2156	X Buck	6.38	–	–	X	843,005
735	Flasher	5.80	–	X	–	848,837
736	Flasher	5.80	–	X	–	854,669
50274	X Buck	5.17	–	–	X	875,185
2146	X Buck	4.94	–	–	X	895,701
3749	X Buck	4.89	–	–	X	916,217
3740	X Buck	4.82	–	–	X	936,733
8674	X Buck	4.73	–	–	X	950,509
8679	X Buck	4.48	–	–	X	964,284
4996	X Buck	4.39	X	–	–	977,921
140	X Buck	4.27	X	–	–	988,837
8678	X Buck	4.18	–	–	X	1,002,613
50405	X Buck	4.10	X	–	–	1,014,391
50403	X Buck	3.97	X	–	–	1,026,169
2979	X Buck	3.38	X	–	–	1,039,805
7289	X Buck	3.20	–	–	X	1,053,581
2173	X Buck	2.64	X	–	–	1,074,097
5001	X Buck	2.48	X	–	–	1,087,733
2159	X Buck	2.00	X	–	–	1,101,369
50440	Flasher	1.97	–	X	–	1,107,015
50441	Flasher	1.97	–	X	–	1,112,661
50001	X Buck	1.37	X	–	–	1,126,297
8667	X Buck	1.25	X	–	–	1,136,677

[a]Accumulated totals of installation costs only; maintenance expenditures necessitated by the program are omitted as these are part of a separate program of the Texas Highway Department.

TABLE 3

FIXED FUND ALLOCATION

Crossing No. A[a]	Crossing No. B[b]	Priority Index (1)	Improvement Decisions: Flashers (2)	Improvement Decisions: Gates (3)	Improvement Decisions: Flashers and Gates (4)	Initial Investment[c] (5)
8771		22.81	–	X	–	$ 3,396
8666		22.81	–	X	–	6,792
50417		22.81	–	X	–	10,188
50199		22.80	–	X	–	13,584
5820		22.72	–	X	–	16,980
5823		22.45	–	X	–	20,376
12363		21.96	–	X	–	23,986
5826		20.13	–	X	–	30,778
5874		20.13	–	X	–	34,174
5880		20.13	–	X	–	37,570
5882		20.13	–	X	–	40,966
5903		20.13	–	X	–	44,362
7804		20.13	–	X	–	47,758
8775		20.13	–	X	–	51,154
50128		20.13	–	X	–	54,550
50414		20.13	–	X	–	57,946
50415		20.13	–	X	–	61,342
5888		20.12	–	X	–	64,738
50413		20.12	–	X	–	68,134
7286		20.12	–	X	–	71,530
5856		20.01	–	X	–	74,926
8669		20.01	–	X	–	78,322
8680		19.73	–	X	–	81,718
5853		19.16	–	X	–	85,114
5851		18.11	–	X	–	88,510
5854		17.66	–	X	–	91,906
50416		17.33	–	X	–	95,302
50402		14.52	–	X	–	100,948
143		13.46	–	X	–	106,780
151		13.45	–	X	–	112,612
152		13.44	–	X	–	118,444
	12296	12.59	X	–	–	127,864
	50132	12.59	X	–	–	137,284
	50270	12.59	X	–	–	146,704
	50271	12.59	X	–	–	156,124
5821		12.58	–	X	–	159,520
12305		12.21	–	X	–	165,883
50406		11.90	–	X	–	171,529
138		11.87	–	X	–	177,361
146		11.87	–	X	–	183,193
150		11.86	–	X	–	189,025
749		11.85	–	X	–	194,857
739		11.52	–	X	–	200,689
137		11.49	–	X	–	206,521
2148		11.12	–	X	–	213,402
2179		11.12	–	X	–	220,283
2962		11.12	–	X	–	227,164
	12350[d]	11.11	X	–	–	236,584
	12389[d]	11.11	X	–	–	246,004
	12391[d]	11.11	X	–	–	255,424
	12410[d]	11.11	X	–	–	264,844
	50124[d]	11.11	X	–	–	274,264
	50130[d]	11.11	X	–	–	283,684
	50131[d]	11.11	X	–	–	293,104
	50268[d]	11.11	X	–	–	302,524
	12421[d]	11.09	X	–	–	311,944
2971		11.08	–	X	–	318,825
12298		10.99	–	X	–	325,188
12299		10.99	–	X	–	331,551
12354		10.99	–	X	–	337,914
12367		10.99	–	X	–	344,277
50129		10.99	–	X	–	350,640
12318		10.97	–	X	–	357,003
730		10.96	–	X	–	362,835
3732		10.87	–	X	–	369,716
12355		10.82	–	X	–	376,079
2071		10.81	–	X	–	382,960
3720		10.80	–	X	–	389,841
	50276	10.48	X	–	–	400,221
742		10.32	–	X	–	406,053
8681		10.23	–	X	–	409,449
	7287	9.87	X	–	–	419,829
	8663	9.85	X	–	–	430,209
	8664	9.85	X	–	–	440,589
	50266	9.85	X	–	–	450,969
	50267	9.85	X	–	–	461,349
	50273	9.85	X	–	–	471,729
	5881	9.84	X	–	–	482,109
	157	9.49	X	–	–	493,025
	159	9.49	X	–	–	503,941
	160	9.49	X	–	–	$ 514,857
	708[d]	9.49	X	–	–	525,773
	5885	9.43	X	–	–	536,153
	50275	9.03	X	–	–	546,533
2986		8.68	–	X	–	553,414
2164		8.42	–	X	–	560,295
	50127[d]	8.39	X	–	–	573,931
	2069[d]	8.39	X	–	–	587,567
	2957[d]	8.39	X	–	–	601,203
12309		8.17	–	X	–	607,566
	2982[d]	8.02	X	–	–	621,202
2963		7.82	–	X	–	628,083
	2956[d]	7.06	X	–	–	641,719
12314		6.76	–	X	–	648,082
	2156[d]	6.38	X	–	–	661,718
735		5.80	–	X	–	667,550
736		5.80	–	X	–	673,382
	50274[d]	5.17	X	–	–	687,018
	2146[d]	4.94	X	–	–	700,654
	3749[d]	4.89	X	–	–	714,290
	3740[d]	4.82	X	–	–	727,926
	3674[d]	4.73	X	–	–	738,306
	8679[d]	4.48	X	–	–	748,686
4996		4.39	–	X	–	762,322
140		4.27	–	X	–	772,702
	8678[d]	4.18	X	–	–	786,478
50405		4.10	–	X	–	798,256
50403		3.97	–	X	–	810,034
	50276	*3.59*	–	–	*X*	*813,430*
	7287	*3.38*	–	–	*X*	*816,826*
2979		3.38	–	X	–	830,462
	8663	*3.38*	–	–	*X*	*833,858*
	8664	*3.38*	–	–	*X*	*837,254*
	50266	*3.38*	–	–	*X*	*840,650*
	50267	*3.38*	–	–	*X*	*844,046*
	50273	*3.38*	–	–	*X*	*847,442*
	5881	*3.38*	–	–	*X*	*850,838*
	5885	*3.23*	–	–	*X*	*854,234*
	7289[d]	3.20	X	–	–	864,614
	50275	*3.09*	–	–	*X*	*868,010*
2173		2.64	–	X	–	888,526
5001		2.48	–	X	–	902,162
	12296	*2.09*	–	–	*X*	*908,525*
	50132	*2.09*	–	–	*X*	*914,888*
	50270	*2.09*	–	–	*X*	*921,251*
	50271	*2.09*	–	–	*X*	*926,614*
	157	*2.00*	–	–	*X*	*933,446*
	159	*2.00*	–	–	*X*	*939,278*
	160	*2.00*	–	–	*X*	*945,110*
	708	*2.00*	–	–	*X*	*950,942*
2159		2.00	–	X	–	964,578
50440		1.97	–	X	–	970,224
50441		1.97	–	X	–	975,870
	50127	*1.87*	–	–	*X*	*982,751*
	2069	*1.87*	–	–	*X*	*989,632*
	2957	*1.86*	–	–	*X*	*996,513*
	12350	*1.84*	–	–	*X*	*1,001,876*
	12389	*1.84*	–	–	*X*	*1,009,239*
	12391	*1.84*	–	–	*X*	*1,015,602*
	12410	*1.84*	–	–	*X*	*1,021,965*
	50124	*1.84*	–	–	*X*	*1,028,328*
	50130	*1.84*	–	–	*X*	*1,034,691*
	50131	*1.84*	–	–	*X*	*1,041,054*
	50268	*1.84*	–	–	*X*	*1,047,417*
	12421	*1.84*	–	–	*X*	*1,053,780*
	2982	*1.78*	–	–	*X*	*1,060,661*
	8674	*1.61*	–	–	*X*	*1,064,057*
	2956	*1.56*	–	–	*X*	*1,070,938*
	8679	*1.54*	–	–	*X*	*1,074,334*
	8678	*1.43*	–	–	*X*	*1,077,730*
	2155	*1.42*	–	–	*X*	*1,084,611*
50001		1.37	–	X	–	1,098,247
8667		1.25	–	X	–	1,108,627
	50274	*1.15*	–	–	*X*	*1,115,508*
	2146	*1.10*	–	–	*X*	*1,122,389*
	7289	*1.10*	–	–	*X*	*1,125,785*
	3749	*1.09*	–	–	*X*	*1,132,666*
	3740	*1.07*	–	–	*X*	*1,136,677*

[a]Crossing numbers in this column appear only once.

[b]Crossing numbers in this column appear twice, the second time in italics.

[c]Accumulated totals of installation costs only; maintenance expenditures necessitated by the program are omitted as these are part of a separate program of the Texas Highway Department.

[d]The matching number in italics is below the program decision line.

Were each crossing to be evaluated individually, it would seem appropriate to install only flashing lights; however, when all crossings are evaluated simultaneously, the additional increment of protection provided by gates may be justified if the priority index value of 2.22 exceeds the value for the addition of lights to another crossing further down the list. This example clearly shows that adding gates contributes more to costs than to benefits; however, it should be emphasized again that when all crossings are evaluated simultaneously neither a policy of always adding flashing lights and gates nor one of omitting all gates is necessarily desirable. The third alternative shown earlier is not included in ranking the crossings because only increments of protection are of interest in this analysis.

APPLICATION OF THE GENERAL PROCEDURE

Tables 2 and 3 give the results of the application of the general procedure to the problem of allocating funds for protection devices at rail-highway grade crossings within the selected highway district. Each table is based on a different criterion. The criterion in Table 2 is that the program will be carried to the point at which the incremental cost of improvement equals the incremental benefit from improvement. Stated another way, the program is carried to a point at which the incremental B-C ratio has a value of 1.0. This criterion determines not only which crossing locations are selected and what level of protection is required but also what total investment expenditure is required for maximum net benefits. The improvement decision for each rail-highway intersection is shown in columns 3, 4, and 5. Accumulated investment totals are given in column 6. Based on this analysis, 118 of the 138 rail-highway intersections in this highway district would be included in the program if the objective were to maximize net benefits. An estimated initial investment of approximately $1.14 million is required in the program. This includes only installation costs; the maintenance costs necessitated by the program are administered through a separate program by the Texas Highway Department.

Table 3 gives the results of an analysis of data based on a decision criterion in which the total budget is given and fixed. Therefore, the procedure to be followed is the allocation of the fixed or appropriated funds among the competing rail-highway intersections and levels of protection. As in Table 2, incremental B-C ratios are ranked; however, in this analysis the intersections to be included in the program are dependent on that point in the priority ranking at which total initial investment exhausts the given budget, provided no increments are included having a B-C ratio less than 1.0.

The fixed fund for the example program in Table 3 is $950,000. The intersections to be included in this program appear above a line drawn at the point at which accumulated initial investment exceeds $950,000. Improvement decisions for each increment are shown in columns 2, 3, and 4. In this example, intersections are repeated in the analysis and become a part of the program when additional levels of protection are warranted by incremental B-C ratios.

The accumulated initial investment is the same for both tables. The two alternative programs differ in that Table 2 demonstrates the results of an improvement decision determined on an economic basis, and Table 3 demonstrates the results of an improvement decision based on political constraints.

SUMMARY

The procedure outlined in this paper should prove quite flexible in practice. Essentially it provides a framework for the construction of a priority index for ranking traffic intersections according to their relative attractiveness as investment alternatives. With this framework and the rationale implicit within it, those charged with implementation of a safety program may make those changes that best suit their purposes.

For example, the components of the accident cost calculation may be changed to reflect the differing weights that might be placed on the value of a life. Similarly, the cost of protection can be revised to allow for salvage values and for different discount rates in computing the capital recovery factor used in annually prorating installation costs. Consideration might also be given to the cost factor of delays to vehicles because of a particular type of protection.

The flexibility of the procedure is also evident in the various decision criteria that may be used when employing the priority index. If the funds allocated for the safety program are determined solely on an institutional (legislative or executive) basis, then the problem is one of protecting crossings in descending order of ranking until these funds are exhausted. However, if the total budget for the program is to be determined on an economic basis, the decision criterion should be to protect all intersections in descending order of ranking until the incremental benefit or marginal reduction in accident cost equals the incremental or marginal cost of added protection. This will ensure maximum net benefits. The latter method requires that the cost of accidents include value of future earnings and other indirect costs incurred in both benefit and cost computations.

This paper has not dealt with all factors involved in the economic evaluation of safety programs at intersections. Refinements may be made in calculating both the benefits and the costs of increasing the level of protection at such locations. In addition, the effectiveness of the alternative devices and the expected accident rate indexes are certainly not perfect measures. Yet it is felt that the procedure described in this paper is sound and that any shortcomings mentioned are easily rectified within this framework.

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