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A METHODOLOGY FOR DETERMINATION OF GRADE CROSSING RESOURCE-ALLOCATION GUIDELINES

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16. Abstract

This report describes a computer-aided analytical approach to estimation of the potential benefits, costs, and implementation implications associated with allocation of grade crossing safety resources. Three types of information are required as input: (1) the grade crossing population, categorized by hazard, location (urban/rural), and existing warning systems; (2) warning system alternatives, characterized by cost and effectiveness; and (3) criteria for acceptable or preferred resource-allocation strategies (required benefit-cost ratio, total resources available, number of fatalities to be prevented, etc). A computer program has been prepared that determines all solutions meeting stated criteria and characterizes them in detail (specifying warning systems for each crossing category). Operation is highly interactive, and requires only seconds of computer time. Examples are presented based upon national statistics, and cases are chosen to indicate sensitivity to uncertainties in input data. An extensive discussion of the currently-estimated crossing population is included, with a brief review of accident prediction equations.

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PREFACE

The work described in this report was performed at the Transportation Systems Center to provide a technical basis for the improvement of railroad-highway grade crossing safety. The program is sponsored by the Federal Railroad Administration, Office of Research and Development. The program supports Government activities designed to promote greater safety in railroad freight and passenger service.

Overall formulation and utilization of the methodology described here was the responsibility of J.B. Hopkins. M.E. Hazel carried out the elaborate computer programing necessary to the concept; the comprehensive and flexible program which he created was crucial to the success of the project.

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1. ANALYTICAL METHODOLOGY

1.1 INTRODUCTION

Effective formulation of grade-crossing protection programs requires the capability to estimate with reasonable accuracy the costs, potential benefits, and implementation needs of alternative resource allocation decisions. One of the special difficulties of orderly planning in the area of railroad-highway crossing safety is the diffuseness of the subject. Crossings can range from the lightly traveled, with a mean time between accidents of hundreds of years, to high-traffic-density situations for which collisions may occur several times annually. Protection options range from simple passive signing, through flashing lights or lights plus automatic gates, to grade separations. Basic decisions concerning the type of protection to be used at each class of crossing depend not only upon the costs and effectiveness of the warning systems, but also on overall program objectives, available resources, and implementation strategy. This report describes a computer-aided analytical approach which can aid significantly in the planning/decision-making process, and presents preliminary results (based upon data of limited precision) intended to illuminate both the approach and the problem.

The methodology and associated computer program described here provide no magic circumvention of the limitations of inadequate information concerning crossing population, inherent hazard, or costs; nor are they intended to indicate the protection to be used at a particular crossing. Both input data and answers obtained represent only gross averages. However, these average values can make possible a relatively accurate understanding, in terms of program alternatives, of overall characteristics (magnitude and nature of required investment, number of crossings affected, potential safety benefits, etc.). In addition, examination of the sensitivity of these results to alternative policies, data system limitations, hardware cost, warning effectiveness, etc. can be most useful in development of policy for both implementation and research programs.

1.2 BACKGROUND

The most effective expenditure of crossing protection funds is determined largely by two incremental factors. If one categorizes crossings by hazard — the probability of an accident during a particular unit of time — a distribution such as that shown in Figure 1-1 is typically found. There is clearly greater "leverage" — more lives saved for a given percentage reduction in accident probability — for the higher-risk crossings. In addition, even the relatively small number of crossings characterized by high hazard ratings are found to contribute a large total number of accidents. Thus, effective protection at these crossings is an obvious component of any viable overall strategy.

However, one has a discrete (but very broad) spectrum of protective systems and devices to choose from. These range from passive systems with a price in the range of a few hundred to a few thousand dollars, through active devices of greater effectiveness which typically cost (installed) $15,000 to $75,000, to grade separations which reduce train-vehicle collisions to zero but may cost $500,000 to $1 million. This spread is illustrated qualitatively in Figure 1-2. Selection of the protection appropriate to each crossing category thus requires a matching of the protection effectiveness to the potential hazard in a manner which optimizes the overall result.

In essence, delineation of an overall grade crossing protection program consists of the specification of the type of protection suitable to each major defined category of crossing. Ideally, this might be developed from a "formula" which could be applied individually to each crossing. However, one cannot even begin to approach this without a means of characterizing the hazard associated with a crossing (its accident potential) and a good measure of the effectiveness of alternative motorist warning devices in preventing collisions. The infrequency of accidents at any particular location and the tremendous variation among crossings has always been a severe limitation. The major effort of past studies has generally been in this difficult area. Thus, it is not surprising that the criteria typically used are imprecise and often

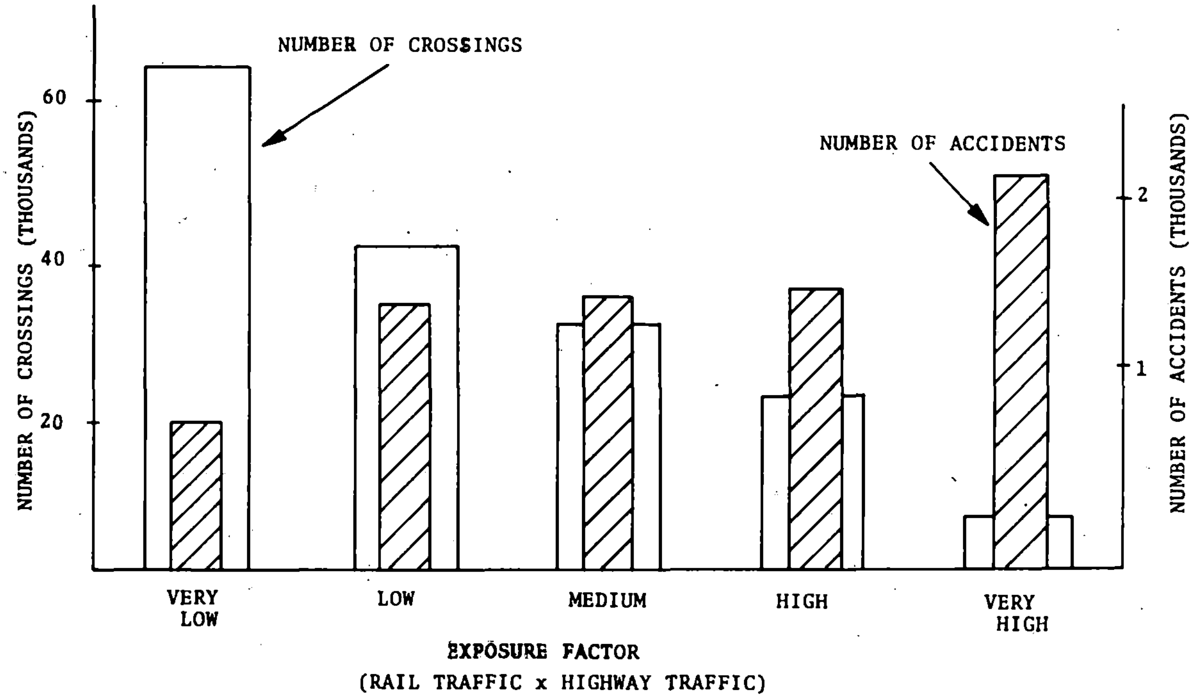

Figure 1-1. Qualitative Breakdown of Accident and Inventory Statistics

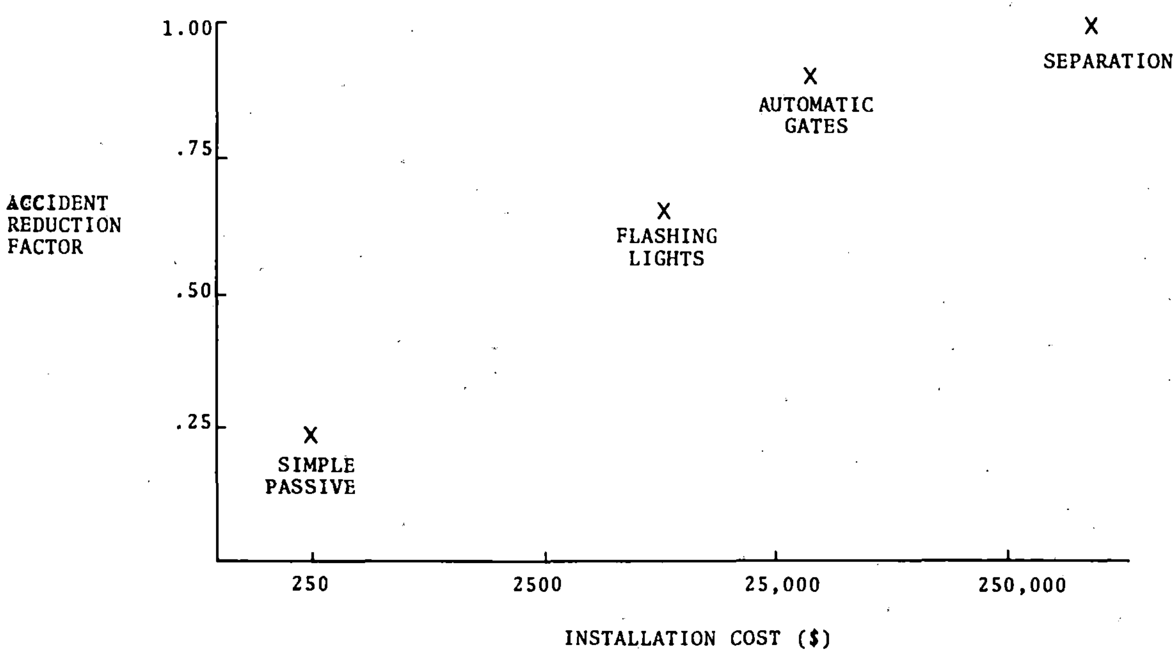

Figure 1-2. Estimated Approximate Effectiveness and Cost of Typical Grade Crossing Motorist Warning Systems

subjective. For example, one common rule-of-thumb is that active warnings are warranted if the product of daily rail and highway traffic exceeds 3000, with automatic gates used for multiple-track cases. In several states with large-scale programs, the basic approach is establishment of a priority list, in which crossings are rated according to estimated hazard, and one works down the list as resources permit. Some states (and railroads) have a policy of automatic gates at all crossings, based upon their high effectiveness; others prefer lights alone, arguing that more crossings can be protected for a given expenditure. Some past studies have suggested a middle-ground, in which only crossings above a particular accident potential receive gates.

One of the first major attempts at an economic analysis of the most effective allocation of resources was that of D. Newnan, in 1966[1] He brought to bear existing practices in traffic engineering and economics to provide an orderly computation of both costs and benefits, and utilized computer assistence for treatment of a large number of crossings simultaneously. As must be true of any complete economic model, this required not only accident prediction and effectiveness data, but also information as to the costs of both equipment and accidents. In 1970 Richards and Lamkin[2] reported a comprehensive study relating to grade-crossing resource allocation in Texas. Accident prediction equations were developed and combined with economic data, based upon extensive examination of Texas statistics. The overall methodology included rating of crossings by hazard and moving down the list until the incremental cost was greater than the incremental benefit; i.e., incremental benefit-cost ratio = 1.0.

A more general approach was followed by Schoppert, [3] under FRA contract, in 1969. As part of an overall program definition study, the national grade crossing population was estimated, categorized by rail and highway traffic densities, location (rural/urban), and protection type. Using accident prediction equations and effectiveness data from a previous study[4] Schoppert determined the type of warning device improvement, if any, appropriate to each crossing category. The criterion imposed was maximization of the net benefit — the overall anticipated benefit minus the costs of the improvements. His conclusions are summarized in Table 1-1. The same basic approach was followed in preparation of the FRA/FHWA Report to Congress,[5] utilizing more recent data, substantially modified with respect to assumed inventory and accident probability, with results summarized in Table 1-2.

1.3 BASIC METHODOLOGY

The work reported here builds upon all of these and other previous studies, particularly the work of Schoppert. The categorization of crossings by hazard, estimated from vehicle and train traffic densities, is crucial. The primary addition is implementation of the approach in a manner which permits imposition of a variety of possible criteria for "best" allocation strategies, allows examination of near-optimal policies, which may be more attractive in the real world than nominal "best" approaches, and utilizes the most recent data available, particularly for accident prediction and crossing inventory.

Definition of the "best" solution is, to some degree, a matter of judgment and policy. If resources are fixed, one may seek the allocation which achieves maximum accident reduction. Alternatively, the means to an explicit goal — perhaps a specified reduction in death toll — can be chosen for minimum cost. Net benefit and benefit-cost ratio have often been used. Further, given specific criteria, there may be a number of alternative strategies with similar overall characteristics, but rather different implications for implementation.

Thus, the means chosen to analyze crossing resource allocation should provide not a single "best" answer, but rather must present a variety of possible variations, within acceptable constraints. Only then are fully informed decisions possible. This result can be obtained in a conceptually simple manner; one can merely consider all possible combinations of protective systems or devices (as in Figure 1-2) and the actual crossing population, categorized by hazard (typified in Figure 1-1). For the simplified case indicated in the figures, this involves four protection alternatives, and five crossing categories. This implies that 625 combinations

TABLE 1-1. SUMMARY OF IMPROVEMENTS FOUND WARRANTED IN PROGRAM DEFINITION STUDY

Improvement	Number of Crossings			Cost ($M)		
	Urban	Rural	Total	Urban	Rural	Total
New Installations						
Flashing Lights	14350	12950	27300	153.2	138.2	291.4
Auto. Gates	450	290	740	10.8	7.0	17.8
Upgrading from Lights Alone to Lights plus Gates	400	1140	1540	8.0	22.6	30.6
Total Crossing Improvements	15200	14380	29580	172.0	167.8	339.8
Separations	30	440	470	26.0	211.2	237.2

Grand Total: $577M invested at 30,050 crossings.
Safety benefits, estimated accident prevention not made explicit in Ref. 3.
Resource allocation (warrants) based upon composite safety, motorist delay, and vehicle operating costs.

Source: Ref. 3

TABLE 1-2. PROGRAM RECOMMENDED IN REPORT TO CONGRESS, PART II, BASED ON SAFETY BENEFITS ALONE

Summary of Costs and Benefits of Current and Total (to 1992) Warranted Improvements

(Dollar Amounts in Thousands of Dollars)

Needs	Number of Improvements	Initial Cost	Reduction in Annual Accidents	Annual Lives Saved	Gross Benefits 2/	Total Improvement Costs 1/ 2/	Net Benefits 2/
Current Needs (1972)							
Protection	26,116	$661,691	3,588	449	$2,426,070	$691,050	$1,735,020
Separation	5	3,575	7	1	6,226	2,512	3,714
Total	26,121	$665,266	3,595	450	$2,432,296	$693,562	$1,738,734
Total Needs (to 1992)							
Protection	30,026	$759,146	4,213	539	$3,798,590	$797,728	$3,000,862
Separation	7	5,005	11	2	15,776	4,524	11,252
Total	30,033	$764,151	4,224	541	$3,814,366	$802,252	$3,012,114

1/ Total Improvement Costs include both initial and recurring costs.
2/ Gross Benefits, Total Improvement Costs, and Net Benefits are expressed in terms of present worth at the time the improvement is made.

Distribution of Costs and Safety Benefits of Recommended Program by Location and Administrative Highway System

(Dollar Amounts in Thousands of Dollars)

Costs and Benefits	Federal-aid			Non-Federal-aid			
	Urban	Rural	Total	Urban	Rural	Total	Total
Initial cost of improvements	$113,635	$253,477	$367,112	$151,135	$143,536	$294,671	$661,783
Reduction in annual accidents	928	929	1,857	1,172	562	1,734	3,591
Annual lives saved	60	195	255	76	118	194	449

Source: Ref. 5, Part II, pp. 84 and 89.

("protection strategies") are possible, although most can be eliminated immediately as being either ineffective or unnecessarily costly. More realistic analysis involves many more alternatives.

Fortunately, consideration of a very large number of alternatives can readily be carried out by use of a digital computer, with automatic rejection of the vast number of strategies not meeting specified criteria such as total cost, lives saved, cost per life saved, net societal benefits, etc. It is this methodology which is reported here. In use it not only permits convenient evaluation of alternatives, based upon available data, but also allows immediate evaluation of the policy options resulting from a hypothetical change in either cost or effectiveness of any protection system, new or conventional. This method makes possible tailoring programs to specific safety objectives, funding limitations, implementation constraints, or policy guidelines. The approach is intended to provide immediate information, through a highly interactive computer program, as to the characteristics of overall, "macroscopic" protection programs associated with particular policy decisions or protective systems. Conceptually, the computations involved are very simple. Input information of two types is required: 1) the population of grade crossings, categorized in terms of hazard (accident potential), and 2) the alternative motorist warning systems to be considered, with cost and effectiveness specified. Hypothetical data of this type are given in Tables 1-3 and 1-4 for purposes of illustration. (The values indicated are not to be taken as highly accurate, but do represent a reasonable approximation to the actual case for rural, passively protected crossings.) "Hazard" (H), the anticipated number of accidents per year per crossing, is typically determined from rail and highway traffic density, although the computations to follow are independent of the definition of hazard, and more sophisticated approaches may easily be substituted when available. "Effectiveness" (E) is the factor by which the protective system in question is expected to reduce accidents and deaths; it normally can range from zero (no effect) to unity (perfect protection). "Cost" (C) is the total expense of installation.

TABLE 1-3. CATEGORIZATION OF CROSSING POPULATION FOR PURPOSES OF ILLUSTRATION

Category Number	Number of Crossings	Hazard	Description
X01	104798	0.015320	VERY LOW DENSITY
X02	10207	0.054260	LOW DENSITY
X03	5800	0.091770	MEDIUM DENSITY
X04	2440	0.165120	HIGH DENSITY
X05	573	0.582360	VERY HIGH DENSITY
	123818		TOTAL RURAL

TABLE 1-4. CATEGORIZATION OF PROTECTION SYSTEMS FOR PURPOSES OF ILLUSTRATION

Protection System Number	Cost ($)	Effectiveness	Description
W0	0	0.0000	CROSSBUCKS (EXISTING)
W1	25000	0.7000	FLASHING LIGHTS
W2	40000	0.9500	AUTOMATIC GATES
W3	400000	1.0000	GRADE SEPARATION

For any given crossing category, installation of a specified protection system at all crossings within that category will have an associated total cost of N x C, where N is the number of crossings. In the computations here described, the resultant cost values calculated are divided by a factor of 10. This permits two (approximate) interpretations: (1) the undiscounted annual total installation cost of a 10-year program to achieve the protection specified at all crossings, or (2) the steady-state annual societal cost, including both amortization and maintenance. Although the 10% value is not precise in either case, it represents a useful approximation, at least as accurate as the basic effectiveness, hazard, and cost data. (This point is discussed further in Section 2.)

Similarly, one can readily calculate the potential saving of life and accident prevention associated with a particular class of protection for a specified crossing category. As used here, hazard represents the annual number of accidents at the crossing in question. Thus, the number of lives saved by installation of given protection at all crossings in a category will save N x H x E lives per year; other benefits – reduction of injuries, property damage, etc. – are readily incorporated.

Given the categorized crossing population and a set of protective systems, one can readily generate a "cost/lives" matrix, as seen in Table 1-5. From it, one may read cost (as defined above) and lives saved for each possible combination of crossing category and protection. In Table 1-5 cost per accident prevented and benefit/cost ratio are also displayed for each cell.

1.4 PROTECTION STRATEGIES

A total grade crossing protection policy requires a decision as to the type of protection to be installed at each class of crossing. In terms of the cost/lives matrix, this consists of selection of one cell for each crossing category. Possible overall choices will be referred to as "protection strategies"; two such strategies are illustrated in Tables 1-6 and 1-7. As displayed in the tables, each strategy has associated with it a total cost and saving of life, consisting of the summation of these factors for

TABLE 1-5. "COST/LIVES" MATRIX FOR HYPOTHETICAL CROSSING POPULATION AND PROTECTION SYSTEM ARRAY OF TABLES 1-3 AND 1-4.

	Protection System			
Crossing Categories	W0	W1	W2	W3
X01	0.0	262.0	419.2	4191.9
	0.0	187.2	254.1	267.5
	0.0	233.1	274.8	2611.0
	1.00	0.26	0.22	0.02
X02	0.0	25.5	40.8	408.3
	0.0	64.6	87.7	92.3
	0.0	65.8	77.6	737.2
	1.00	0.93	0.79	0.08
X03	0.0	14.5	23.2	232.0
	0.0	62.1	84.2	88.7
	0.0	38.9	45.9	435.9
	1.00	1.57	1.33	0.14
X04	0.0	6.1	9.8	97.6
	0.0	47.0	63.8	67.1
	0.0	21.6	25.5	242.2
	1.00	2.82	2.39	0.25
X05	0.0	1.4	2.3	22.9
	0.0	38.9	52.8	55.6
	0.0	6.1	7.2	68.7
	1.00	9.94	8.43	0.89

EACH CELL CONTAINS: TOTAL COST ($MILLIONS)
TOTAL LIVES SAVED ANNUALLY
COST PER ACCIDENT PREVENTED ($1000'S)
BENEFIT/COST RATIO

TABLE 1-6. SAMPLE PROTECTION STRATEGY FOR MATRIX OF TABLE 1-5 - COST: $146 M, LIVES SAVED: 216

	W0	W1	W2	W3
X01	0.0 0.0 0.0 1.00	262.0 187.2 233.1 0.26	419.2 254.1 274.8 0.22	4191.9 267.5 2611.0 0.02
X02	0.0 0.0 0.0 1.00	25.5 64.6 65.8 0.93	40.8 87.7 77.6 0.79	408.3 92.3 737.2 0.08
X03	0.0 0.0 0.0 1.00	14.5 62.1 38.9 1.57	23.2 84.2 45.9 1.33	232.0 88.7 435.9 0.14
X04	0.0 0.0 0.0 1.00	6.1 47.0 21.6 2.82	9.8 63.8 25.5 2.39	97.6 67.1 242.2 0.25
X05	0.0 0.0 0.0 1.00	1.4 38.9 6.1 9.94	2.3 52.8 7.2 8.43	22.9 55.6 68.7 0.89

TABLE 1-7. SAMPLE PROTECTION STRATEGY FOR MATRIX OF TABLE 1-5 - COST: $422.5 M, LIVES SAVED: 437

	W0	W1	W2	W3
X01	0.0	262.0	419.2	4191.9
	0.0	187.2	254.1	267.5
	0.0	233.1	274.8	2611.0
	1.00	0.26	0.22	0.02
X02	0.0	25.5	40.8	408.3
	0.0	64.6	87.7	92.3
	0.0	65.8	77.6	737.2
	1.00	0.93	0.79	0.08
X03	0.0	14.5	23.2	232.0
	0.0	62.1	84.2	88.7
	0.0	38.9	45.9	435.9
	1.00	1.57	1.33	0.14
X04	0.0	6.1	9.8	97.6
	0.0	47.0	63.8	67.1
	0.0	21.6	25.5	242.2
	1.00	2.82	2.39	0.25
X05	0.0	1.4	2.3	22.9
	0.0	38.9	52.8	55.6
	0.0	6.1	7.2	68.7
	1.00	9.94	8.43	0.89

each cell comprising the strategy.

The total number of possible strategies can be very large, even in a simple case: $N_x^{N_P}$, where N_P is the number of protection alternatives and N_X is the number of crossing categories. For $N_X = 5$ and $N_P = 5$ (including "no change"), the total is 3125. In addition, the possibility of installing protective devices (lights, energy-management structures, etc.) on locomotives is an additional parameter to be considered, and each candidate generates an additional array in the cost/lives matrix. A more realistic case, with more crossing categories and the possibility of upgrading existing protection, implies a very large number of possibilities.

1.5 EVALUATION OF ALTERNATIVE STRATEGIES

The object of this model is calculation, sorting, and ranking of the possible alternative strategies, applying specifically stated (and readily changed) constraints and criteria to eliminate all but those sufficiently close to basic policy objectives. In the present form of the program, several such constraints are applied:

1. Total Cost. All strategies exceeding a specified total cost are eliminated.

2. Minimum Lives Saved. All strategies which fail to save any required minimum number of lives are eliminated.

3. Cost/Benefit. Acceptable strategies must provide at least a specified cost/benefit ratio. Two limits, different if desired, are imposed: one on each element of the matrix (each crossing category), and one on the total strategy.

Calculations and sorting are carried out in a manner intended to reduce computation time; i.e., the most expensive cases are examined first. In Table 1-5, for example, if one examines the X01, W4 case first and finds that it alone already exceeds the total cost constraint, there is no need to consider further any of the $5^4 = 625$ strategies of which it forms an element.

1.6 INFORMATION OUTPUT

The focus of the computation is listing of the costs and benefits associated with the more desirable alternatives. (However, the basic cost/lives matrix is readily displayed). In operation, after all input data have been supplied and constraints (maximum total cost, minimum lives saved, etc.) specified, acceptable strategies are selected, and each is characterized in terms of cost, lives saved, cost per accident prevented, and net benefit – benefits minus cost. A specified number of "acceptable" alternatives can be ranked on the basis of any of these characteristics. In the resulting list, all parameters are printed, including (if requested) the total number of installations of each type of wayside protection.

The program is highly interactive, providing frequent opportunity for modification of input data, injection of new constraints, or choice of alternative output information. Running time is primarily determined by these interactions, with typical runs requiring only seconds of CPU time on the TSC PDP-10.

2. INPUT DATA

2.1 INTRODUCTION

As described in the preceding section, several classes of information are required as input to the analytical models. In no case are the data truly satisfactory, and choices must be based upon selection from among numerous partial, limited, or otherwise inadequate sources. These ambiguities inevitably limit the confidence which one may have in the final results. However, the objective in this work is determination of gross effects, based on averages over large categories. Thus some uncertainties can be tolerated as affecting only fine details. Secondly, the flexible form of the computer program permits consideration of sufficient cases to assess the sensitivity of final results to variations in input data and at least allows the establishment of a range within which "truth" almost certainly lies.

2.2 THE GRADE-CROSSING POPULATION

As a result of the many institutions and governmental jurisdictions involved with grade crossings, the true crossing population has remained something of an enigma. In recent years responsible estimates of as fundamental a number as the total of public grade crossings had a range of approximately 10%, and private crossings have never been subjected, on a nationwide scale, to more than the crudest of approximations. Uncertanties in this regard have proven sufficient to warrant the undertaking by FRA and AAR of a national inventory, now in progress, which will represent a most dramatic improvement in knowledge of the scope and nature of the present problem. Pending results of that program, other sources must be sought as foundations for analysis. The Voorhees Program Definition Study[3] of 1968-69 extrapolated existing state inventories to arrive at the first national estimate categorized by location (urban/rural), protection type, and rail and highway traffic densities. As part of preparation of the FRA/FHWA Report to Congress,[5] these estimates were substantially improved by FHWA, and these data form the basis for the research described here; they are summarized in Table 2-1.

One relatively minor correction has been applied. On average, approximately 1200 crossings per year receive new active warning systems.[6] Since this continuing activity is presumably focused upon the more hazardous crossings, the effect of even a 1/2% annual reduction in passively protected crossings could be of significance. The Report to Congress data represent the assumed situation in 1970, and thus a three-year correction was appropriate in the TSC analysis. To achieve this, a somewhat optimistic view was taken: it was assumed that the more hazardous crossings were the ones receiving new protection. Specifically, the assumed (FHWA) crossing population was ranked according to estimated hazard (using accident prediction equations described in the following section) for the six categories shown in Table 2-1. For each relevant classification, the improvements were assigned in proportion to the estimated number of annual accidents, and crossings were eliminated from each group in order of hazard, working down from the most dangerous. The crossings thus eliminated from the passive categories then were added, as appropriate, to the flashing light and automatic gate groups, or moved from flashing light to gate classes, with an adjustment for the reduced hazard resulting from the improvement. The entire process is summarized in Table 2-2.

Changes not reflected in this approach include closing of crossings, opening new crossings, and construction of grade separations; these modifications have been omitted primarily due to the absence of necessary data. However, they are unlikely to represent significant effects. Those crossings eliminated, except in infrequent major relocation projects, are likely to be of relatively low traffic density, and are thus of little impact on accident occurrance. It has become increasingly difficult to open new crossings without at least providing active protection, and the relatively small number of separations constructed annually are typically part of new road construction, rather than eliminating existing crossings. Thus it is felt that these changes are relatively minor in affecting grade crossing protection analyses, and may be omitted without compromising the results.

TABLE 2-1. 1970 FHWA ESTIMATE OF CROSSING POPULATION

Type of Warnings	Urban	Rural	Total
Passive	51006	123901	173907
Flashing Lights*	22203	17269	39499
Automatic Gate	5974	2970	8944
Totals	79183	144167	223350

*includes all active warnings except automatic gates

TABLE 2-2. MODIFICATION OF ESTIMATED CROSSING POPULATION FOR WARNING SYSTEM INSTALLATIONS, 1970-1973

Crossing Category	1970 Estimate	Effect of New Flashing Light Installations	Effect of New Automatic Gate Installations	Effect of Up-Grading from Lights to Gates	Resulting 1973 Estimate
Passive					
Urban	51006	-907	-229		49870
Rural	123901	-1159	-291		122451
Total	173907	-2066	-520		172321
Flashing Lights					
Urban	22203	+907		-384	22726
Rural	17296	+1159		-694	17761
Total	39499	+2066		-1078	40487
Automatic Gates					
Urban	5974		+229	+384	6587
Rural	2974		+291	+694	3955
Total	8944		+520	+1078	10542

2.3 ESTIMATION OF ACCIDENT PROBABILITY

The ability to characterize crossings in terms of accident probability, or expected accident rate, is at the heart of the type of analysis used here. Thus this topic must receive careful attention. The subject has recently been the subject of comprehensive review elsewhere,[7,8] and a detailed historical survey will not be given here. As a general rule, research in this area has found only limited success, in the sense that the equations and coefficients which best fit existing data have shown only limited validity in explaining the variabity actually observed. There is a clear consensus that neither regression analyses nor formal prioritization formulas are adequate for the determination of the protection needs of any individual crossing. It appears highly unlikely that any completely mechanistic approach to the setting of protection priorities can be successful; the experience, common sense, and professional intuition of traffic and signal engineers and others must always play a key role in determining the treatment of a particular case. At the same time, there is a pronounced need, by those with program-formulation responsibilities, for an analytical formulation which can provide estimation of the benefits to be expected from a specified expenditure, or the resources required to achieve a particular goal. This requirement, involving only large-scale averages, is far less demanding than consideration of individual crossings. Indeed, the assumption upon which this study is founded is that overall policy and program decisions can legitimately be based upon very general assumptions and data. Accident prediction equations may be of relatively little value in forecasting the collision experience of a particular crossing, but when applied to a large group of crossings (of comparable highway and rail traffic), the projections for total number of accidents can achieve sufficient accuracy to be of great utility. Further, as the statistical sample is enlarged to a significant fraction of the total population, the results for any major category are necessarily forced into fair conformity with national totals. In recent years the FHWA has devoted substantial effort to this topic, as documented in papers delivered at the 1972 and

1974 grade crossing conferences.[9,10] The results of the latter study, based upon data for 35,335 crossings and 7795 accidents, have been adopted in this work with slight modification. The general form of the equation found by FHWA to give the best representation of the data is $\log_{10}(A) = C_o + C_1 \log_{10} \bar{V} + C_2 (\log_{10} \bar{T}) + C_3 (\log_{10} \bar{V})^2 + C_4 (\log_{10} \bar{T})^2$, where

A = Number of accidents expected annually per crossing
$\bar{V}$ = Average daily motor vehicle traffic
$\bar{T}$ = Average daily rail traffic.

For the TSC analysis this equation was applied, with specified coefficients, to the assumed 1970 crossing population, described in the preceding section. The initial coefficient (C_o) was then adjusted to yield the number of accidents estimated for 1970 in the Report to Congress.[5] The breakdown by type of active protection is inferred from the annual FRA summary of grade crossing accident statistics.[11] The assumed categorization of accidents is indicated in Table 2-3, which also shows the factor (C_o^1/C_o) by which the coefficients of Ref. 10 were modified to bring the equations into conformity with estimated actual experience. (It should be noted that the Report to Congress estimates of accident experience are extrapolations, from traffic accident records, which reveal that — due in part to differing reporting requirements — the FRA crossing accident statistics show only half of the actual injuries and less than one-third of the accidents.)

The final coefficients used are displayed in Table 2-4. Some insight into the meaning of these expressions can be obtained through plotting expected annual accidents per crossing for each case, as done in Figures 2-1 through 2-6. The most pronounced effect is the saturation which occurs at higher values of ADT; the traditional expectation that accident rate is simply proportional to highway traffic is seen to be quite misleading for these cases. This is of considerable importance, as it is the more hazardous crossings which offer the greatest benefits for automatic protection, and errors for these categories can have substantial effect.

It is appropriate to note that this leveling off is to be expected on theoretical grounds. When the mean time between vehicles

TABLE 2-3. ESTIMATED DISTRIBUTION OF ACCIDENTS AMONG CROSSING CATEGORIES, 1970

Crossing Category	Assumed Number of Accidents (1970)	Correction Factor (C_o'/C_o)
Passive		
Urban	3839	.979
Rural	3429	1.008
Total	7268	
Flashing Lights		
Urban	2878	.977
Rural	1438	.966
Total	4316	
Automatic Gates		
Urban	729	.977
Rural	97	N/A
Total	826	
Overall Total	12410	

TABLE 2-4. ACCIDENT PREDICTION EQUATIONS USED (OBTAINED FROM FHWA, REF. 10, WITH C_O VALUES MODIFIED)

Crossing Category	C_o	C_1	C_2	C_3	C_4
Passive					
Urban	-3.91181	1.47000	.42379	-.20265	0.00
Rural	-4.08601	1.52211	.41623	-.21282	0.00
Flashing Lights					
Urban	-2.47875	.30726	.77665	0.00	-.16075
Rural	-5.00906	1.74150	1.91167	-.21923	-.93909
Automatic Gates					
Urban	-2.55358	.23998	.96516	0.00	-.22067
Rural	-5.48618	1.74150	1.91167	-.21923	-.93909

Estimated Number of Accidents per Crossing per Year $= 10^A$, With A given by $A = C_o + C_1 \log\overline{V} + C_2 \log\overline{T} + C_3(\log\overline{V})^2 + C_4(\log\overline{T})^2$, and $\overline{V}$ = average daily vehicular traffic, $\overline{T}$ = average daily number of trains.

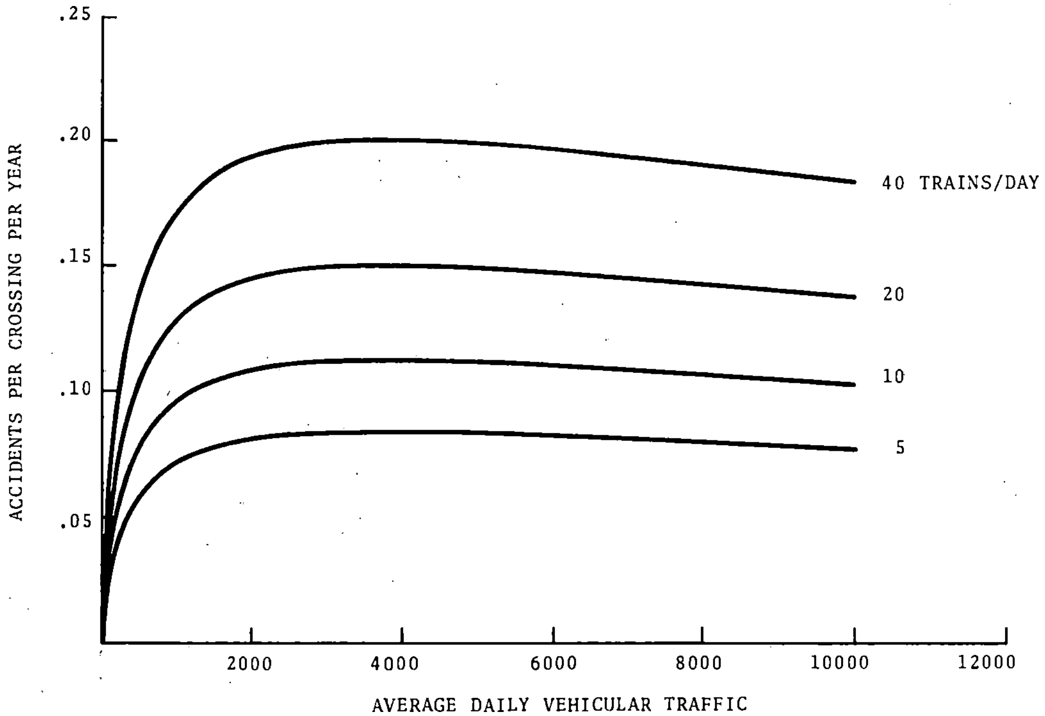

Figure 2-1. Estimated Number of Accidents per Crossing per Year - Rural, Passive Case

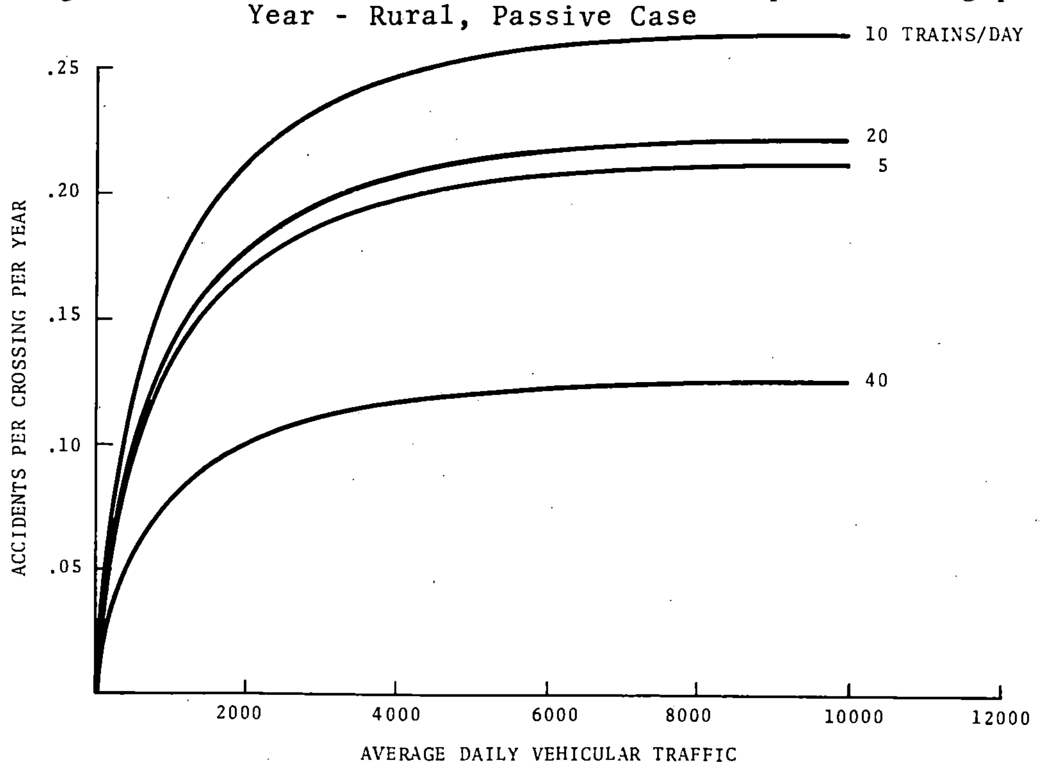

Figure 2-2. Estimated Number of Accidents per Crossing per Year - Rural, Flashing Light Case

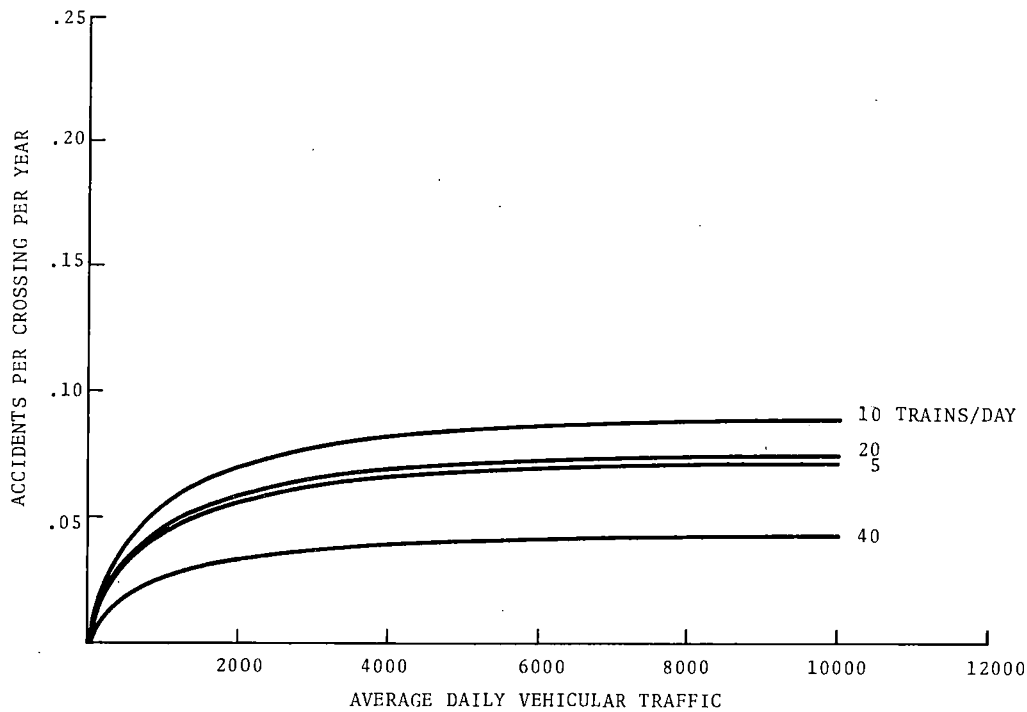

Figure 2-3. Estimated Number of Accidents per Crossing per Year - Rural, Automatic Gate Case

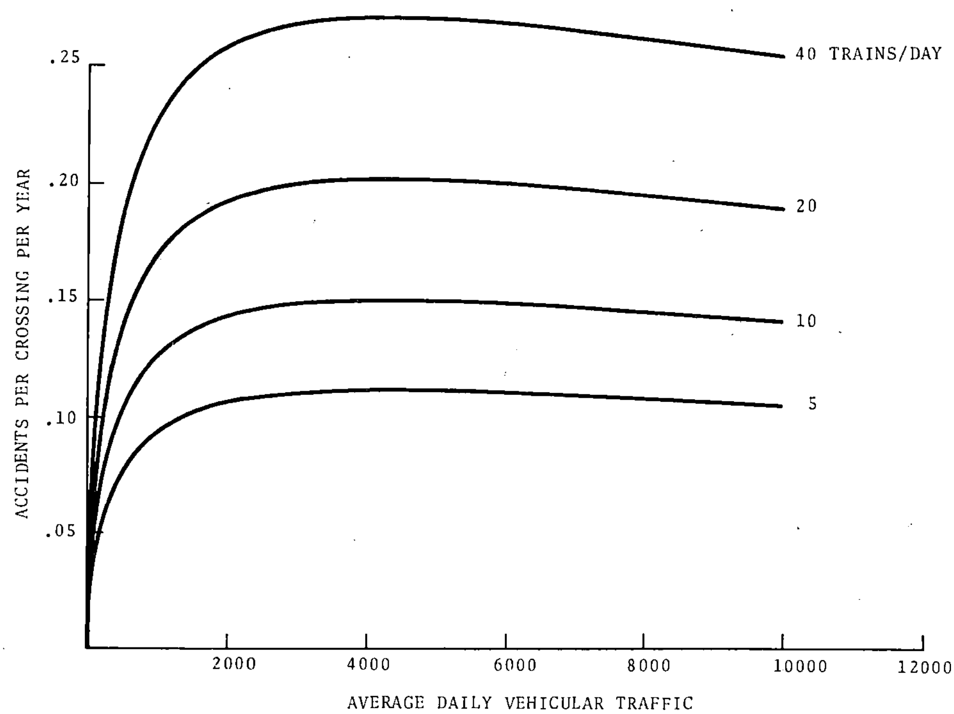

Figure 2-4. Estimated Number of Accidents per Crossing per Year - Urban, Passive Case

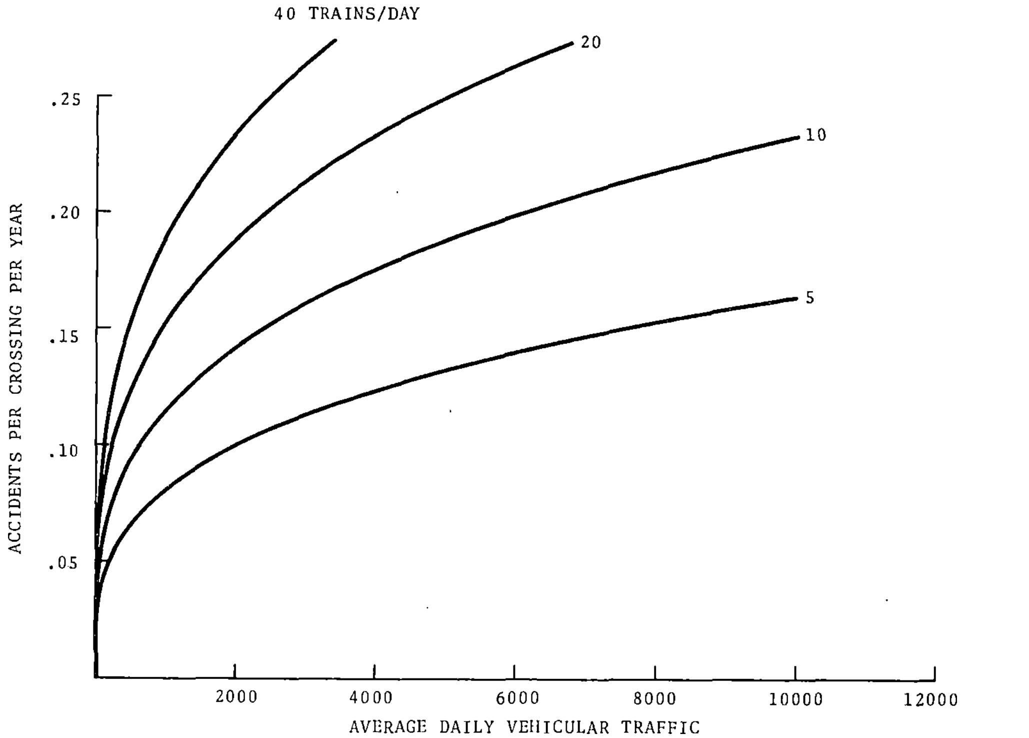

Figure 2-5. Estimated Number of Accidents per Crossing per Year - Urban, Flashing Light Case

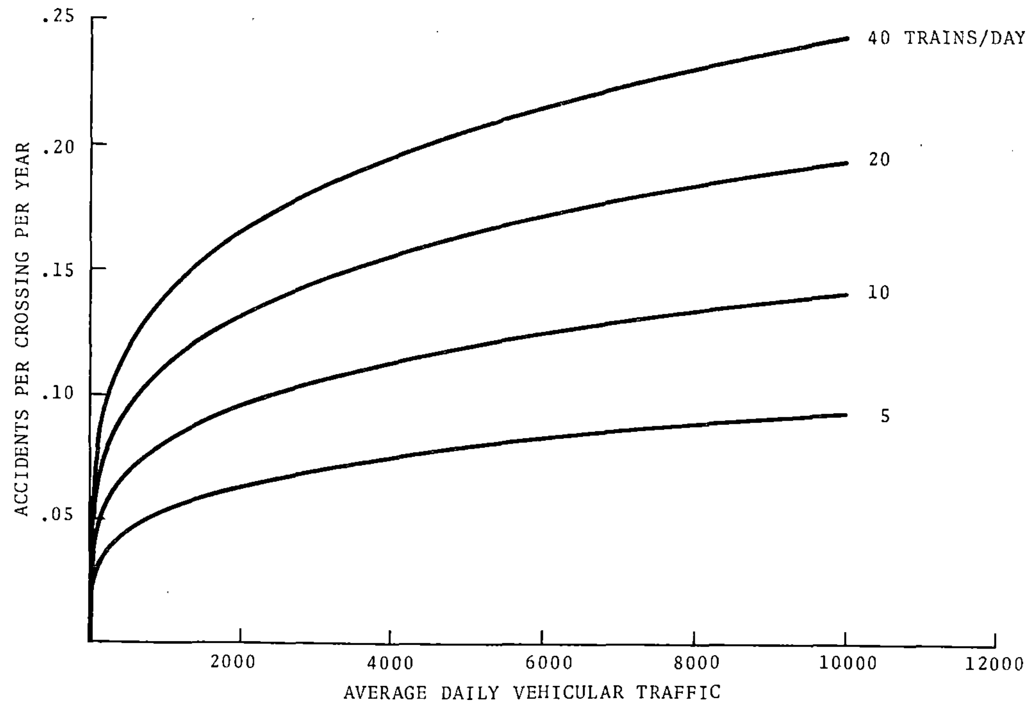

Figure 2-6. Estimated Number of Accidents per Crossing per Year - Urban, Automatic Gate Case

is large — several minutes or more — a driver is entirely on his own in detecting the presence of a train or activated motorist warnings. However, if cars are separated in time by only seconds, each driver can be influenced by those ahead of him, and the more cautious or attentive motorists will tend to influence — and thus protect — those behind them. On high-traffic highways the "safer" drivers thus may be seen as the equivalent of active protection systems, with a "warning" - slowing and stopping of a vehicle - likely to be at least as effective as an automatic gate. The numbers for this plausibility argument are consistent with the prediction equations. An ADT of 5000, assumed to be concentrated in a 16-hour period, implies an average vehicle separation of 11 seconds, for which a strong effect would be expected. For an ADT of 1000, this becomes slightly under 1 minute, and much less effect would be expected.

As will be discussed in a later section, accident cost is largely associated with fatalities. Thus the number of deaths per accident is also an important parameter to determine. The study upon which the Report to Congress was based found that there is a marked difference in this quantity between urban and rural crossings; the values used there were .065 deaths/accident for urban and .210 for rural. (The cause is presumably the higher speeds — particularly for motor vehicles — in the rural cases.) However, in the work reported here, these coefficients have been modified for greater consistancy with more recent statistics. The figures in the Report to Congress were based upon the average number of fatalities reported to FRA during the period 1967-1970, 1428. Since that was a period of declining death rate, a more satisfactory procedure, now that later data are available, is to take the 1969-71 average, 1336. As in the Report to Congress, this number is increased by approximately 5% to include deaths occuring more than 24 hours after the accident. This changes the deaths/accident to .0608 (urban) and .1965 (rural).

One further adjustment is necessary. If one uses the FHWA accident prediction equations and the estimated 1973 crossing population to "predict" the number of fatalies in 1973, a substantial discrepancy is found: 1318 (predicted) vs. 1129 (actual), including the estimated 5% post-24-hour adjustment. It is interesting to note that the installation of active warning systems over that 3-year period (2056 flashing light, 1600 automatic gate), as summarized in Table 2-2, apparently only accounts for approximately 80 out of the total reduction of 271 deaths.

Any attempt to assess the actual cause of this discrepancy must be largely speculative. The assumptions already embodied in the modified population and accident prediction equations are far from certainties. Yet the magnitude of the difference is great enough to suggest that other factors are involved, particularly since increasing traffic might be assumed to have generated a concomitent <u>increase</u> in crossing fatalities. Random fluctuation is unlikely to be the answer; the standard deviation for annual crossing deaths is approximately 35.

One possibility suggests itself. An examination of FRA grade crossing accident statistics for recent years shows a steady decline in fatalities per accident; the value for 1973 is only 86% of the average for 1960-71. This trend should not be totally unexpected, since the efforts of NHTSA and the automobile industry have strongly been directed toward improvement of motor vehicle crashworthiness since the mid-1960's. If the fatalities per accident are adjusted by this factor, regardless of its cause, the 1973 "predicted" toll becomes 1133, almost identical with the observed 1129. This extremely close agreement is almost certainly fortuitous in part, in view of the many approximations upon which it is based. However, it does make reasonable .05122 (urban) and .1656 (rural) as final values for fatalities per accident.

The FHWA accident prediction equations are based upon data far greater in magnitude and broader in sources than any previous study. This has made them particularly suited to TSC research, which is directed toward analysis applicable to the entire country. However, it is felt to be of some value to compare the FHWA results to some of the formulations previously suggested, many of which are now in use for state and local planning. The alternative equations considered are shown in Table 2-5, with sources indicated. The means of comparison has been application of these equations to the estimated national crossing population. In Table 2-6 each case is

TABLE 2-5. ALTERNATIVE ACCIDENT PREDICTION FORMULATIONS

Source	Reference	Abbreviated Title	Basic Form of Equation for Annual Number of Accidents per Crossing
Peabody-Dimmick	12	P-D	$\frac{C\bar{V}^{.170}\bar{T}^{.151}}{P}$ + correction term
Richards-Lamkin	2	Texas	$C(.02091 + .26689(1 - \exp(c\bar{V}\bar{T})) -.03996P)$
Schoppert-Hoyt	4	NCHRP50	$CP\bar{T}(1-\exp(c\bar{V}))$
Newnan	1	Newnan	$C_1 + C_2\bar{V} + C_3\bar{T}$ (Different C's for each warning system; Numerous crossing characteristics in C_1)

$\bar{V}$ = Average daily vehicular traffic $\bar{T}$ = Average daily train traffic

C's are generally coefficients associated with crossing characteristics; P's are characteristic of various warning systems. These represent general functional form only; the appropriate reference should be consulted for the exact formulations. The simplest form – the exposure index, VT – is nearly identical to NCHRP50.

TABLE 2-6. OVERALL MULTIPLIERS NECESSARY TO BRING VARIOUS ACCIDENT PREDICTION EQUATIONS INTO AGREEMENT WITH 1970 ESTIMATED ACCIDENT RECORD

Crossing Category	Texas	Newnan	NCHRP50	P-D	FHWA
Passive					
Urban	.629	.025	1.70	.333	1.21
Rural	.900	.050	6.75	.231	.93
Flashing Lights					
Urban	.820	.028	10.28	.637	1.14
Rural	.884	.018	6.75	.655	1.50
Automatic Gates					
Urban	.662	.012	12.98	.645	1.14
Rural	.273	.011	5.71	.290	N/A

characterized by a constant multiplier necessary to bring the prediction into conformity with the actual (estimated) accident totals for various categories. A multiplier of unity indicates a perfect match; a very small value shows that the original equation leads to a substantial overestimate when applied to the national population and used to predict all accidents.

This comparison can have only limited meaning, since different decades, parts of the country, and definitions of "accident" are involved. Also, the form in which various equations are expressed and assumptions made for certain parameters may cause results which differ somewhat from the exact form originally proposed. To provide a qualitative comparison, predicted accident rate (utilizing the required multiplier) is plotted in Figure 2-7 for rural passive crossings as a function of highway ADT, for 15 trains per day, and in Figure 2-8 as a function of rail traffic for an ADT of 1000. Since the Texas formulation varies rapidly at low traffic densities, additional curves are plotted for it.

2.4 EFFECTIVENESS OF MOTORIST WARNING DEVICES

Given an estimate of the crossing population and the hazard associated with classes of crossings, the effect of changes can be predicted only with knowledge of the effectiveness of both the old and the new warning systems. In this report, effectiveness E will be defined according to

$$E = 1 - \frac{\text{number of accidents with specified system}}{\text{number of accidents with crossbacks only}}$$

Thus a system which reduces hazard (number of accidents per year) by 90% would be described as having an effectiveness of .9; this in contrast to many studies in which devices are described in terms of relative hazard, which is simply the fractional portion shown above, or 1-E.

Attempts to characterize warning devices have generally been based on either before-and-after studies or accident experience at different corssings within a given jurisdiction. This report will deal primarily with only two basic categories: flashing lights

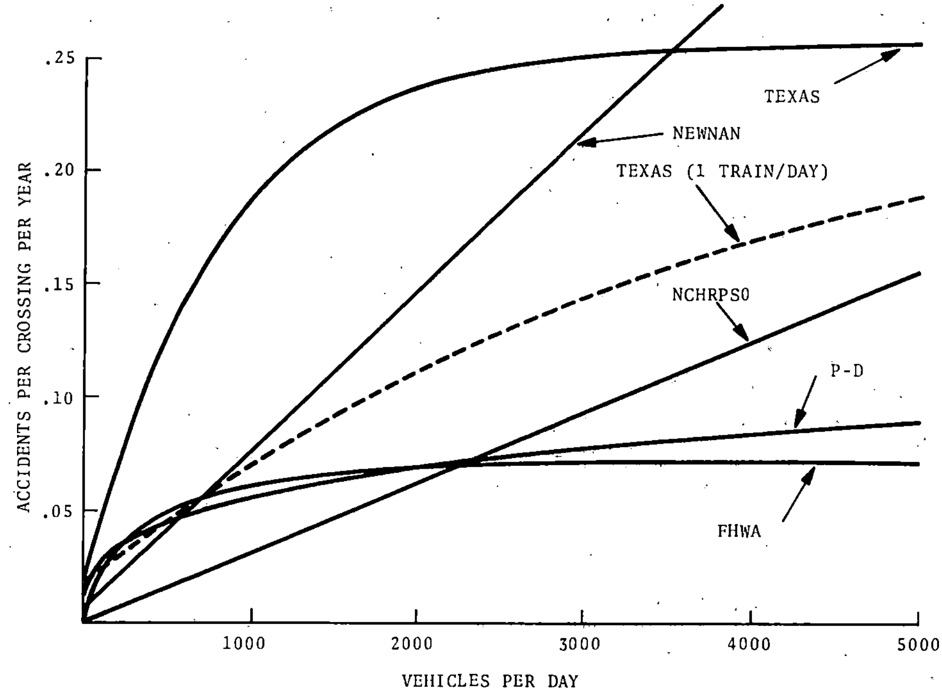

Figure 2-7. Accidents per Crossing Year as Estimated by Alternative Accident-Prediction Equations as a Function of Average Daily Vehicular Traffic: 5 Trains per Day

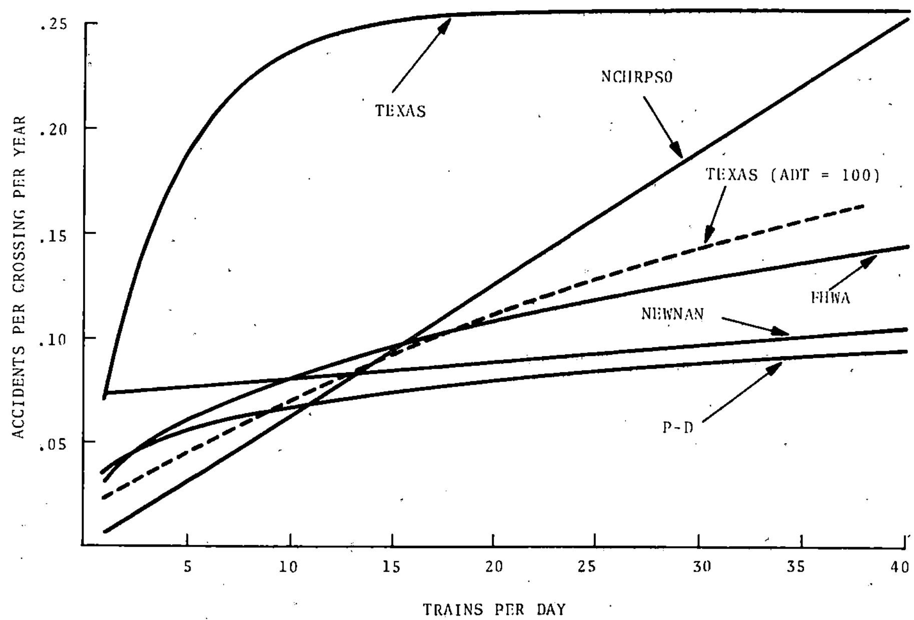

Figure 2-8. Accidents per Crossings per Year as Estimated by Alternative Accident-Prediction Equations as a Function of Average Daily Train Traffic: 1000 Vehicles per Day

alone, and automatic gates with flashing lights. The range of E-values for flashing lights has generally been reported as .6 to .8 (60% to 80% accident reduction), and .85 to .98 for automatic gates.[4,7,8] (Although such numbers obviously must be functions of numerous variables concerning the crossing, the available data are insufficient to permit inclusion of this refinement in the present analysis; thus a single number will be assumed.) In view of the major impact the selection of E's can have on analytical findings, the approach used in this study has been selection of "standard" numbers, with additional presentation of results for a range of E-values. This both illustrates the sensitivity of conclusions to E and permits the reader to find a case closer to his own preference. The "standard" values selected here are .70 for flashing lights, .90 for automatic gates.

Another approach could be taken to estimation of effectiveness. Given a set of accident prediction equations, one can (for example) apply the equations for rural-passive crossings to the rural-flashing light population. In principle, this should demonstrate the effect of flashing lights at those crossings. Unfortunately, this methodology is found to confuse rather than clarify the matter. Table 2-7 shows the results of this procedure for the several forms of accident prediction equation previously discussed. It is distressing to note that the FHWA equations, presumably the most firmly based, show a negative effectiveness for flashing lights. A more-detailed view of the situation is obtained by plotting the ratio of the expected accident rate for flashing lights to that for passive warnings. This is done in Figure 2-9 for urban and rural cases as a function of ADT and train volume, and the anomolous effect is seen to exist primarily for very low rail traffic.

In fact, this finding need not be especially surprising. When one categorizes crossings only by traffic densities, there will obviously be many in a particular subset which are more hazardous than others, and they are more likely to have received active warnings. Thus it is possible that those crossings equipped in the past with flashing lights were (for example) four times as hazardous as the average passive crossing, so that reduction in hazard of

TABLE 2-7. WARNING SYSTEM EFFECTIVENESS INFERRED FROM APPLICATION OF ALTERNATIVE ACCIDENT PREDICTION EQUATIONS TO 1970 ESTIMATED CROSSING POPULATION

Warning System	Texas	Newnan	NCHRP50	P-D	FHWA
Flashing Lights					
Urban	-.05	.23	.54	-.12	-.38
Rural	.27	.25	.56	-.59	-.38
Automatic Gates					
Urban	.88	.40	.80	.16	.20
Rural	.77	.75	.92	.49	.60

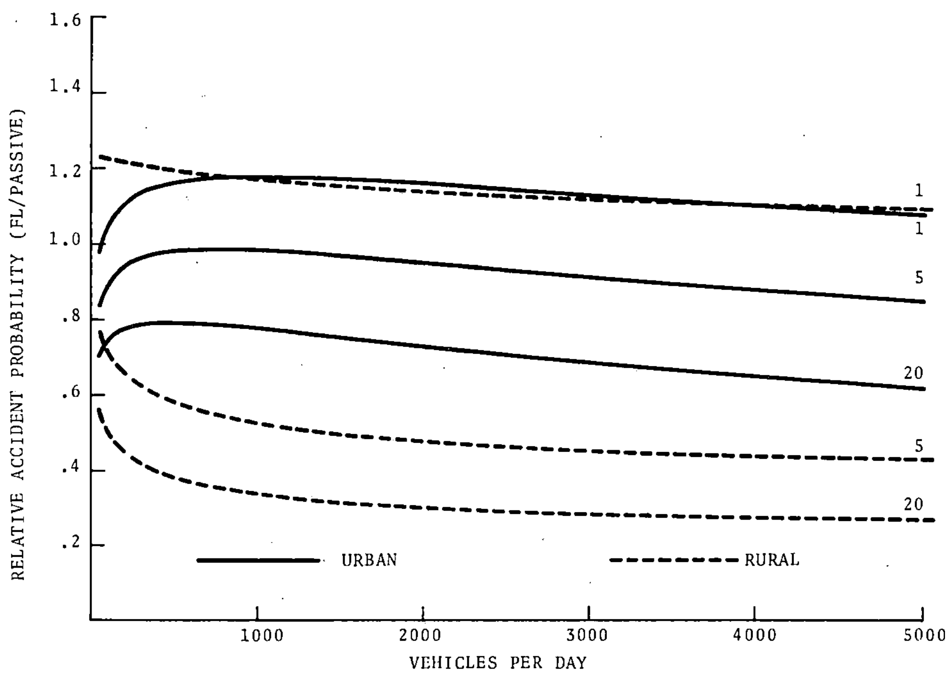

Figure 2-9. Ratio of Accident Rate Estimated from Flashing Light Accident Prediction Equation to That Estimated from Passive Equation

even 70% would leave a more dangerous actively protected crossing than the "typical" passive case for the same traffic densities. Another important factor is that the crossings upon which the equations are based will, on average, be protected with older, possibly obsolete and non-standard equipment. Thus, modern flashing lights may provide substanti^lly better protection than the "average" flashing lights (or wig-wag signals) now in service.

This finding adds another complication to the present analysis. One must estimate not only the effectiveness of new equipment, but also that of the systems being replaced. Only then can an accurate prediction of the improvement be obtained. Expressed formally, the net effectiveness E_{ab} in changing from system "a" to system "b," becomes

$$E_{ab} = 1 - \frac{1-E_b}{1-E_a}$$

In view of the extremely limited data available relating to this complication, the approach taken has been to assume existing flashing lights to have an average effectiveness of .35 — half that assumed for new lights. The ambiguities surrounding this question apply almost entirely to the estimation of the benefits of upgrading from lights alone to lights plus gates. The error is not, however, comparable to the uncertainty in the old effectiveness value. If automatic gates are taken as having $E_{ag} = .9$, and old flashing lights, $E_{fl} = .35$, the net effectiveness change in adding gates is .85; if E_{fl} is taken as .7, the net improvement is .67.

2.5 COST OF PROTECTIVE SYSTEMS

The expense associated with installation of a particular class of motorist warning at a grade crossing will obviously be a function of many parameters — number of tracks, type of highway, railroad signal system, prevalence of lightning, availability and reliability of commercial power, etc. The question is even more complex when upgrading is considered, since the possibities range from total removal of the existing protection, with a fresh start, to merely adding a gate mechanism and necessary control circuitry. The cost of cantilever-mounted flashing lights is strongly affected by the size of the structure required for a particular road. In 1973, the lowest cost installation made in California had a price of $2400 and the highest, $74,400; greater expense can easily arise at complex multi-track intersections.

California now estimates the average new installation of gates plus flashing lights at $17,700, lights alone, $9,200, and upgrading from lights to gates, $19,700.[8] These figures are relatively low compared to many others; another large state estimates $41,000, $29,000, and $19,000, reopectively for the same categories. (These, on the other hand, are somewhat higher than are commonly reported.)

A further complication arises in attempting to develop true overall costs, which must include maintenance and amortization of the protection. Again using California as an example, the estimated total annual cost, assuming a 30-year life and 10% cost of capital, is $1588 for flashing lights and $3445 for gates. The goal of the TSC analysis is development of broad guidelines, rather then precise treatment of a specific case. Hence the decision has been made to attempt to circumvent (or omit) the use of details of maintenance costs, assumed discount rate, economic life, etc. Rather, a much simplified course is followed: it is assumed that the total annual cost of a protective system is equal to 10% of the initial installation cost. Several years ago, this appeared to be a reasonably accurate approximation; current interest rates make it a somewhat conservative view at present. The attraction of this simplification is that the costs of a crossing protection program can be interpreted in two alternative ways, depending on the purpose. The same number then represents both the annual installation cost for a 10-year total program, or the annual total societal costs in the steady state situation. For example, the program expressed as Alternative 3 in the Report to Congress, Part II, had an estimated annual cost of $75M for 10 years. By the convention adopted here, one would expect this program, when completed, to add a national annual amortization-plus-maintenance cost of $75 M. As long as this convention is clearly understood, results of the TSC analysis can readily be converted as desired for a specific case or application. The values used for equipment installation cost are to be thought of as equal – by definition – to ten times the total annual cost. Discount rate, lifetime, etc., are then embodied in the single number which results. The costs assumed as the standard case for the examples of the following chapter are:

Flashing Lights: $20,000
Automatic Gates: $35,000
Upgrade from Lights to Gates: $25,000

These values are essentially somewhat arbitrary estimates; refinement is anticipated in the coming year. Separation of cantilever and non-cantilever costs, and division into single-track and multiple-track cases is desirable, along with greater precision. In general, however, until better effectiveness numbers are determined for such aspects as cantilevers and constant-warning-time train detection, there is no purpose to exact cost speculation.

The cost of grade separations can also vary over a wide range. However, for the purpose of this analysis, separations are not of great interest. The expense compared to that of automatic gates is simply too great ever to be warranted purely on grounds of safety, particularly in view of the leveling-off of hazard at high traffic densities. Special situations, particularly on high-speed roads where crossings are not expected, may produce a different conclusion, but these factors cannot be incorporated in the general analysis described here. The common justification for separations is economic, based on motorist delay costs at crossings. This expense can be substantial for high-traffic-density cases. However, the constraint within which this study has been carried out has been consideration of safety benefits only. Further, past studies[3,5] have suggested that even inclusion of delay costs warrants a relatively small number of separations – far to few to have a dramatic impact upon crossing safety. In other words, one can treat resource allocation for active crossing protection and for grade separations as distinct subjects, with relatively little interaction or overlap.

2.6 ACCIDENT COSTS

The societal cost of automobile accidents was investigated in 1971 by NHTSA,[13] and this study, although unpublished, has become a basic starting point for ecomomic analyses in this area. Although it is impossible to achieve a generally acceptable "value of a human life," it has been possible to assess, primarily on the basis of unearned future income, the societal cost of a death. Medical costs for injuries, and (particularly relevant for crossing accidents) expenses when a victim is permanently disabled, can also be approximated. Property damage is easily included, although it is a minor aspect of the cost of grade crossing collisions.

Preparation of the Report to Congress required consideration of the different proportion of accidents of various severity levels for crossings as compared to automobile accidents in general. The figures generated for the Report have been used in this study, adjusted for the change in deaths per accident, and arbitrarily increased by 15% to accomodate inflation for the period 1970-1973. The resulting values, expressed in terms of average cost per accident, are $60,770 (rural) and $28,750 (urban).

2.7 BENEFIT AND COST RELATIONSHIPS

It is these numbers which represent the economic benefits of grade crossing protection, and from which guidance must be taken if one wishes to utilize resources in a manner which will maxmize the reduction of injury and death. Only through the formalism of such economics can one readily make decisions between crossing expenditures and those for other highway purposes or totally different safety projects. Possible criteria which might be imposed in determination of policy include consideration of the benefit-cost ratio (benefits divided by cost) and net benefit (benefit minus cost). There are strengths and weaknesses to each approach, discused elsewhere in this report and in other studies.[3] Fortunately, there is one common complication which does not arise in a substantive way in the grade crossing area. It is usually true that a large project will require many years of expenditure before benefits begin to accrue. Appropriate discounting factors must be used, generally causing serious degradation of the benefit-cost ratio. However, a crossing protection program is composed of many small parts — individual crossing projects — and the benefits are gained as soon as installation is complete. Thus in terms of steady-state costs and benefits no discounting is appropriate, and benefit/cost or net benefit can be calculated directly. These are indicators calculated in the TSC computer program, rather than the total benefits associated with total costs over the economic life of the equipment.

2.8 VARIATION WITH TIME

The analysis and results in this report take 1973 as the base year. No modifications for future inflation, population growth, traffic changes, etc., are incorporated. In general, this may be expected to result in understatement of benefits, and to omit some categories of crossings which will – as traffic increases – eventually warrant protection. The uncertainties of such predictions, applied to the ambiguities of the basic data described earlier, make such an exercise inappropriate to this study.

3. APPLICATION OF THE METHODOLOGY TO EXISTING DATA

3.1 ALTERNATIVE SETS OF ASSUMED INPUT DATA

The methodology described in Section 1 has been applied to several alternative sets of assumed input data. In all cases, the crossing population is taken to be that shown in Table 3-1, derived as indicated in Section 2. Ten different possibilities have been considered for warning system cost, effectiveness, and composition. These are as follows:

3.1.1 Case 1: Standard

This case represents a "best estimate" of the existing characteristics of currently available systems. Values used are shown in Table 3-2.

3.1.2 Case 2: Old Warning with High Effectiveness

It was argued previously that new flashing lights and gates can, on average, be expected to provide greater effectiveness than those already in place, particularly when crossings are categorized only by traffic densities. This subject is primarily of relevance to estimation of the effect of upgrading from flashing lights to gates. This case is based upon the assumption that new equipment is as described for Case 1, but the effectiveness of old flashing lights (those now in place, on average) is taken as .6 (rather than .35), with .85 (in place of .7) for old gate installations. In essence, this case provides a measure of the effect of this ambiguity on the calculated results.

3.1.3 Case 3: High Cost

This differs from the Standard case only in that increased warning system costs are assumed, as shown in Table 3-3. This is to provide an indication of the sensitivity of results to estimated equipment costs.

TABLE 3-1. ASSUMED CROSSING POPULATION CATEGORIZED BY WARNING SYSTEM, LOCATION, AND HAZARD

FHWA PART II INVENTORY DATA EXTRAPOLATED TO 1973

DEATHS PER ACCIDENT: 0.1654 RURAL, 0.0512 URBAN.
COST ($1000'S) PER ACCIDENT: 60.770 RURAL, 28.750 URBAN.

NO.	W	XINGS	HAZARD	DESCRIPTION
X01	0R	94686.	0.01958	RURAL,PASSIVE,EXPOSURE 1
X02	0R	21945.	0.04383	RURAL,PASSIVE,EXPOSURE 2
X03	0R	4731.	0.06871	RURAL,PASSIVE,EXPOSURE 3
X04	0R	1089.	0.09631	RURAL,PASSIVE, EXPOSURE 4
X05	1R	11654.	0.03192	RURAL,FLASHING LIGHTS,EXPOSURE 1
X06	1R	1018.	0.09380	RURAL,FLASHING LIGHTS,EXPOSURE 2
X07	1R	3119.	0.13958	RURAL,FLASHING LIGHTS,EXPOSURE 3
X08	1R	1970.	0.19984	RURAL,FLASHING LIGHTS,EXPOSURE 4
X09	3R	2696.	0.01929	RURAL,AUTOMATIC GATES,EXPOSURE 1
X10	3R	715.	0.04876	RURAL,AUTOMATIC GATES,EXPOSURE 2
X11	3R	544.	0.07039	RURAL,AUTOMATIC GATES,EXPOSURE 3
X12	0U	24766.	0.04597	URBAN,PASSIVE,EXPOSURE 1
X13	0U	18172.	0.08037	URBAN,PASSIVE,EXPOSURE 2
X14	0U	5707.	0.13260	URBAN,PASSIVE,EXPOSURE 3
X15	0U	1225.	0.18179	URBAN,PASSIVE,EXPOSURE 4
X16	1U	12208.	0.06529	URBAN,FLASHING LIGHTS,EXPOSURE 1
X17	1U	7199.	0.15270	URBAN,FLASHING LIGHTS,EXPOSURE 2
X18	1U	2578.	0.23632	URBAN,FLASHING LIGHTS,EXPOSURE 3
X19	1U	740.	0.31570	URBAN,FLASHING LIGHTS,EXPOSURE 4
X20	3U	5389.	0.09334	URBAN,AUTOMATIC GATES,EXPOSURE 1
X21	3U	1071.	0.20771	URBAN,AUTOMATIC GATES,EXPOSURE 2
X22	3U	128.	0.28278	URBAN,AUTOMATIC GATES,EXPOSURE 3
END		223350.		TOTAL

Note: Exposure ratings are only relative, and have no absolute implications.

TABLE 3-2. WARNING SYSTEM CHARACTERISTICS FOR "STANDARD" CASE

Description	Effectiveness	Cost($K)
New Installation of Flashing Lights	.70	20
New Installation of Automatic Gates	.90	35
Upgrade from Flashing Lights to Auto. Gates	.90	25
Separation	1.00	400
Existing Flashing Lights	.35	
Existing Automatic Gates	.70	

TABLE 3-3. WARNING SYSTEM CHARACTERISTICS FOR "HIGH COST" CASE

Description	Effectiveness	Cost ($K)
New Installation of Flashing Lights	.70	25
New Installation of Automatic Gates	.90	45
Upgrade from Flashing Lights to Auto. Gates	.90	32.5
Separation	1.00	400
Existing Flashing Lights	.35	
Existing Automatic Gates	.70	

3.1.4 Case 4: Low Cost

This case, which is analogous to Case 3, assumes significantly reduced equipment costs, and gives an indication of the potential safety benefits of cost reduction, as well as the sensitivity to assumed data values. The numbers used are displayed in Table 3-4.

3.1.5 Case 5: Low Effectiveness

This case assumes lower values for warning system effectiveness than in Case 1 to permit sensitivity estimation; it is characterized in Table 3-5.

3.1.6 Case 6: High Effectiveness

The assumption of higher effectiveness relates to both sensitivity of results and safety benefits of actual improvements through research and development. Values are given in Table 3-6.

3.1.7 Case 7: Gates Only

This case assumes no installation of flashing lights unaccompanied by gates – a policy in effect in some jurisdictions and widely considered as a potential strategy. (Costs and effectiveness of gates are assumed to be as for Case 1.)

3.1.8 Case 8: Flashing Lights Only

In this case, installation of gates is not considered as an allowed option. Although this may seem a somewhat unreasonable assumption, there are jurisdictions which do lean in this direction, adopting the view that more crossings can be protected for fixed resources, and that difference in effectiveness is not sufficiently great to warrant the more expensive device. (Costs and effectiveness of flashing lights are as in Case 1.)

3.1.9 Case 9: Improved Gates Only

Here the implications of development of improved gates, with no use of flashing lights alone, are assessed. Note that the improvement need not be attained in the gate hardware itself for this

TABLE 3-4. WARNING SYSTEM CHARACTERISTICS FOR "LOW COST" CASE

Description	Effectiveness	Cost ($K)
New Installation of Flashing Lights	.70	15
New Installation of Automatic Gates	.90	25
Upgrade from Flashing Lights to Auto. Gates	.90	17.5
Separation	1.00	400
Existing Flashing Lights	.35	
Existing Automatic Gates	.70	

TABLE 3-5. WARNING SYSTEM CHARACTERISTICS FOR "LOW EFFECTIVENESS" CASE

Description	Effectiveness	Cost ($K)
New Installation of Flashing Lights	.60	20
New Installation of Automatic Gates	.85	35
Upgrade from Flashing Lights to Auto. Gates	.85	25
Separation	1.00	400
Existing Flashing Lights	.35	
Existing Automatic Gates	.70	

TABLE 3-6. WARNING SYSTEM CHARACTERISTICS FOR "HIGH EFFECTIVENESS" CASE

Description	Effectiveness	Cost ($K)
New Installation of Flashing Lights	.85	20
New Installation of Automatic Gates	.95	35
Upgrade from Flashing Lights to Auto. Gates	.95	25
Separation	1.00	400
Existing Flashing Lights	.35	
Existing Automatic Gates	.70	

analysis to be applicable; any increase in effectiveness – better advance warning, constant-warning-time detection, etc. – will have the same result. An effectiveness of .98 is used.

3.1.10 Case 10: Improved Flashing Lights Only

This case is to provide reassessment of the Flashing-Lights-Only policy under the assumption that effectiveness could be improved to .85.

3.2 DISCUSSION

For each of the sets of warning system characteristics described above, the potential saving of life resulting from 10-year programs of specified dollar size was computed as a function of annual program cost. There are, of course, many strategies which are suboptimal in the sense that they either save fewer lives for a particular cost or cost more for the same saving of life than for some alternative strategy. If all strategies were shown as points on a graph of lives saved versus program (annual) cost, the qualitative result would be as shown in Figure 3-1. The constraints implied in this analysis of benefit-cost ratios eliminates many strategies, as shown in Figure 3-2. In particular, the limitation on incremental cost-benefit ratio determines a maximum program magnitude. As one "uses up" the high-traffic-density, high-hazard crossings, for which active protection yields substantial benefits, further investment of protection resources can be made only at crossings for which hazard, and potential benefits, are significantly lower. Eventually the point is reached at which the <u>incremental</u> benefit-cost ratio is less than unity (or any other threshold which may be selected), implying that funds are more beneficially expended in other areas. Thus there is a natural limitation on the total amount which can optimally be spent upon crossing warnings, although in practice this point has seldom been reached (it is, of course, dependent upon policy decisions concerning evaluation of "benefits" and the required benefit-cost ratio threshold).

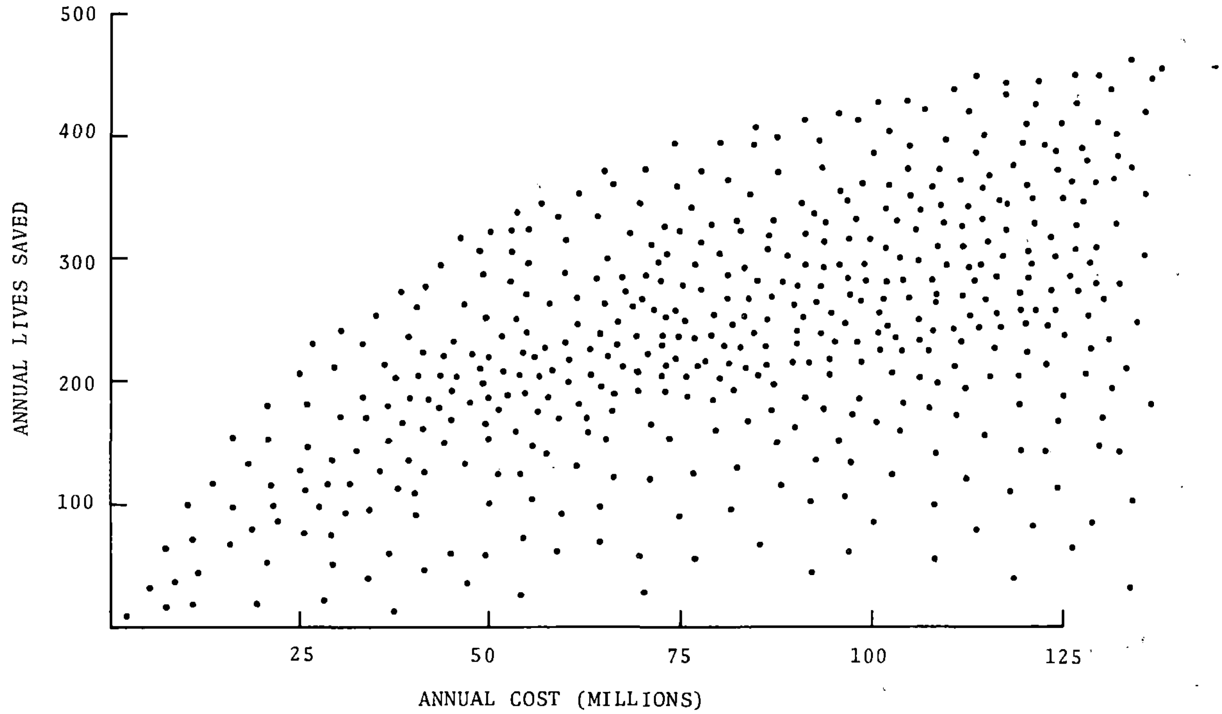

Figure 3-1. Lives Saved as a Function of Annual Program Cost — Illustrative Example Showing All Strategies

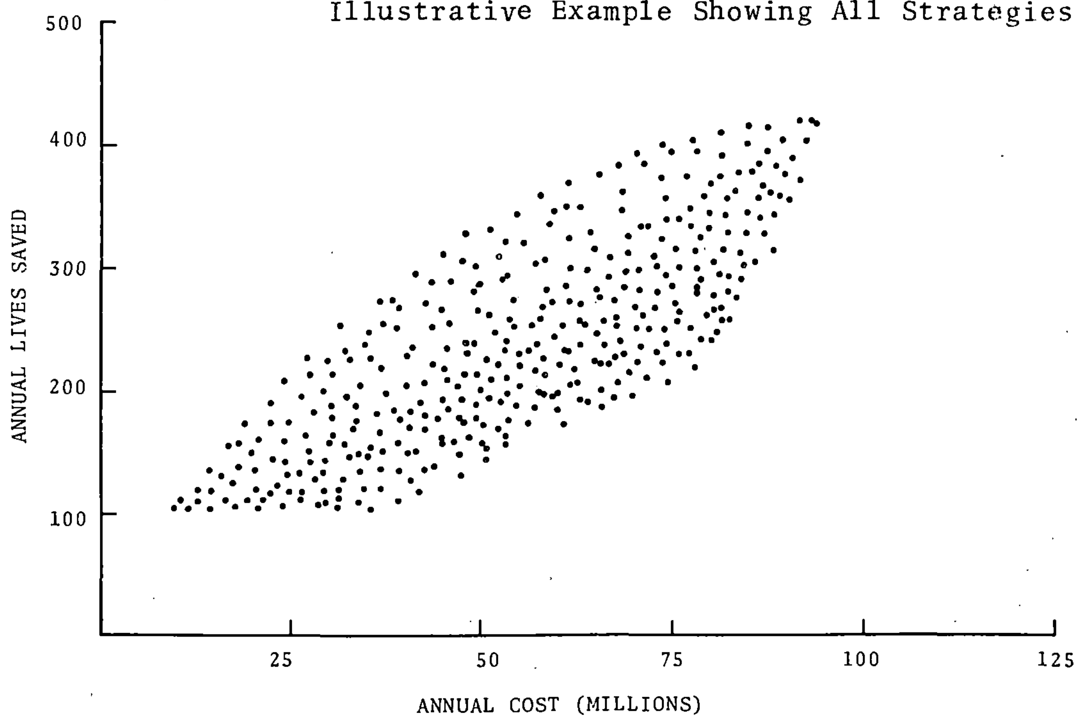

Figure 3-2. Lives Saved as a Function of Annual Program Cost — Illustrative Example Showing All Strategies Falling within Required Constraints on Total Cost, Benefit-Cost Ratios, and Minimum Lives Saved

For the purpose of characterizing alternative policy or research implications, it is basically the upper edge of the lives-cost plot — the envelope — that is of interest, since this represents the best result that one can obtain for specific resource limitations. This information can be plotted as in Figure 3-3, and calculated results of this type (for case 1) are shown in Figure 3-4. However, for clarity of presentation it is simpler to show instead a smoothed continuous curve, and this has been done for various combinations of Cases 1-10 in Figures 3-5 through 3-10. (The many uncertainties, approximations, and marginally valid assumptions upon which the computations are based further justify submerging the individual points in this manner.)

Figure 3-5 simply shows the impact on overall results of the value assumed for the effectiveness of existing warning systems, which is seen to be substantial but not of sufficient magnitude to distort the analysis seriously. Figure 3-5 provides a good measure of the degree to which the other curves would be changed for a given variation in assumed old-system effectiveness.

Variations with cost and effectiveness are shown in Figures 3-6 and 3-7, respectively, and the implications of gate-only or flashing-light-only policies can be seen in Figure 3-8. Note that use of lights-only eliminates major upgrading, and results in a sharp restriction on the total amount that can be spent within the incremental benefit-cost constraint. (This would change substantially if one were to include upgrading to substantially more complex flashing light systems, possibly including cantilevers, motion sensing train detection, etc.)

Figure 3-9 indicates the parallel role played by cost and effectiveness changes. One noteworthy feature of these comparisons is the very substantial differences in the maximum amount which can be spent within the constraints. In Figure 3-10 the effect of significant improvement in the performance of both gates and flashing lights is seen; the implications of achieving .85 effectiveness for flashing lights are particularly noteworthy, although this is a challenging objective.

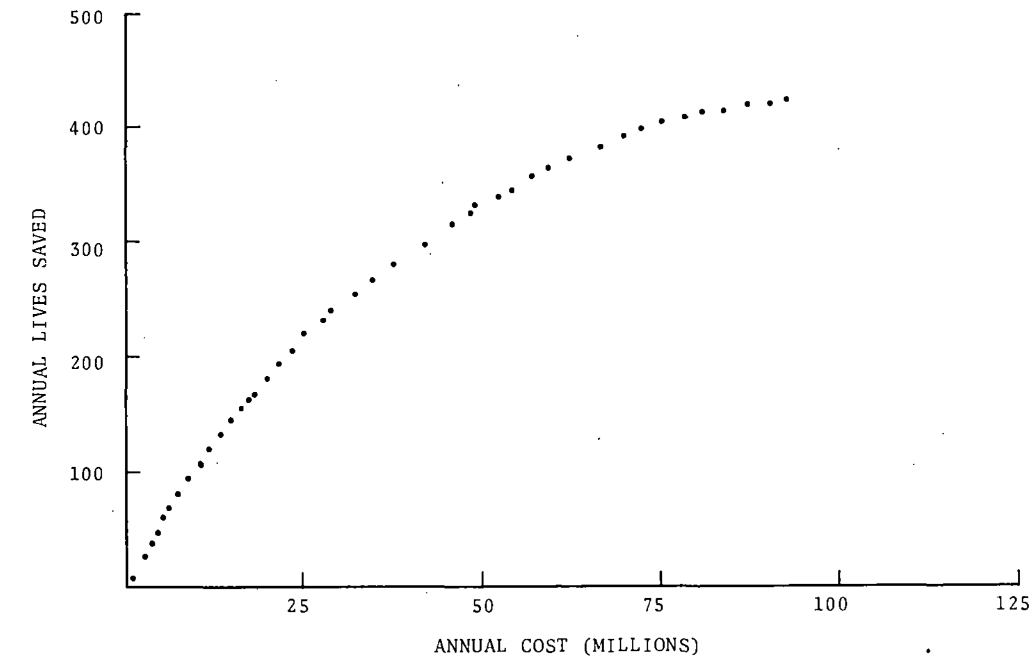

Figure 3-3. Lives Saved as a Function of Annual Program Cost — Illustrative Example Showing Only Those Strategies Which Represent the Maximum Saving of Lives Possible within the Indicated Cost

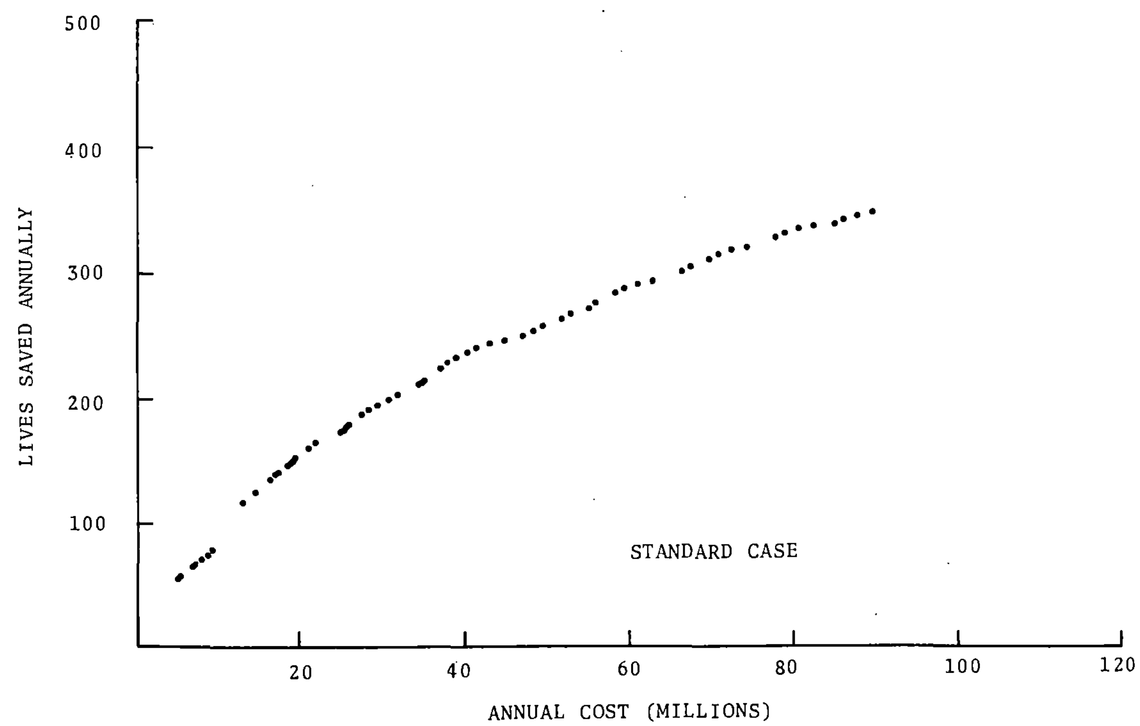

Figure 3-4. Lives Saved as a Function of Annual Program Cost — "Best" Strategies for the Standard Case

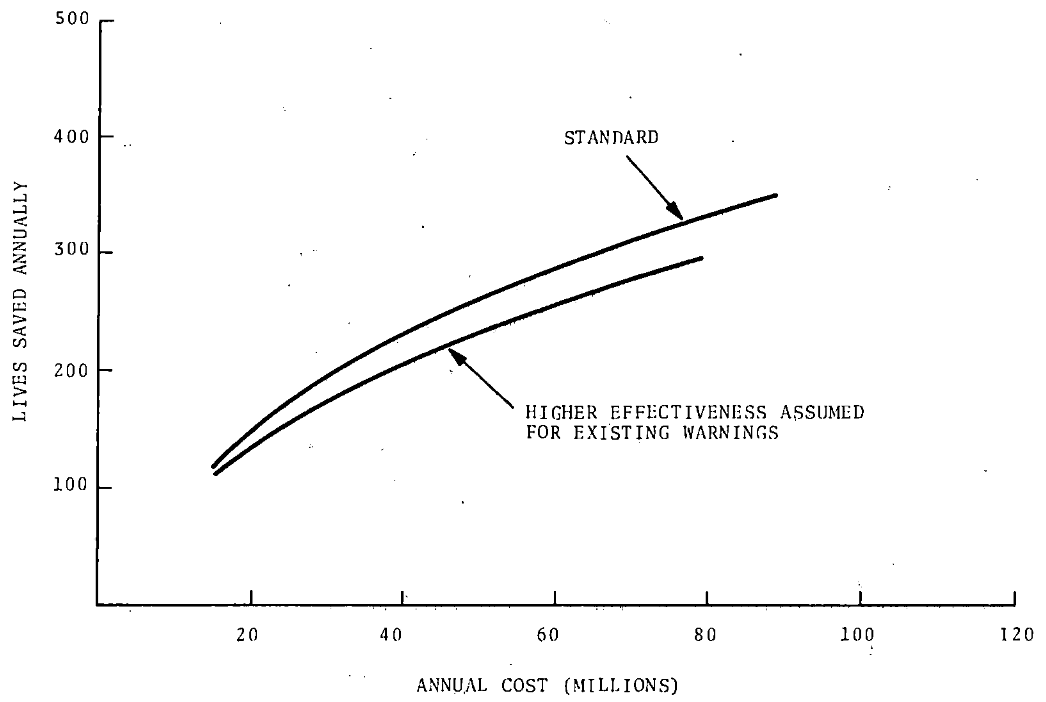

Figure 3-5. Lives Saved as a Function of Annual Program Cost — Standard Case and Case Which Assumes a Higher Value for the Effectiveness of Existing Installed Warning Systems

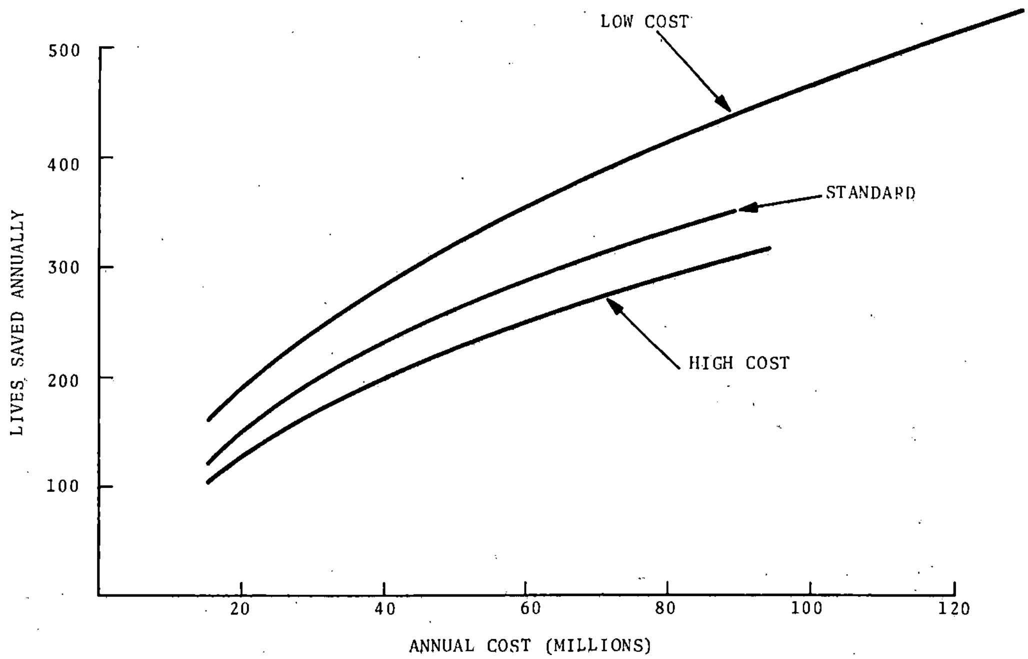

Figure 3-6. Lives Saved as a Function of Annual Program Cost — Standard Case for Higher and Lower Assumed Installation Costs

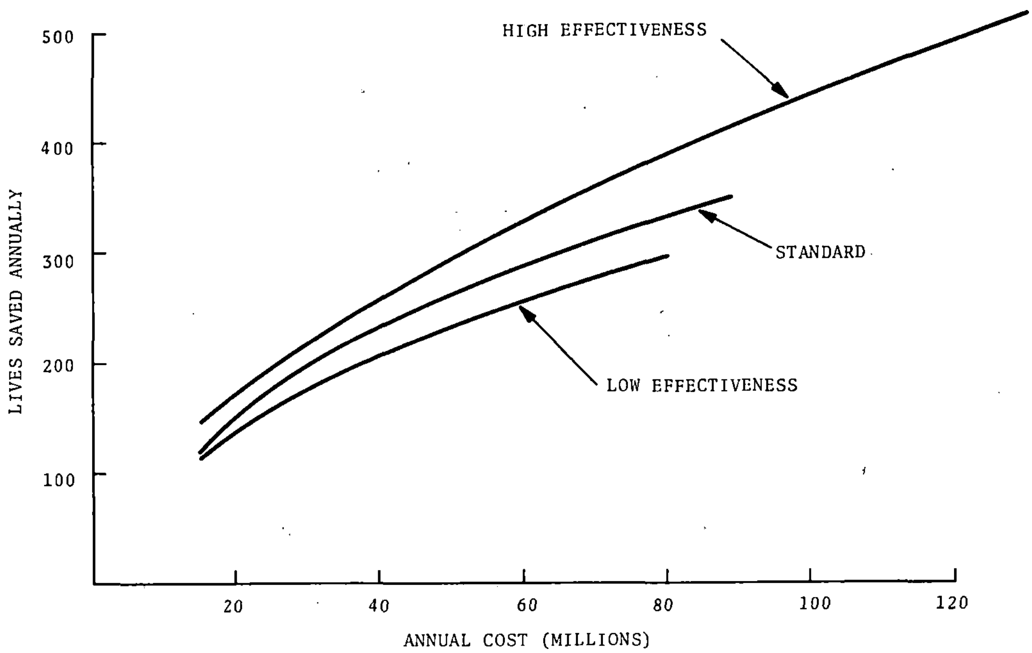

Figure 3-7. Lives Saved as a Function of Annual Program Cost — Standard Cases and Cases for Higher and Lower Assumed Warning System Effectiveness

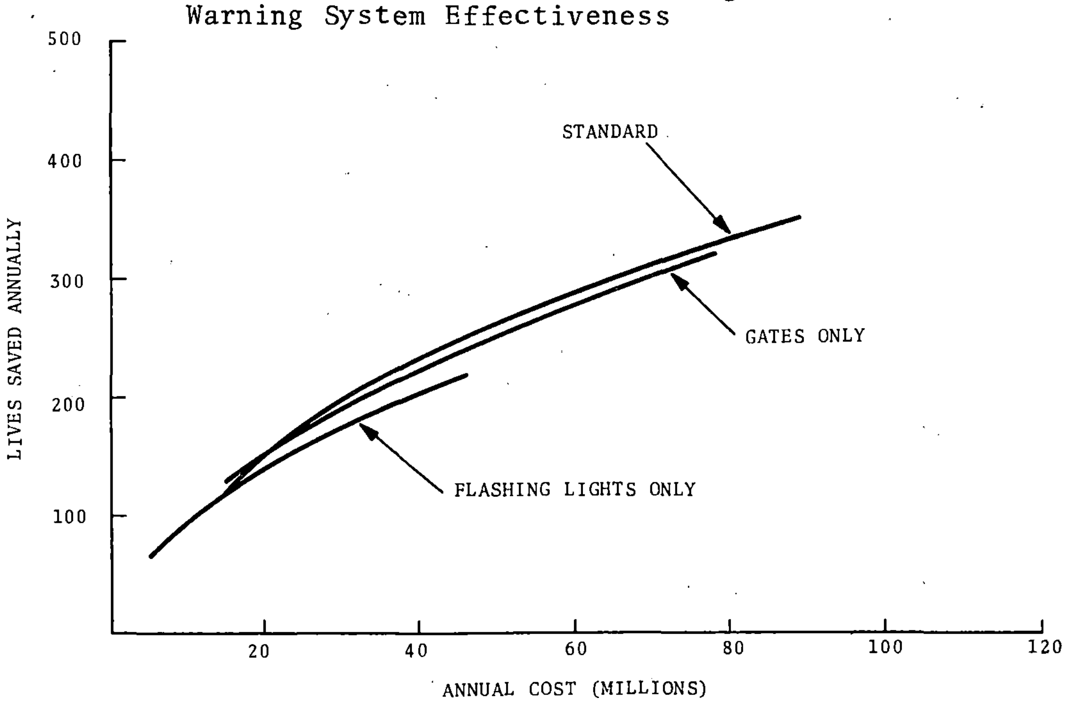

Figure 3-8. Lives Saved as a Function of Annual Program Cost — Standard Case and Cases Assuming Use of Automatic Gates Only and Flashing Lights Only

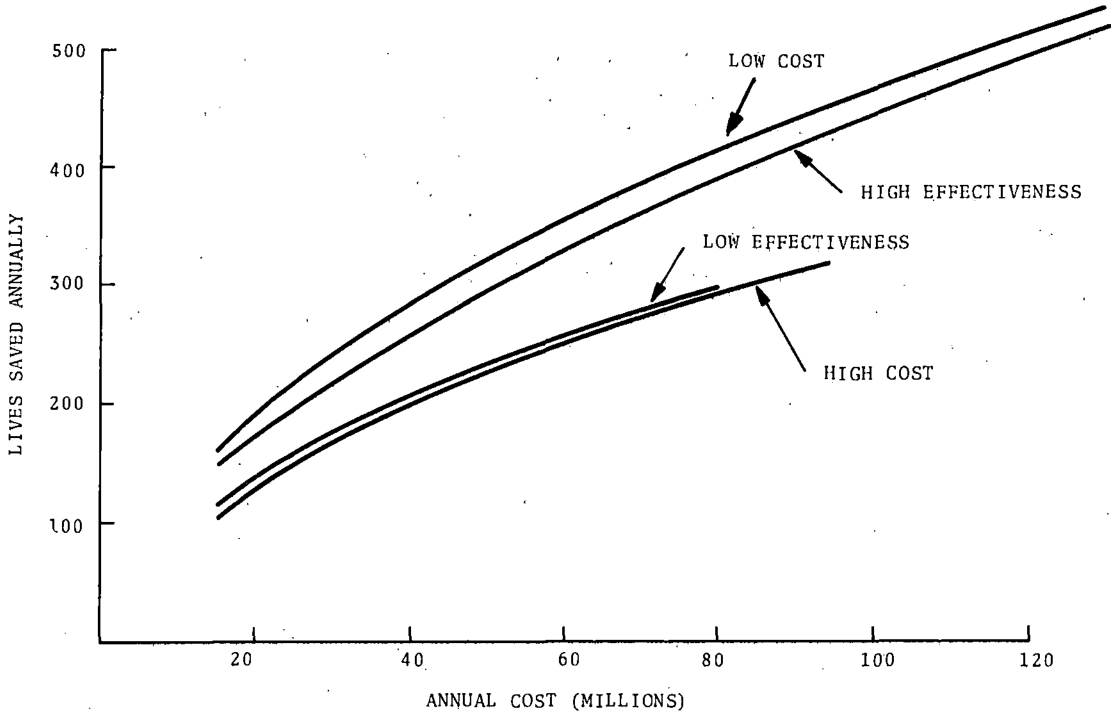

Figure 3-9. Lives Saved as a Function of Annual Program Cost — Cases Plotted are Based upon High Cost, Low Cost, High Effectiveness and Low Effectiveness Assumptions

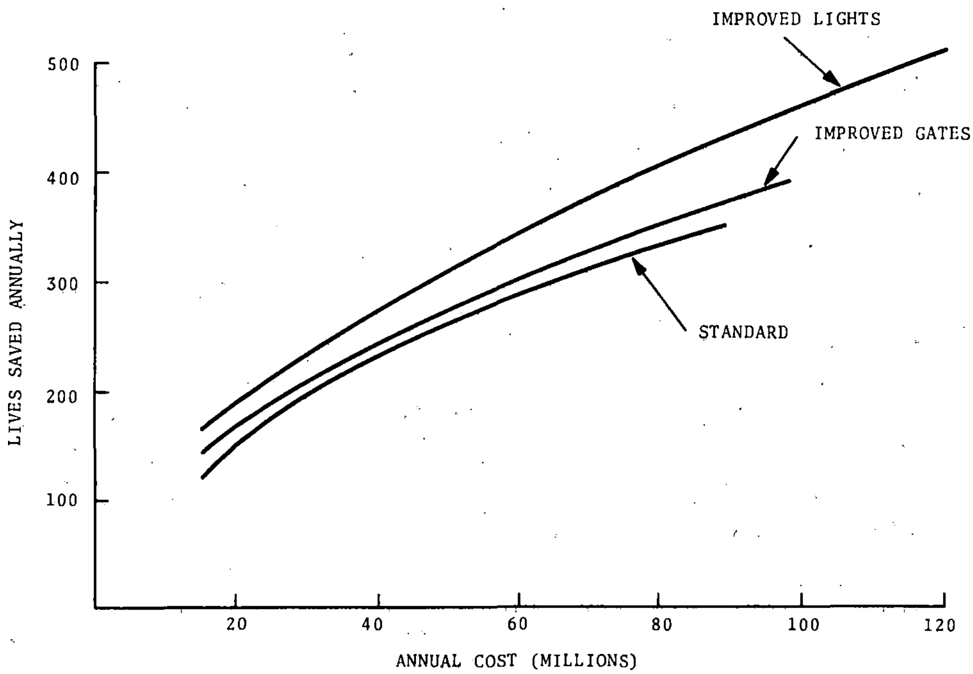

Figure 3-10. Lives Saved as a Function of Annual Program Cost — Standard Case and Alternatives Based upon Assumption of Improvements in Effectiveness of Flashing Lights or Automatic Gates

Similar curves can be determined for two other characteristics particularly relevent to policy formulation: net benefit, and benefit-cost ratio (overall). These are displayed in Figures 3-11 and 3-12, respectively, for the Case 1 (Standard) input data. The benefit-cost curve simply illustrates the "using up" of the more hazardous crossings, so that additional expenditures buy less safety. The net-benefit graph is of interest in that this measure has in the past been used as a policy criterion. Although it follows "lives saved" in general shape, it will be seen to have a maximum which occurs at a slightly lower value than that which terminates the lives vs. cost curves. Also, it shows a relatively flat form at higher values, which tends to limit its utility as a criterion.

A more specific means of comparing and contrasting the different cases is to consider the nature of the optimal strategies found for some specific investment level. For this analysis, a $50-million per year, 10-year program is assumed. This value is somewhat below the range often discussed in recent years, but is well above estimated current expenditures, and appears to be a reasonable compromise for illustrative purposes. Table 3-7 provides a listing of the computed characteristics for Cases 1-10 in terms of lives saved, benefit-cost ratio, net benefit, cost per life saved (which does not include the benefits of injury reduction), and the number of crossings affected.

A more detailed description of near-optimal strategies is provided by Table 3-8. Six examples are presented, all with an approximate cost of $50M. Pairs are presented for Cases 1 (Standard), 4 (Low Cost), and 5 (Low Effectiveness). Both samples for each case represented are estimated to provide the same saving of life, but through markedly differing implementation.

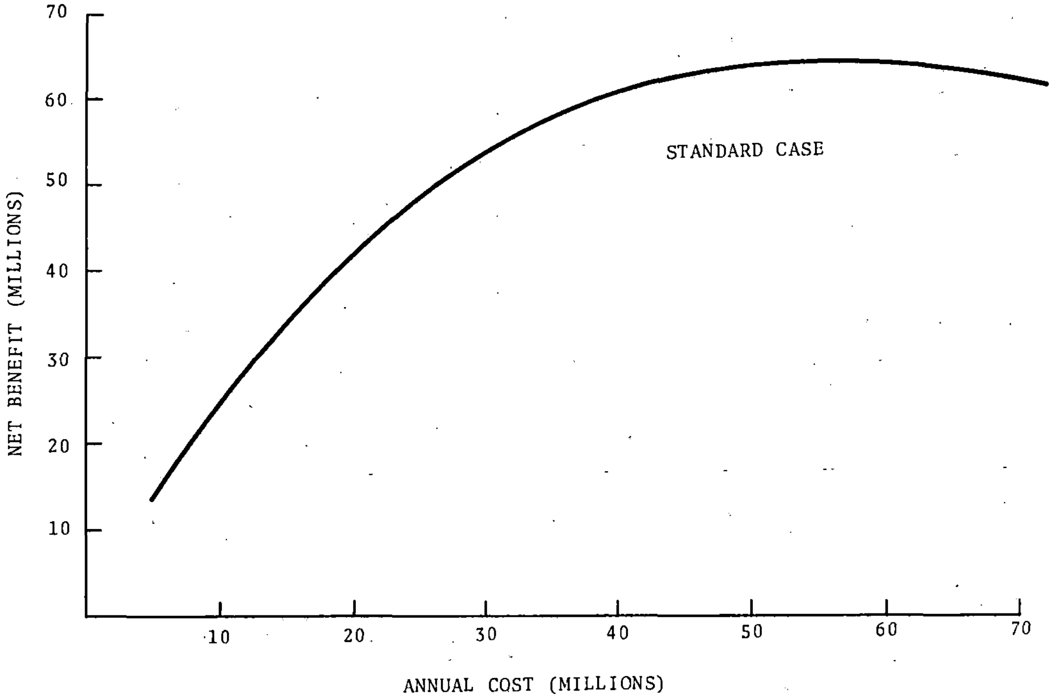

Figure 3-11. Net Benefit as a Function of Annual Program Cost — Standard Case

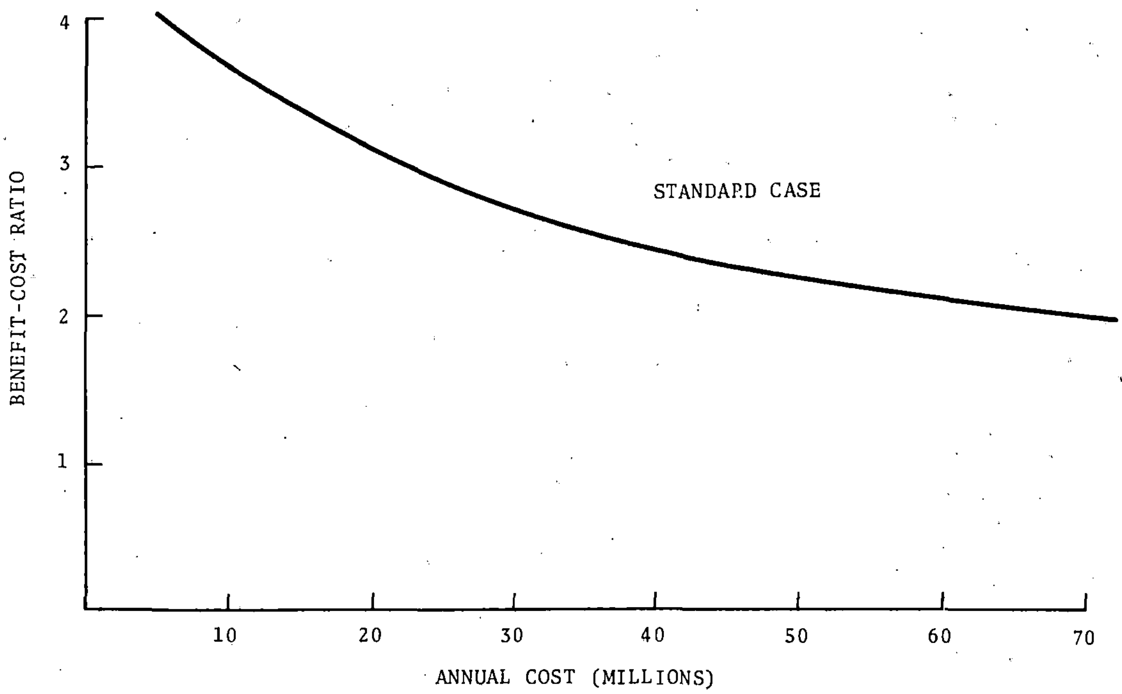

Figure 3-12. Benefit-Cost Ratio as a Function of Annual Program Cost — Standard Case

TABLE 3-7. CHARACTERISTICS OF OPTIMAL STRATEGIES FOR TEN-YEAR $50M/YEAR PROGRAM

Case	Title	Lives Saved	Benefit-Cost Ratio	Net Benefit ($M)	Cost per Life Saved ($K)	Number of Crossings Affected
1	Standard	260	2.2	58.5	194	23,000
2	Higher Effect. Assumed for Old Warnings	234	2.0	47.5	216	22,000
3	High Cost	230	1.9	44.0	217	17,000
4	Low Cost	317	2.8	90.5	159	32,000
5	Low Effectiveness	232	1.9	47.0	221	23,000
6	High Effectiveness	295	2.5	73.8	170	23,000
7	Gates Only	251	2.0	52.2	201	18,000
8	Flashing Lights Only*	221	2.1	52.0	210	29,000
9	Improved Gates Only	272	2.4	61.0	185	18,000
10	Improved Flashing Lights Only	312	2.6	81.7	158	35,000

*$46M is maximum investment permissable within constraints.

TABLE 3-8. DETAILED CHARACTERISTICS OF NEAR-OPTIMAL STRATEGIES – ANNUAL COST OF $50M, VARIOUS WARNING SYSTEM ASSUMPTIONS

Case	Install New Flashing Lights	Install New Automatic Gates	Upgrade from Flashing Lights to Auto. Gates	Upgrade Gates	Total Changes (Urban)	Total Changes (Rural)	Total Changes
Standard							
a.	5956	1089	9425	7132	11131	12471	23602
b.	11527	0	9425	2330	10096	13186	23282
Low Cost							
a.	12752	0	16624	2458	18648	13186	31834
b.	1225	5820	16624	7303	18330	12642	30972
Low Effectiveness							
a.	0	7045	9425	1743	5742	12471	18213
b.	12752	0	9425	1199	11449	11927	23376

4. POTENTIAL APPLICATIONS

The methodology described and illustrated here can be utilized quite broadly. Given the necessary input data and constraints, it can be applied at any level with a sufficiently large crossing population to make average values meaningful. This would include most states, many counties, and a number of railroads. The only specific data required are the crossing population, categorized by rail and highway traffic densities. (Data gathered as part of the National Grade Crossing Inventory are entirely satisfactory.) Local accident prediction equations, if available, may prove preferable to the more general (FHWA) formulation used here. Recent accident statistics are desirable for "calibration" of the equations – adjustment of the forms used so that they predict the correct values for the existing situation. Similarly, either "standard" values or any others better suited to a particular application may be used for equipment cost and effectiveness.

To the degree that the data can be trusted, greater refinement is possible. More warning system options can be considered (if effectiveness can be estimated), and the crossing population can be broken into a larger number of categories. A natural extension, for example, would be to distinguish between single and multiple track crossings.

Another possible application is simplification of consideration of strategies involving on-board equipment. In recent years consideration has been given both to locomotive-mounted beacons to enhance train conspicuity and to energy absorption/deflection structures which might reduce the severity of collisions. The computer program now in use facilitates resource allocation analysis for various possible cases: onboard equipment assumed present, crossing-located warnings assumed in place, or an unconstrained situation. A more detailed sensitivity analysis can readily be carried out to assess more precisely the impact of changes in equipment cost and effectiveness or the total uncertainty associated with ambiguities in those parameters.

5. CONCLUSIONS

1. The methodolgy utilized here provides a convenient and flexible means of analysis. Detailed, quantitative information is readily obtained based upon alternative assumptions, criteria, and input data. The implications of various policy options can thus be readily determined.

2. The results obtained are basically consistent with those of earlier analyses, particulary the FRA/FHWA Report to Congress (Ref. 5). However, the estimated reduction in fatalities is somewhat less than for previous projections, apparently arising from use of accident-prediction equations which indicate little or no increase in accident rate above relatively low ADT values. This implies the existence of relatively few very-high-accident-rate crossings, and thus reduces the total benefits obtainable through installation of warning systems at such locations.

3. The analysis is still severely limited by ambiguities in input data, particularly with respect to warning system effectiveness and estimation of expected accident rates. Lack of inclusion of specific options such as cantilevered flashing lights and motion/speed sensing train detection is a serious weakness, as is inability to characterize hazard as a function of single vs. multiple track, train and vehicle speeds, etc.

4. Very similar results are predicted for both improvements in warning effectiveness and reduction of system costs. However, competitive forces have tended to focus research and development efforts upon costs and equipment durability, with public discussion of safety effectiveness virtually precluded by sensitivities associated with legal liability. This situation, coupled with the fact that 40% of accidents occur at crossings with active warning systems, suggests that improvements in effectiveness will be more readily achieved than significant cost reduction.

5. A policy of gates-only is virtually indistinguishable from a true optimum for the assumed cost and effectiveness values. Although flashing lights used alone represent near-optimal protection for some crossing categories, a policy which permitted only lights with no gates would severely limit the maximum resources which could be allocated – and lives which could be saved – in keeping with the criteria used.

6. A number of resource allocation strategies will achieve the same basic objectives. For example, the widespread use of flashing lights may have overall net results little different from more limited installation of automatic gates, for the same total cost. Thus there remains the option – even the necessity – of the imposition of nontechnical policy considerations. Widespread installation of new warning systems have more popular appeal than a smaller number of less-visible upgradings, but the latter might be advantageous in terms of reduced implementation effort.

7. Within the constraints of this analysis, based on safety alone, grade separation is never warranted. More general inclusion of other societal cost elements, such as motorist delay, can markedly change this conclusion, but with the cost of grade spearation comparable to 10 to 20 automatic installations, the modest safety differential becomes insignificant. However, this analysis is based upon average values. It is quite likely that there are a significant number of crossings characterized by particularly high hazard – well above that predicted by equations used – and separation may be the optimal solution on safety criteria alone for these special cases.

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