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Effectiveness of Motorist Warning Devices at Rail-Highway Crossings

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16. Abstract

This study has determined the safety effectiveness of various types of motorist warning devices in reducing accidents at rail-highway crossings. The study was based on analysis of data included in the DOT-AAR Rail-Highway Crossing Inventory and the FRA Railroad Accident/Incident Reporting System for the years 1975 through 1980. Emphasis was placed on determining the effectiveness of cantilevered flashing lights, mast-mounted flashing lights, stop signs, crossbucks, highway signals, constant warning time devices and crossing illumination; influences of crossing characteristics on warning device effectiveness; and refined effectiveness estimates of flashing lights and gates over those obtained in an earlier DOT study which used data for the years 1975 through 1978.

Standard highway stop signs were found to significantly reduce crossing accidents by an average of 35 percent. Number of trains and tracks are the crossing characteristics which were found to consistently influence warning device effectiveness. Crossing characteristics found not to influence warning device effectiveness include the following: crossing surface, maximum timetable train speed, crossing angle, highway paved, highway traffic, and number of highway lanes. Revised installation and maintenance costs for warning device upgrades (in 1983 dollars) were obtained.

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PREFACE

The Transportation Systems Center (TSC) of the U.S. Department of Transportation, has developed a Rail-Highway Crossing Resource Allocation Procedure, which requires numerical estimates of warning device effectiveness. New effectiveness estimates which are more accurate than previous values were developed in a study documented in this report. This work was sponsored jointly by the Federal Highway Administration's Offices of Research, Development and Technology; and the Federal Railroad Administration's Office of Safety.

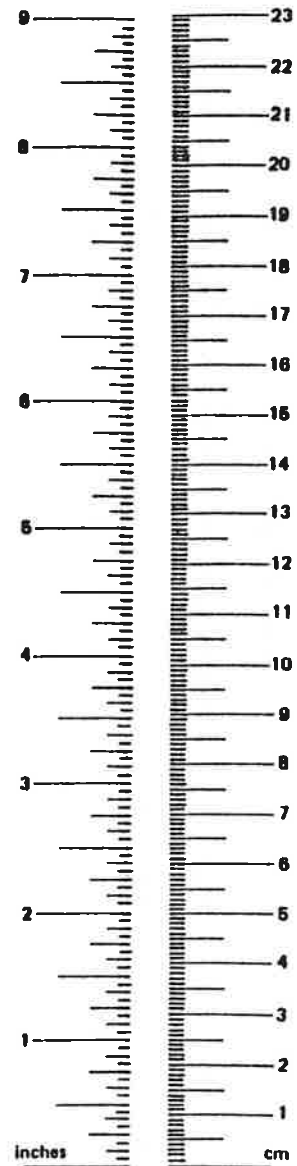
The authors express their appreciation for the technical contributions of Bruce George, Federal Railroad Administration, and Janet Coleman, Federal Highway Administration. Mary Cross of TSC was responsible for providing systems support to the project. Dr. Peter Mengert, also of TSC, provided consultation on statistical procedures.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

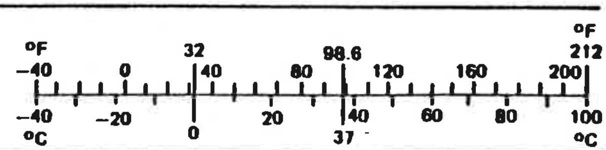
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SUMMARY

This study has developed estimates of the safety effectiveness of various types of motorist warning devices in reducing accidents at rail-highway crossings. Results of the study are intended as possible enhancements to the DOT Rail-Highway Crossing Resource Allocation Procedure (the DOT Procedure). This procedure assists state and railroad program managers in identifying candidate crossings for safety improvements. The study was based on analysis of data included in the U.S. Department of Transportation-Association of American Railroads (DOT-AAR) Rail-Highway Crossing Inventory and the Federal Railroad Administration (FRA) Railroad Accident/Incident Reporting System for the years 1975 through 1980. The study involved three areas of emphasis: (1) determining refined effectiveness estimates of flashing lights and gates over those obtained in an earlier DOT study which used data for the years 1975 through 1978 (Ref. 3); (2) determining the effectiveness of cantilevered versus mast-mounted flashing lights, stop signs, crossbucks, highway signals, constant warning time devices, and crossing illumination; and (3) determining the influences of other crossing characteristics on warning device effectiveness.

New effectiveness values determined for flashing lights and gates are slightly different than earlier results but are more accurate as indicated by the narrower confidence intervals shown in Table S-1.

A significant finding of the study was that standard highway stop signs installed at crossings with passive signs are 35 percent effective in reducing accidents. This level of effectiveness combined with their low cost make stop signs prime candidates for improving the safety of crossings under certain

TABLE S-1. EFFECTIVENESS OF FLASHING LIGHT AND GATE UPGRADES

WARNING DEVICE UPGRADE	EFFECTIVENESS CURRENT STUDY	EFFECTIVENESS EARLIER STUDY	CONFIDENCE INTERVAL CURRENT STUDY	CONFIDENCE INTERVAL EARLIER STUDY
Passive to Flashing Lights	.70	.65	.66 to .75	.57 to .73
Passive to Gates	.83	.84	.80 to .85	.80 to .89
Flashing Lights to Gates	.69	.64	.65 to .73	.56 to .71

conditions (e.g., single tracks, high train volumes and low highway traffic density). Stop signs should thus be considered for possible inclusion in the DOT Procedure. Detailed guidelines for making stop sign installation decisions are presented.

The data analyzed did not show a significant level of effectiveness for crossbucks nor a significant difference in effectiveness between cantilevered and mast-mounted flashing lights. Two types of situations, not fully accounted for by the data investigated, could have contributed to a lower bias on effectiveness results for these two warning devices: (1) crossings selected for upgrades to these devices may have had greater than average increases in their hazard level after the upgrade (e.g. increases in highway and train traffic) and (2) crossings selected for cantilevered rather than mast-mounted flashing lights may have had characteristics that generally diminished warning device effectiveness (e.g. restricted sight distance). Further research is suggested to determine the extent to which the characteristics of crossings selected for upgrades, or changes in these characteristics after upgrades may influence the effectiveness estimates of warning devices.

There was insufficient data available for developing useful estimates of the effectiveness of crossing illumination and constant warning time devices.

It was found that warning device effectiveness generally declines with increasing numbers of tracks and trains per day. Further analysis of train traffic showed that the influence of this characteristic is dominated by thru trains. Flashing light upgrades from passive signs at crossings with a rural location have a significantly higher level of effectiveness than those with an urban location. For crossings with fewer than 25 percent of its trains operating during daylight, the effectiveness of upgrades from passive signs to flashing lights and from flashing lights to gates was found to be significantly higher than cases with a greater percentage of day trains. A number of crossing characteristics investigated showed no consistent influence on warning device effectiveness, including: crossing surface, maximum timetable train speed, crossing angle, highway paved, daily highway traffic, predicted accident rate and number of highway lanes.

The study has provided an extended set of warning device effectiveness values which can be used for possible enhancements to the DOT Procedure. These values, shown in Table S-2, define warning device effectiveness as a function of numbers of trains and tracks. In addition, revised installation and maintenance costs in 1983 dollars, shown in Table S-3, were obtained for use in updating the DOT Procedure.

TABLE S-2. WARNING DEVICE EFFECTIVENESS VERSUS TRACK AND TRAINS

Number of Tracks	Total Trains Per Day	Effectiveness Passive (Cl 1 to 4) to Fl Lights (Cl 7)	Effectiveness Passive (Cl 1 to 4) to Gates (Cl 8)	Effectiveness Fl. Lights (Cl 5, 6, 7) to Gates (Cl 8)
Single	0 - 10	.75	.90	.89
Single	≥ 11	.61	.80	.69
Multiple	0 - 10	.65	.86	.65
Multiple	≥ 11	.57	.78	.63

TABLE S-3. WARNING DEVICE LIFE CYCLE COSTS

Warning Device Upgrade	Installation Cost	Life Cycle Maintenance Cost*	Total Life Cycle Cost*
Passive to Flashing Lights	$43,800	$10,700	$54,500
Passive to Gates	65,300	18,700	84,000
Flashing Lights to Gates	58,700	18,700	77,400
Passive to Stop Signs	400	400	800

*Present value of maintenance and lift cycle costs assumes a 30-year life and 10% discount rate.

1. INTRODUCTION

1.1 PURPOSE

This report documents a study to determine the effectiveness of various motorist warning devices in reducing accidents at rail-highway crossings.

1.2 BACKGROUND

The Highway Safety Acts of 1973 and 1976 and the Surface Transportation Assistance Acts of 1978 and 1982 provide funding authorizations for individual states to improve safety at public rail-highway crossings. Safety improvements frequently consist of the installation of active motorist warning devices such as flashing lights or flashing lights with gates. In support of these safety efforts, several projects have been undertaken by the U.S. Department of Transportation (DOT) to assist states and railroads in effectively utilizing Federal funds available for rail-highway crossing safety improvements. One of these projects has developed the DOT Rail-Highway Crossing Resource Allocation Procedure (the DOT Procedure) to assist state and railroad program managers in identifying candidate crossings for improvement (Ref. 1, 2).

The DOT Procedure requires information on the effectiveness of different warning device options for installation at crossings. The effectiveness information is provided in the form of a decimal fraction number assigned to each type of warning device being considered. The effectiveness value reflects the reduction in accidents expected from installation of the warning device at a typical crossing. For example, the estimated effectiveness of flashing lights installed at crossings, currently equipped with only passive signs, is .70 since an average reduction in accidents of 70 percent has been experienced for such installations. Effectiveness values are required for three types of warning device installations currently considered by the DOT Procedure: (1) flashing lights installed at passively signed crossings, (2) gates installed at passively signed crossings, and (3) gates installed at crossings with flashing lights.

Effectiveness values for the three warning device options listed above were determined in an earlier study using data from the U.S. DOT-AAR National Rail-Highway Crossing Inventory (the Inventory) and the FRA Rail Accident/Incident Reporting System (RAIRS) for the years 1975 through 1978 (Ref. 3, 4). Since then, two more years of data have become available. This allows for expanded opportunities to determine the effectiveness of various warning devices. This study has analyzed the additional data with the objectives listed below.

1. To obtain more accurate estimates of effectiveness for the three warning device options currently considered by the DOT Procedure.

2. To obtain, where data were sufficient, effectiveness estimates for other types of warning device installations for possible consideration by the DOT Procedure, including the following:

   - upgrades among the eight FRA classes of warning devices[1]

   - upgrades to illumination, cantilevered and mast-mounted flashing lights, crossbucks, standard highway stop signs, highway signals, wig-wags, bells and constant warning time devices.

3. To determine the influence of various crossing characteristics on warning device effectiveness including: number of tracks and trains, number of highway lanes and vehicles, train speed, crossing angle, whether the highway is paved, predicted accidents prior to upgrading, and whether the crossing is urban or rural.

[1]See Section 2 for definition of FRA warning device classes.

2. STUDY APPROACH

The DOT-AAR Inventory contains 20 data elements used in this study to describe the type of warning device at a crossing as shown in Figure 2-1. The FRA reviews this data and assigns an FRA warning device class to each crossing. The FRA classes describe eight categories of warning devices considered in this study that generally reflect the level of motorist warning present. The higher the FRA class, the more warning information is provided to the motorist. The composition of the FRA warning device classes in terms of the 20 Inventory warning device data elements is shown in Table 2-1. The FRA class includes the warning device for which it is named and could also include any combination of lower class devices. For example, Class 7, flashing lights, could also include crossbucks. Effectiveness values were determined in this study for various combinations of warning devices, including those defined by the FRA classes and the individual types defined by the 20 Inventory elements.

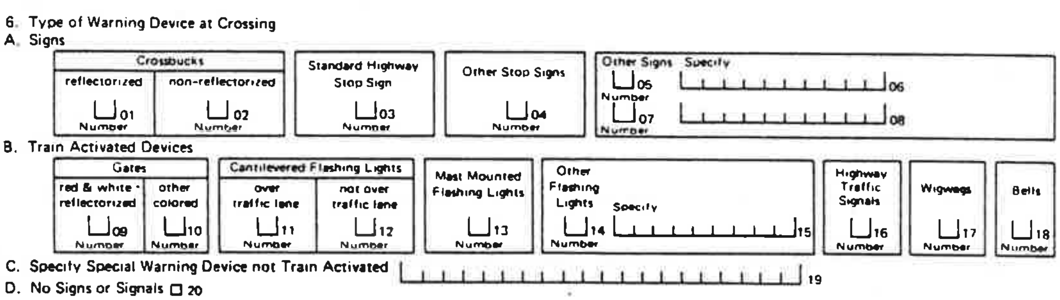

FIGURE 2-1. WARNING DEVICE INFORMATION CONTAINED IN THE DOT-AAR INVENTORY

TABLE 2-1. INVENTORY WARNING DEVICE TYPES BY FRA WARNING DEVICE CLASS

FRA WARNING DEVICE CLASS	INVENTORY WARNING DEVICE TYPE INCLUDED IN IN WARNING DEVICE CLASS (DATA ELEMENT CODE)
Class 1, No Signs or Signals	- No Signs or Signals (20)
Class 2, Other Signs	- Other Signs (05-08)
Class 3, Stop Signs	- Standard Highway Stop Sign (03) - Other Stop Signs (04)
Class 4, Crossbucks	- Reflectorized Crossbucks (01) - Nonreflectorized Crossbucks (02)
Class 5, Special	- Special Warning Device not Train Activated (19)
Class 6, Highway Signals, Wigwags or Bells	- Highway Traffic Signals (16) - Wigwags (17) - Bells (18)
Class 7, Flashing Lights	- Cantilevered Flashing Lights over Traffic Lane (11) - Cantilevered Flashing Lights not over Traffic Lane (12) - Mast-Mounted Flashing Lights (13) - Other Flashing Lights (14, 15)
Class 8, Gates	- Red and White Reflectorized Gates (09) - Other Colored Gates (10)

The effectiveness of an upgrade to warning device X is determined relative to the present warning device Y at a given crossing. The effectiveness is defined as the ratio of the reduction in accident rate after installation of warning device X to the accident rate before installation of warning device X with warning device Y at the crossing. The basic analytical approach to determining this effectiveness was to group together all crossings upgraded from Y to X. An estimate of the effectiveness was obtained by comparing the composite accident rates (in accidents per crossing month) for this group before and after installation of warning device X. The effectiveness was calculated from the accident rate data using the following formula:

$$E = \frac{\text{Before accident rate - After accident rate}}{\text{Before accident rate}}$$

$$= \frac{B_a/B_m - A_a/A_m}{B_a/B_m} = 1 - \frac{A_a B_m}{A_m B_a} \quad (1)$$

where: E = effectiveness of warning device

B_a = number of accidents before installation of warning device

B_m = number of months of accident data before warning device installation

A_a = number of accidents after warning device installation

A_m = number of months of accident data after warning device installation.

The 95 percent confidence interval, CI, about the effectiveness value, E, was calculated from the following formula:

$$CI = \pm 1.96\sigma \quad (2)$$

where $\sigma = \frac{A_a B_m}{A_m B_a} \sqrt{1/A_a + 1/B_a}$

When comparing two effectiveness values, say E_1 and E_2, it is desirable to determine when they are significantly different. Assuming that $E_1 > E_2$, and if σ_1 and σ_2 are the corresponding values of σ from equation (2), the difference $E_1 - E_2$ is formed and assumed to be the mean of a normal distribution with standard deviation $\sqrt{\sigma_1^2 + \sigma_2^2}$. Then the criterion for concluding that E_1 is significantly greater than E_2 is that the probability of the random variable represented by this normal distribution being positive must be greater than 0.95.

The parameters in Equations 1 and 2 are the cumulative values for all the crossings that have the warning device change being evaluated. For example, if the effectiveness of flashing lights at crossings currently equipped with crossbucks is to be calculated, then the parameter B_a would equal the total cumulative number of accidents that occurred at all crossbuck crossings prior to being upgraded to flashing lights. This approach is necessary because accidents occur too infrequently at any one crossing to permit a meaningful effectiveness calculation using only before-and-after data at that crossing.

The data used for effectiveness analysis was obtained from the FRA Railroad Accident/Incident Reporting System (RAIRS) and the DOT-AAR Inventory (Ref. 4, 5). The Inventory, as of July 1981, was analyzed to obtain a subset of crossings consisting of all crossings having some change in warning device during the period between 1971 and 1981. A total of 28,369 crossings are included in this subset. The RAIRS was then analyzed to determine the number of accidents that occurred at these crossings before and after the warning device change. Since the latest RAIRS data available for the analysis was for 1980 and RAIRS can be linked with the Inventory only after 1975, a reduced subset of 27,546 crossings was available for analysis. These crossings included all those for which linking could be established between RAIRS and the Inventory regardless of whether actual accidents occurred. In fact, many of the crossings included in the data base had no accidents prior to or after the warning device change. Table 2-2 lists the number of crossings by year obtained for the analysis.

TABLE 2-2. CROSSINGS WITH WARNING DEVICE CHANGES OBTAINED FOR ANALYSIS

YEAR	CROSSINGS WITH WARNING DEVICE CHANGES	CROSSINGS MATCHED WITH ACCIDENT DATA
1971	147	--
1972	1	--
1973	28	--
1974	111	--
1975	566	566
1976	2720	2720
1977	2221	2221
1978	3609	3609
1979	7309	7309
1980	11,121	11,121
1981	536	--
TOTAL	28,369	27,546

The 27,546 crossings used in the analysis are categorized by type of warning device change, on the basis of FRA class, in Table 2-3. As indicated in the table, most of the warning device changes involve an upgrade from a lower class to a higher class. In addition, there are many records indicating no change in warning device class. These cases are represented by the diagonal in Table 2-3; e.g., there were 9,731 crossings with warning device Class 4, both before and after a warning device change. These diagonal cases represent changes to the warning devices that did not result in a net change in warning device class. For example, the Class 4 before and Class 4 after case could have involved a new crossbuck sign (e.g., non-reflectorized to reflectorized crossbuck) and could also have included a change in lower class devices such as the addition of a stop sign along with the new crossbuck. The relatively few cases represented by the combinations below the diagonal are warning device downgrades; e.g., there were 91 cases where a crossbuck (Class 4) was replaced with a stop sign (Class 3) as the highest class warning device.

TABLE 2-3. NUMBER OF WARNING DEVICE CHANGE RECORDS BY FRA CLASS

WARNING DEVICE CLASS BEFORE CHANGE	WARNING DEVICE CLASS AFTER CHANGE 1	2	3	4	5	6	7	8	TOTAL
1	6	6	31	1608	12	5	58	27	1753
2	3	1	1	53	2	1	12	7	80
3	150	2	93	2090	2	0	11	2	2350
4	384	17	91	9733	78	48	1922	1991	14264
5	66	0	0	11	650	3	130	69	929
6	1	0	0	9	2	282	203	200	697
7	19	0	0	10	3	20	3860	1604	5516
8	3	0	0	7	0	2	9	1936	1957
TOTAL	632	26	216	13521	749	361	6205	5836	27546

Each of the 27,546 crossing records in the analysis file contains the following data:

1. Crossing ID
2. State
3. Date of change
4. Warning device data described by the 20 Inventory data elements shown in Figure 2-1, both before and after the change
5. Train operations data included in the Inventory Part II, Items 1A, 1B, 2A, 2B, and 3 (see Appendix B)
6. Crossing physical data and highway data included the Inventory, Parts III and IV (see Appendix B)
7. Number of accidents before warning device change, B_a
8. Number of accidents after warning device change, A_a
9. Number of months of accident data before warning device change, B_m
10. Number of months of accident data after warning device change, A_m
11. Predicted accident rate prior to upgrade from the DOT Accident Prediction Formula

The crossing data available for analysis was entered into a data base management system. With this system, great flexibility and ease of retrieval and manipulation are achieved. All of the data for each crossing record, described above, are attributes which can be searched for, retrieved and aggregated for all crossings that have the same attributes. For example, a typical interrogation could be to find the cumulative values for B_a, B_m, A_a and A_m, for all crossings upgraded from passive warning devices (Classes 1, 2, 3, 4) to automatic gates (Class 8) with cantilevered flashing lights, which have more than one track and two highway lanes (there are 177 such cases). The effectiveness of this particular type of upgrade can then be calculated using the values of B_a, B_m, A_a and A_m obtained.

3. ANALYSIS RESULTS

3.1 INTERPRETATION OF RESULTS

For any particular warning device investigated, a sufficient number of upgrade records must have been available for the analysis to produce useful results. In general, if there were fewer than 50 upgrade records or less than a total of 25 accidents both before and after the upgrade, the confidence intervals were so large that the results were of little practical value. Results with confidence intervals greater than ±0.50 about the mean value of effectiveness were therefore not presented, and indicated in the tabularized results by the comment "not enough records".

The effectiveness results for a particular warning device are presented in terms of a mean effectiveness value and a 95 percent confidence interval. These results can be interpreted as meaning that there is a 95 percent probability that the true value of effectiveness lies within the confidence interval and that the expected value is the mean.

If the effectiveness values for two warning devices were compared to determine if one was greater than the other, the procedure described in Section 2 was used. A practical means of applying this procedure is to examine whether the confidence intervals of the two warning devices overlap. If there is no overlap then there is greater than a 95 percent probability that the effectiveness values for the two warning devices are different. If a small amount of overlap exists, the effectiveness values may be different at the 95 percent level, but the procedure described in Section 2 must be performed to verify this. When these tests were performed and the two effectiveness values found different at the 95 percent level, the text refers to the difference as being "significant". Similarly, if the 95 percent confidence interval for a particular warning device is entirely above zero, the text will refer to the device as having a "significant level" of effectiveness.

When interpreting results of the study, two types of data limitations should be considered. The first type of limitation (Type I) results from inability of the data to fully describe features of crossings that may influence the effectiveness of warning devices. For example, restricted sight distance, not included in the Inventory, could diminish the effectiveness of warning devices. If a particular type of warning device is systematically chosen for installation at crossings with these adverse, but unaccounted for, characteristics, the device may appear from the data to have a lower than expected effectiveness.

The second type of data limitation (Type II) results from possible changes to crossing characteristics after a warning device upgrade that may influence effectiveness, but are not considered in the analysis. For example, significant changes to highway and train traffic could occur after an upgrade. Anticipated changes in crossing characteristics may, in fact, lead to some upgrade decisions. These changes may influence the hazard level of the post upgrade period relative to the prior upgrade period. However, since the study did not analyze the possible influence of such changes, the resulting effectiveness results could be biased. Where it appears possible that Type I and/or Type II limitations may be influencing results, it will be noted in the discussion.

3.2 EFFECTIVENESS OF FLASHING LIGHT AND GATE WARNING DEVICES

The effectiveness values and confidence intervals for upgrades to flashing light and gate warning devices from passive warning devices (Classes 1, 2, 3 and 4) and to gate warning devices from flashing light warning devices were determined and compared with results for the same upgrade categories in an earlier DOT study (Ref. 3). The earlier study had available only four years of upgrade data, totalling 2,994 warning device changes within the three categories listed above, compared with 5,903 changes for this study. With the additional data for this study, the effectiveness results have changed slightly, as shown in Table 3-1, but are considered more accurate as reflected by the smaller confidence intervals. It should be noted that the earlier study included Class 5 and 6 warning devices (special and highway signals) within the general category of flashing lights. The present study defines upgrades to flashing lights as including only Class 7 warning devices.

TABLE 3-1. EFFECTIVENESS OF FLASHING LIGHT AND GATE UPGRADES

WARNING DEVICE UPGRADE	EFFECTIVENESS CURRENT STUDY	EFFECTIVENESS EARLIER STUDY (Ref. 3.)	95 PERCENT CONFIDENCE INTERVAL CURRENT STUDY	95 PERCENT CONFIDENCE INTERVAL EARLIER STUDY (Ref. 3.)
Passive to Flashing Lights	.70	.65	.66 to .75	.57 to .73
Passive to Gates	.83	.84	.80 to .85	.80 to .89
Flashing Lights to Gates	.69	.64	.65 to .73	.56 to .71

See Appendix A, Table A-1 for data.

A review of the results of Table 3-1 shows that the effectiveness values for flashing light upgrades from passive warning devices has increased relative to the earlier DOT study (Ref. 3). This increase is partially due to the removal of Class 5 and 6 warning devices from the flashing light category in the new study. These devices have a lower effectiveness than flashing lights and thus tended to reduce the overall effectiveness of upgrades to the combined Class 5, 6 and 7 flashing light category assumed in the earlier study.

The increase in effectiveness of gates installed at flashing light crossings over the earlier DOT study is difficult to explain. A possible explanation for this difference may be that flashing light crossings more recently selected for upgrading to gates have unique characteristics that cause flashing lights to be particularly ineffective relative to gates. For example, flashing lights at crossings with restricted sight distance or a cluttered visual environment may be unusually ineffective. In these cases, upgrades to gates may produce a greater improvement in safety than would be expected based on their performance in other applications.

3.3 EFFECTIVENESS OF FRA WARNING DEVICE CLASSES

Effectiveness values for all possible combinations of upgrades from one FRA warning device class to another were determined, data permitting. This phase of the analysis did not consider warning device changes that occurred within a warning device class; e.g., many upgrades occurred within (Class 4) involving removal of non-reflectorized crossbucks and installation of reflectorized crossbucks. The effectiveness values and confidence intervals for upgrade combinations with sufficient data for calculations are shown in Table 3-2.

The results presented in Table 3-2 for upgrades to crossbucks (Class 4) from Class 1 and 3 devices show that the confidence intervals ($\pm$.36 and $\pm$.23, respectively) are relatively large. Hence, a precise value of effectiveness can not be obtained. The confidence intervals are centered about a mean value of zero, however. The data therefore fails to show a significant level of effectiveness for upgrades to crossbucks. As discussed in Section 3.1 these results could be influenced by Type II data limitations (i.e., more hazardous crossing conditions after upgrades). A more detailed analysis of the

TABLE 3-2. EFFECTIVENESS OF FRA WARNING DEVICE CLASS UPGRADES

FRA WARNING DEVICE TYPE UPGRADE FROM	TO	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
Class 1, No Signs	- Class 4, Crossbucks	-.02	-.38 to .35
	- Class 7, Flashing Lights	.58	.22 to .95
Class 3, Stop Signs	- Class 4, Crossbucks	.03	-.19 to .26
Class 4, Crossbucks	- Class 6, Highway Signals, Wigwags and Bells	.61	.24 to .98
	- Class 7, Flashing Lights	.71	.67 to .76
	- Class 8, Gates	.83	.80 to .86
Class 5, Special	- Class 8, Gates	.61	.30 to .93
Class 6, Highway Signals, Wigwags and Bells	- Class 7, Flashing Lights	.62	.43 to .81
	- Class 8, Gates	.66	.52 to .80
Class 7, Flashing Lights	- Class 8, Gates	.69	.65 to .73

See Appendix A, Table A-2 for data

effectiveness of passive warning devices within these classes (e.g. reflectorized crossbucks and standard highway stop signs) is presented in Sections 3.6 and 3.7.

Highway signals (Class 6) show a moderate level of effectiveness (0.612) for upgrades from Class 4. Further analysis of the data to identify specific Class 6 devices involved in the upgrades (e.g. highway signals, wig-wags, bells) is contained in Section 3.9.

Flashing lights (Class 7) and gates (Class 8) show a high level of effectiveness for upgrades from Classes 1 and 4. Gates also have a high level of effectiveness for upgrades from flashing lights.

3.4 EFFECTIVENESS OF ILLUMINATION

This type of warning device is not specifically coded in the Inventory and must be written in under the category of special warning device. A search of this data field showed that illumination is typically designated as "floodlights" in data element #15 of the Inventory (see Figure 2-1). The effectiveness of illumination can be determined through analysis of: (1) all upgrades from Classes 1 through 4 to Class 5 where the only change to Class 5 was the addition of "floodlights," and (2) all changes within Class 5 where the change involved the addition of "floodlights." The results of these two analyses are shown below in Table 3-3. In both cases, the data, as indicated by the very large confidence intervals, were not sufficient to produce practical results. The analysis is complicated by the fact that other special warning devices (e.g., flagmen) may also be present at the crossings but cannot be identified because the Inventory description is limited to one entry.

TABLE 3-3. EFFECTIVENESS OF CROSSING ILLUMINATION

TYPE OF ILLUMINATION INSTALLATION	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
From: Classes 1 through 4 To: Illumination	-.06	-.74 to .62
From: Class 5 without Illumination To: Class 5 with Illumination	-.06	-.74 to .62

See Appendix A, Table A-4 for data.

3.5 EFFECTIVENESS OF CANTILEVERED AND MAST-MOUNTED FLASHING LIGHTS

The fundamental question considered in this section is whether cantilevered flashing lights are more effective than mast-mounted flashing lights. The effectiveness of these two types of flashing lights was determined from analysis of data elements #11, 12, 13 and 14 in the Inventory (see Figure 2-1) for upgrades from all passive warning devices combined, Classes 1 to 4. In addition, the effectiveness of these two devices in combination with gates (i.e., gates with cantilevered lights and gates with mast-mounted lights) was determined for upgrades from all passive devices. The results are summarized in Tables 3-4 and 3-5 below.

TABLE 3-4. EFFECTIVENESS OF UPGRADES TO CANTILEVERED AND MAST-MOUNTED FLASHING LIGHTS

TYPE OF UPGRADE FROM PASSIVE (CLASS 1 to 4) WARNING DEVICES	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
To Cantilevered Flashing Lights	.67	.60 to .75
To Mast-Mounted Flashing Lights	.74	.69 to .80

See Appendix A, Table A-5 for data.

TABLE 3-5. EFFECTIVENESS OF UPGRADES TO GATES WITH CANTILEVERED AND MAST-MOUNTED FLASHING LIGHTS

TYPE OF UPGRADE FROM PASSIVE (CLASS 1 TO 4) WARNING DEVICES	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
To Gates with Cantilevered Flashing Lights	.87	.82 to .92
To Gates with Mast-Mounted Flashing Lights	.81	.78 to .85

See Appendix A, Table A-6 for data.

For upgrades to flashing lights, Table 3-4, the mean value of effectiveness for cantilevered lights is less than that for mast-mounted lights. However, at the 95 percent level of confidence, no difference in the effectiveness of cantilevered and mast-mounted flashing lights can be shown (note the large overlap in confidence intervals). A contributing factor to these results may be both Type I and II data limitations. For example, considering Type I limitations, crossings singled out for cantilevered lights rather than mast-mounted lights may have unusually hazardous characteristics which detract from the effectiveness of the lights. Also, the conditions at many crossings selected for cantilevered lights may have changed after the upgrade in a manner to increase their hazard level; e.g. increased train and/or highway traffic (Type II limitation).

As shown in Table 3-5, the estimate of effectiveness of gates with cantilevered flashing lights is greater than that for gates with mast-mounted flashing lights. As indicated by the large overlap in confidence intervals, however, the difference is not statistically significant.

To provide an improved explanation of the results for cantilevered versus mast-mounted flashing lights, additional analyses were done to determine how the effectiveness of these devices is related to crossing characteristics. As discussed above, it has been suggested that crossings selected for cantilevered flashing lights may be more hazardous than those selected for mast-mounted flashing lights. Indeed, examination of the data in Table A-5 shows that the actual average rate of accidents at crossings selected for cantilevered flashing lights is 1.4 times the rate of accidents at crossings selected for mast-mounted flashing lights (.16 versus .11 accidents per year). If the effectiveness of lights is diminished at higher hazard crossings this could provide some explanation for the results showing no significant difference in effectiveness between cantilevered and mast-mounted flashing lights. To test this hypothesis, the effectiveness of cantilevered and mast-mounted flashing lights was determined for crossings of equivalent hazard level prior to upgrade as measured by the DOT Accident Prediction Formula (Ref. 1). The crossings were grouped according to predicted accident rates before upgrade calculated by the "basic" formula (Ref. 1,6). The effectiveness values for mast-mounted and cantilevered flashing lights (combined and separately) were then calculated for these groups.

Results of the analysis are shown in Table 3-6. The results indicate a statistically significant lower effectiveness for flashing lights when installed at crossings with a predicted accident rate greater than 0.15 prior to the upgrade. When the data were disaggregated by mast-mounted and cantilevered flashing lights, the confidence intervals were too large to demonstrate a significant difference in effectiveness between the two predicted accident rate intervals. In both mast-mounted and cantilevered cases, however, the same trend of lower effectiveness at higher predicted accident rate crossings was evident but not at the 95 percent confidence level. This finding may provide some explanation for the results regarding cantilevered effectiveness. If cantilevered flashing lights are systematically installed at higher accident rate crossings (as the data suggests), then their effectiveness can be expected to be lower relative to mast-mounted flashing lights which are installed at lower accident rate crossings.

TABLE 3-6. EFFECTIVENESS OF MAST-MOUNTED AND CANTILEVERED FLASHING LIGHTS BY PREDICTED ACCIDENTS (FROM BASIC FORMULA) FOR UPGRADES FROM PASSIVE (CLASS 1 TO 4) WARNING DEVICES

PREDICTED ACCIDENT RATE-BASIC FORMULA	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
	All Flashing Lights Combined	
0 TO .15	.77	.72 TO .81
>.15	.61	.50 TO .71
	Mast-Mounted Flashing Lights	
0 TO .15	.80	.75 TO .86
>.15	.64	.49 TO .78
	Cantilevered Flashing Lights	
0 TO .15	.72	.66 TO .78
>.15	.58	.43 TO .73

See Appendix A, Tables A-7 and A-8 for data.

Another estimate of the effectiveness of cantilevered flashing lights relative to mast-mounted lights was obtained by examining flashing light and gate crossings, where cantilevered lights replaced mast-mounted lights. In these cases any crossing characteristics that may influence effectiveness (i.e. Type I data limitations) are cancelled out since the mast-mounted and cantilevered lights are subject to the same conditions. The results, shown in Table 3-7, indicate no significant difference in effectiveness for cantilevered lights relative to mast-mounted lights without gates (Class 7 case). Type II data limitations may be influencing these results. If the crossings with mast-mounted lights that were upgraded to cantilevered lights generally experienced increases in train or highway traffic, for example, the effectiveness values for cantilevered lights would trend downward. The effectiveness of cantilevered lights is significantly greater than mast-mounted lights at crossings with gates (Class 8 case). The confidence interval for the Class 8 case, while very large, is entirely positive with a mean value of .37. In determining these effectiveness values, only upgrades that had no Other Flashing Lights (data element 14) were included.

TABLE 3-7. EFFECTIVENESS OF CANTILEVERED FLASHING LIGHTS INSTALLED AT CROSSINGS WITH MAST-MOUNTED FLASHING LIGHTS

UPGRADE CLASS	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
Class 7 Mast to Class 7 Cantilevers	-.02	-.20 to .17
Class 8 Mast to Class 8 Cantilevers	.37	.09 to .65

See Appendix A, Tables A-9 and 10 for data.

The effectiveness results for the Class 7 case (Table 3-7) is compatible with previous results (Table 3-4) which do not show a statistically significant difference in effectiveness between cantilevered and mast-mounted flashing lights for upgrades from passive devices. For the Class 8 case, the positive mean effectiveness is also compatible with the previous results which show a higher mean effectiveness for gates with cantilevered flashing lights than for gates with mast-mounted flashing lights for upgrades from passive devices.

The effectiveness results for cantilevered flashing lights shown in Table 3-7 are disaggregated by highway lanes and placement of cantilevered lights in Table 3-8. There were insufficient cases involving cantilevers not over the highway lane to compute meaningful effectiveness values. The results for cantilevered lights over the highway by lanes show large confidence intervals that span both positive and negative values. The data, therefore, does not show a significant difference in effectiveness between cantilevered lights and mast-mounted lights when the cantilevered lights are placed over the highway. Similarly, the number of lanes does not appear to significantly influence the effectiveness of flashing lights.

TABLE 3-8. EFFECTIVENESS OF CANTILEVERED FLASHING LIGHTS BY HIGHWAY LANE AND PLACEMENT OF CANTILEVERS FOR UPGRADES FROM MAST-MOUNTED LIGHTS

PLACEMENT OF CANTILEVERS	LANES	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
Over Traffic Lane	2	.12	-.14 to .37
Over Traffic Lane	>2	.04	-.20 to .29
Over Traffic Lane	all lanes	.02	-.16 to .31
Not Over Traffic Lane	2	Not enough cases	
Not Over Traffic Lane	>2	Not enough cases	
Not Over Traffic Lane	all lanes	Not enough cases	

The effectiveness of cantilevered and mast-mounted lights for upgrades from passive warning devices broken down by placement over highway and number of lanes is shown in Table 3-9. Similar to previous results (Table 3-8), the confidence intervals overlap to the extent that the data does not show a significant difference in effectiveness between cantilevered and mast-mounted lights by placement over highway or number of lanes.

TABLE 3-9. EFFECTIVENESS OF CANTILEVERED AND MAST-MOUNTED FLASHING LIGHTS BY HIGHWAY LANES AND PLACEMENT OF CANTILEVERS, UPGRADES FROM PASSIVE (CLASS 1 TO 4) WARNING DEVICES

UPGRADE CASE	LANES	EFFECTIVENESS	95 PERCENT CONFIDENCE Interval
Cantilevers Over Traffic Lane	2	.68	.59 to .77
Cantilevers Over Traffic Lane	>2	.65	.49 to .81
Cantilevers Not Over Traffic Lane	2	Not enough cases	
Cantilevers Not Over Traffic Lane	>2	No cases	
All Cantilevers	2	.68	.59 to .74
All Cantilevers	>2	.65	.49 to .81
Mast-Mounted	2	.74	.68 to .80
Mast-Mounted	>2	.76	.51 to 1.00

3.6 EFFECTIVENESS OF CROSSBUCKS

The results of an effort to determine the effectiveness of reflectorized and non-reflectorized crossbucks are shown in Table 3-10. Results for the two cases of upgrades to reflectorized crossbucks (from Class 1 and Class 4 non-reflectorized) are consistent in producing mean values of effectiveness equal to about zero. The confidence interval for the Class 1 to reflectorized crossbuck case is quite large, while the confidence interval for the Class 4 non-reflectorized to Class 4 reflectorized is reasonably small. The data does not show a significant level of effectiveness for reflectorized crossbucks relative to either non-reflectorized crossbucks or no signs. There were too few records for a meaningful analysis of non-reflectorized crossbucks. Type II data limitations may influence these results to the extent that crossings selected for reflectorized crossbucks, more often than not, may have experienced additional hazards (e.g. increased highway or train traffic) after the upgrade.

TABLE 3-10. EFFECTIVENESS OF REFLECTORIZED AND NON-REFLECTORIZED CROSSBUCKS

UPGRADE CASE	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
Class 1 to Class 4, Reflectorized Crossbucks*	-.04	-.44 to .35
Class 1 to Class 4, Non-reflectorized Crossbucks*	Not enough cases	
Class 4, Non-reflectorized Crossbucks to Class 4, Reflectorized Crossbucks**	.03	-.14 to .20

See Appendix A, Table A-13 for data.

* No "standard stop signs" no "other stop signs", and no "other signs" for Class 4 allowed.

** No "standard stop signs", no "other stop signs", and no "other signs" before and after the upgrade allowed.

The effectiveness of upgrades from Class 3 ("other stop signs") to crossbucks is shown in Table 3-11. There were insufficient records for a meaningful analysis of upgrades from standard stop signs. As with previous crossbuck results, the data in Table 3-11 does not indicate that upgrades to crossbucks are significantly effective. The confidence interval, while relatively large, is centered about a mean value of zero effectiveness.

TABLE 3-11. EFFECTIVENESS OF CROSSBUCKS UPGRADED FROM STOP SIGNS

UPGRADE CASE	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
Crossbucks added to or replaced "Standard Stop Sign"	Not enough cases	
Crossbucks added to or replaced "Other Stop Signs"	.00	-.25 to .25

See Appendix A, Table A-14 for data.

3.7 EFFECTIVENESS OF STANDARD STOP SIGNS

Four upgrade cases were analyzed to develop estimates of effectiveness for upgrades to standard stop signs as shown in Table 3-12. Upgraded crossings which had "Other Stop Signs" were excluded from the results. Only the first of the four cases listed in Table 3-12 had sufficient records to produce meaningful individual results; however, the accident data for all four cases was also combined to produce an estimate of effectiveness for all upgrades to standard stop signs. This combined estimate is more precise than each individual case as indicated by the smaller confidence interval. The combined value is more representative of the effectiveness of upgrading to standard stop signs from all other passive warning devices which is required by the DOT Procedure. The two cases indicated by "*" were based on situations actually involving removing stop signs. To calculate effectiveness of installing stop signs for these cases, the before and after data were reversed according to a procedure described in Appendix C.

Combining the four cases given in Table 3-12 results in an estimated effectiveness of 0.35 for installing standard stop signs at crossings currently equipped with other passive warning devices. The 95 percent confidence interval, .16 to .54, is entirely in the positive range. These results therefore indicate a significant level of effectiveness for standard stop signs. The relatively high effectiveness for standard stop signs coupled with their relatively low cost (including the cost of "stop ahead" signs) should make them worthy of serious consideration for installation at crossings requiring safety improvement where funding is not available for active devices. Because standard stop signs require that all highway traffic stop at the crossing, only certain crossings meeting FHWA criteria discussed in Section 4.2 should be considered.

TABLE 3-12. EFFECTIVENESS OF STANDARD STOP SIGNS INSTALLED AT PASSIVE CROSSINGS

UPGRADE CASE	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
Class 4, Crossbucks Only to Class 4 and Standard Stop Signs	.26	.02 to .50
Class 1 to Class 3, Standard Stop Signs	Not enough records	
Class 4, Crossbucks only to Class 4 and Standard Stop Signs*	.61	-.25 to .97
Class 1 to Class 3, Standard Stop Signs*	Not enough records	
Combined Upgrades to Standard Stop Signs	.35	.16 to .54

See Appendix A, Table A-15 for data.
*Calculation based on procedure described in Appendix C.

3.8 INFLUENCE OF CROSSING CHARACTERISTICS ON EFFECTIVENESS

This section describes the results of an effort to determine the influence of different crossing characteristics on warning device effectiveness. The approach used was to initially examine the effectiveness of upgrades from passive devices (Classes 1 through 4) to flashing lights (Class 7) broken down by different levels of the factor being analyzed. If no significant difference in effectiveness was found for the various levels of the factor, it was concluded that the factor did not influence effectiveness. If a significant influence was found, then the other primary upgrade cases of passive to gates and flashing lights to gates were also examined to determine if the influence was consistent for all the upgrade cases considered by the DOT Procedure. A consistent and significant influence of a factor on effectiveness would be cause for its possible inclusion in the DOT Procedure. The crossing characteristic factors investigated and the corresponding tables containing results of the analysis are as follows:

1. Number of Tracks.................................. Table 3-13
2. Crossing Surface.................................. Table 3-14
3. Maximum Timetable Speed........................... Table 3-15
4. Crossing Angle.................................... Table 3-16
5. Highway Paved (?)................................. Table 3-17
6. Annual Average Daily Highway Traffic.............. Table 3-18
7. Total Trains per Day.............................. Table 3-19
8. Fraction of Day Trains............................ Table 3-20
9. Number of Switch Trains and Thru Trains........... Table 3-21
10. Urban-Rural Crossing.............................. Table 3-22
11. Predicted Accidents (Basic Formula)............... Table 3-23

12. Number of Tracks and Train Speed.................. Table 3-24

13. Number of Tracks and Total Trains Per Day.......... Table 3-25

14. Number of Highway Lanes............................ Table 3-9*

The results presented in the tables listed above show that the effectiveness of upgrades to flashing lights is not significantly influenced by the following crossing characteristics: crossing surface, maximum timetable speed, crossing angle, highway paved, AADT, basic predicted accident rate (see also results presented in Section 3.5) and number of highway lanes.

For the results shown in Table 3-13 the effectiveness of upgrades from passive and flashing light devices to gates is significantly less for cases involving multiple tracks. This difference in effectiveness is almost significant for upgrades to flashing lights. This trend toward reduced effectiveness for multiple tracks appears reasonable since multiple track crossings present a more hazardous situation which could diminish the effectiveness of warning devices; e.g., one train can obstruct the view of another at multiple track crossings. The strong influence of multiple tracks on warning device effectiveness indicates that this factor should be considered for potential incorporation into the DOT Procedure.

The number of trains per day also has a significant influence on the effectiveness of upgrades to flashing lights and gates shown in Table 3-19. For crossings with more than 10 trains per day, the effectiveness of flashing light and gate upgrades is significantly less than at crossings with fewer than 10 trains per day. This strong and consistent influence should also be considered for possible inclusion in the DOT Procedure.

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*This table can found in Section 3.5 where highway lanes were included as part of the analysis of cantilevered and mast-mounted lights.

For fraction of day trains (Table 3-20) included in the interval of less than 25 percent ($0 \leq R \leq .25$), the effectiveness is significantly higher for upgrades from passive to flashing lights and from flashing lights to gates than for the other intervals involving greater fractions of day trains. For the first case (passive to flashing lights), this could result if flashing lights are more effective in attracting motorist attention at night than during the day. However, the second case for upgrades from flashing lights to gates represents a contradiction to this premise. In this case, the effectiveness for less than 25 percent day trains should be lower than for the other intervals if flashing lights are more effective at night. This inconsistency and the lack of any influence of this factor for gate upgrades from passive devices indicates that it should not be considered for inclusion in the DOT Procedure.

To determine if different types of trains influence effectiveness, the results in Table 3-21 were obtained to distinguish between switch trains and thru trains. The results indicate that for zero switch trains per day, the effectiveness for all three upgrade cases is significantly less for more than 10 thru trains per day than for fewer than 10 thru trains per day. The influence of switch trains, however, appears to be less than that of thru trains.

The urban-rural characteristic, Table 3-22, shows an inconsistent influence on warning device effectiveness. For upgrades to flashing lights, the effectiveness is significantly less for urban crossings. This may result from the greater visual confusion which confronts motorists in an urban environment. The urban-rural characteristic, however, does not significantly influence the effectiveness of upgrades to gates from either passive or flashing light devices. Even though only passive to flashing light upgrades are significantly affected by the urban-rural factor, inclusion of this factor in the DOT Procedure may be warranted. Since all upgrade decisions are interrelated, a change in the effectiveness of one warning device type may significantly influence the final set of decisions.

The results in Table 3-23 show that there is a significant difference in effectiveness between several upgrade cases grouped by basic predicted accident rates. Since this trend was not consistent, however, it was concluded that this influence had no practical application in the DOT Procedure.

As noted above (See Table 3-13), the effectiveness of warning devices, particulary gates, tends to be less for multiple track crossings. The influence of tracks is further analyzed in Table 3-24 by stratifying tracks into two groups of train speed: less than and greater than 50 mph. The results show that speed does not significantly modify the influence of the number of tracks on the effectiveness of flashing lights. The greater effectiveness of gates at single track crossings, however, can be seen to occur primarily at crossings with less than 50 mph train speeds. These results are of interest since they relate to quantifiable situations for which Federal guidelines pertain (Ref. 7). For all multiple track crossings and crossings with high speed trains (assumed to mean greater than 50 mph), gates are recommended by the guidelines.

The combined influence of tracks and trains together is shown in Table 3-25. Table 3-25 presents the effectiveness values in a form necessary for use in revising the DOT Procedure as discussed in Section 4. The effectiveness values for the various combinations of these factors are not all significantly different. In fact, some combinations have the same or similar effectiveness values. This is to be expected. While the influence on effectiveness of these factors acting separately is generally significant (see Tables 3-13 and 3-19), when acting together their influence can either negate or complement one another depending on how they are combined.

TABLE 3-13. EFFECTIVENESS BY NUMBER OF TRACKS

Number of Tracks	Effectiveness	95 Percent Confidence Level
	Passive (Class 1 to 4) to Flashing Lights (Class 7)	
Single	.72	.67 to .77
Multiple	.63	.51 to .75
Combined	.70	.66 to .75
	Passive (Classes 1 to 4) to Gates (Class 8)	
Single	.86	.82 to .90
Multiple	.80	.76 to .84
Combined	.83	.80 to .85
	Classes 5, 6, 7 to Gates (Class 8)	
Single	.77	.72 to .82
Multiple	.62	.57 to .68
Combined	.69	.65 to .73

See Appendix A, Table A-16 for data.

TABLE 3-14. EFFECTIVENESS OF CLASS 7, FLASHING LIGHTS, BY CROSSING SURFACE. UPGRADES FROM PASSIVE (CLASS 1 TO 4) WARNING DEVICES

CROSSING SURFACE	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
1 - Section Timber	.74	.64 to .83
2 - Full Wood Plank	.69	.53 to .85
3 - Asphalt	.71	.66 to .77
4 - Concrete Slab	Not enough cases	
5 - Concrete Pavement	Not enough cases	
6 - Rubber	Not enough cases	
7 - Metal Sections	Not enough cases	
8 - Other metal	Not enough cases	
9 - Unconsolidated	Not enough cases	
0 - Other	Not enough cases	
Combined	.75	.66 to .75

See Appendix A, Table A-17 for data.

TABLE 3-15. EFFECTIVENESS OF CLASS 7, FLASHING LIGHTS, BY TRAIN SPEED (MAXIMUM TIMETABLE SPEED) - UPGRADES FROM PASSIVE (CLASS 1 TO 4) WARNING DEVICES

MAXIMUM TIMETABLE SPEED (MS)	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
0 ≤ MS < 20	.71	.62 to .81
20 ≤ MS < 40	.67	.59 to .75
40 ≤ MS < 60	.75	.67 to .83
60 ≤ MS < 80	.63	.44 to .83
80 ≤ MS	Not enough cases	
Combined	.70	.66 to .75

See Appendix A, Table A-18 for data.

TABLE 3-16. EFFECTIVENESS OF CLASS 7, FLASHING LIGHTS, BY CROSSING ANGLE - UPGRADES FROM PASSIVE (CLASSES 1 TO 4) WARNING DEVICES

CROSSING ANGLE	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
0 - 29	.74	.61 to .86
30 - 59	.72	.61 to .83
60 - 90	.69	.63 to .75
Combined	.70	.66 to .75

See Appendix A, Table A-19 for data.

TABLE 3-17. EFFECTIVENESS OF CLASS 7, FLASHING LIGHTS, BY HIGHWAY PAVED - UPGRADES FROM PASSIVE (CLASS 1 TO 4) WARNING DEVICES

HIGHWAY PAVED	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
Yes	.71	.66 to .76
No	.62	.36 to .87
Combined	.70	.66 to .75

See Appendix A, Table A-20 for data.

TABLE 3-18. EFFECTIVENESS OF CLASS 7, FLASHING LIGHTS, BY AADT - UPGRADES FROM PASSIVE (CLASS 1 TO 4) WARNING DEVICES

AADT INTERVAL	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
0 ≤ AADT < 1700	.71	.65 to .77
1700 ≤ AADT < 3100	.76	.66 to .87
3100 ≤ AADT < 5000	.63	.45 to .81
5000 ≤ AADT < 6500	.42	.04 to .80
6500 ≤ AADT < 7800	.62	.37 to .87
7800 ≤ AADT	.72	.59 to .84
Combined	.70	.66 to .75

See Appendix A, Table A-21 for data.

TABLE 3-19. EFFECTIVENESS BY TOTAL TRAINS PER DAY

TRAINS PER DAY	EFFECTIVE	95 PERCENT CONFIDENCE INTERVAL	EFFECTIVE	95 PERCENT CONFIDENCE INTERVAL	EFFECTIVE	95 PERCENT CONFIDENCE INTERVAL
	Passive (Cl. 1 to 4) to Flashing Lts. (Cl. 7)		Passive (Cl. 1 to 4) to Gates (Class 8)		Flashing Lts. (Cl. 5, 6, 7) to Gates (Cl. 8)	
0*	Not Enough Cases		Not Enough Cases		Not Enough Cases	
1-2	.73	.65 to .82	.91	.84 to .99	.75	.56 to .84
3-5	.73	.63 to .84	.92	.86 to .98	.84	.73 to .94
6-10	.76	.69 to .83	.87	.82 to .92	.80	.73 to .87
≤11	.60	.48 to .71	.79	.75 to .83	.65	.60 to .70
Combined	.70	.66 to .75	.83	.80 to .85	.69	.65 to .73

See Appendix A, Table A-22 for data.

* Less than one train per day.

TABLE 3-20. EFFECTIVENESS OF CLASS 7, FLASHING LIGHTS, BY FRACTION OF DAY TRAINS - UPGRADES FROM PASSIVE (CLASSES 1 TO 4) WARNING DEVICES

FRACTION OF DAY TRAINS (R)	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
	Passive (Classes 1 to 4) to Flashing Lights (Class 7)	
0 ≤ R .25	.85	.74 to .96
.25 < R ≤ .50	.70	.63 to .77
.50 < R ≤ .75	.69	.59 to .78
.75 < R ≤ 1.00	.69	.58 to .79
Combined	.70	.66 to .75
	Passive (Classes 1 to 4) to Gates (Class 8)	
0 ≤ R ≤ .25	.84	.67 to 1.00
.25 < R ≤ .50	.82	.78 to .87
.50 < R ≤ .75	.83	.78 to .87
.75 < R ≤ 1.00	.86	.78 to .94
Combined	.83	.80 to .85
	Flashing Lights (Classes 5, 6, 7) to Gates (Class 8)	
0 ≤ R ≤ .25	.90	.77 to 1.00
.25 < R ≤ .50	.69	.64 to .75
.50 < R ≤ .75	.69	.63 to .75
.75 < R ≤ 1.00	.64	.49 to .79
Combined	.69	.65 to .73

See Appendix A, Table A-23 for data.

TABLE 3-21. EFFECTIVENESS BY NUMBER OF SWITCH TRAINS AND NUMBER OF THRU TRAINS

Switch Trains Per Day	Thru Trains Per Day	Effectiveness	95 Percent Confidence Interval
	Passive (Classes 1 to 4) to Flashing Lights (Class 7)		
0	0	Not enough cases	
0	1-10	.79	.73 to .85
0	≥11	.62	.45 to .79
0	Combined	.74	.68 to .80
1-10	0	.66	.53 to .79
≥11	0	.79	.55 to 1.00
Combined	0	.66	.55 to .78
All Crossings		.70	.66 to .75
	Passive (Classes 1 to 4) to Gates (Class 8)		
0	0	Not enough cases	
0	1-10	.91	.86 to .95
0	≥11	.76	.69 to .83
0	Combined	.82	.77 to .86
1-10	0	.89	.80 to .98
≥11	0	.87	.62 to 1.00
Combined	0	.85	.76 to .94
All Crossings		.83	.80 to .85
	Flashing Lights (Class 5, 6, 7) to Gates (Class 8)		
0	0	Not enough cases	
0	1-10	.89	.82 to .95
0	≥11	.60	.50 to .71
0	Combined	.70	.63 to .77
1-10	0	.79	.66 to .92
≥11	0	.91	.80 to 1.00
Combined	0	.83	.73 to .92
All Crossings		.69	.65 to .73

See Appendix A, Table A-24 for data.

TABLE 3-22. EFFECTIVENESS BY URBAN-RURAL LOCATION

UPGRADE CASE		EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
Passive (Class 1 to 4) to Class 7, Flashing Lights	Urban	.62	.54 to .70
Passive (Class 1 to 4) to Class 7, Flashing Lights	Rural	.76	.70 to .81
Passive (Class 1 to 4) to Class 7, Flashing Lights	Combined	.70	.66 to .75
Passive (Class 1 to 4) to Class 8, Gates	Urban	.83	.79 to .87
Passive (Class 1 to 4) to Class 8, Gates	Rural	.82	.78 to .86
Passive (Class 1 to 4) to Class 8, Gates	Combined	.83	.80 to .85
Class 5, 6, 7 to Class 8, Gates	Urban	.69	.65 to .74
Class 5, 6, 7 to Class 8, Gates	Rural	.67	.59 to .74
Class 5, 6, 7 to Class 8, Gates	Combined	.69	.65 to .73

See Appendix A, Table A-25 for data.

TABLE 3-23. EFFECTIVENESS OF CLASS 7, FLASHING LIGHTS, BY ACCIDENT RATE CALCULATED WITH BASIC FORMULA - UPGRADES FROM PASSIVE (CLASS 1 TO 4) WARNING DEVICES

ACCIDENT RATE BASIC FORMULA	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
0-.10	.73	.66 to .79
.10-.15	.80	.72 to .87
.15-.20	.61	.46 to .75
.20-.25	.59	.40 to .78
.25-.30	.46	.10 to .82
>.30	.72	.29 to 1.00
Combined	.70	.66 to .75

See Appendix A, Table A-26 for data

TABLE 3-24. EFFECTIVENESS OF FLASHING LIGHTS (CLASS 7) AND GATES (CLASS 8) BY NUMBER OF TRACKS AND TRAIN SPEED - UPGRADES FROM PASSIVE (CLASSES 1 TO 4) WARNING DEVICES

NUMBER OF TRACKS	MAXIMUM TIMETABLE SPEED (MPH)	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERNAL
Passive (Classes 1 to 4) to Flashing Lights (Class 7)			
Single	<50	.72	.66 to .77
Single	≥50	.75	.64 to .87
Multiple	<50	.64	.51 to .77
Multiple	≥50	.59	.31 to .87
Passive (Classes 1 to 4) to Gates (Class 8)			
Single	<50	.88	.84 to .93
Single	≥50	.80	.72 to .88
Multiple	<50	.80	.74 to .85
Multiple	≥50	.81	.75 to .87

See Appendix A, Table A-27 for data.

TABLE 3-25. EFFECTIVENESS BY NUMBER OF TRACKS AND TOTAL TRAINS PER DAY (T)

NUMBER OF TRACKS	T	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
	Passive (Classes 1 to 4) to Flashing Lights (Class 7)		
Single	0-10	.75	.70 to .80
Single	≥11	.61	.47 to .74
Multiple	0-10	.65	.51 to .80
Multiple	≥11	.57	.36 to .78
Combined	---	.70	.66 to .75
	Passive (Classes 1 to 4) to Gates (Class 8)		
Single	0-10	.90	.86 to .94
Single	≥11	.80	.73 to .87
Multiple	0-10	.86	.79 to .92
Multiple	≥11	.78	.73 to .83
Combined	---	.83	.80 to .85
	Flashing Lights (Classes 5, 6, 7) to Gates (Class 8)		
Single	0-10	.89	.84 to .94
Single	≥11	.69	.61 to .76
Multiple	0-10	.65	.53 to .78
Multiple	≥11	.63	.56 to .69
Combined	---	.69	.65 to .73

See Appendix A, Table A-28 for data.

3.9 EFFECTIVENESS OF HIGHWAY SIGNALS, WIGWAGS, AND BELLS

The results of effectiveness calculations for Class 6, Highway Signals, Wigwags, and Bells upgraded from Passive (Class 1 to 4) Warning Devices, are shown in Table 3-26. The effectiveness for the combined Class 6 is 0.71. This is similar to the effectiveness for flashing lights (0.70), however, the confidence interval is rather large for the Class 6 devices. There were insufficient upgrades to the two Class 6 subsets (wigwags or bells/highway signals) to produce any meaningful estimate of effectiveness for these devices separately.

TABLE 3-26. EFFECTIVENESS OF HIGHWAY SIGNALS, WIGWAGS, AND BELLS - UPGRADES FROM PASSIVE (CLASS 1 TO 4) WARNING DEVICES

UPGRADE CASE	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
Passive (Class 1 to 4) to Class 6	.71	.43 to .98
Passive (Class 1 to 4) to Wigwags or Bells	Not enough cases	
Passive (Class 1 to 4) to Highway Signals Only	Not enough cases	

See Appendix A, Table A-29 for data.

Another means of estimating the relative effectiveness of the Class 6 devices was to examine their upgrades to Class 7. The results, shown in Table 3-27, indicate that flashing lights have an effectiveness of 0.62 for upgrades from Class 6 devices, regardless of whether highway signals are included in the Class 6 group. Assuming an effectiveness of 0.70 for flashing light upgrades from passive devices (See Table 3-1), the results in Table 3-27 imply an effectiveness of 0.21 for Class 6 warning devices for upgrades from passive devices.* This result is inconsistent with the effectiveness value of 0.71 for the same upgrade category shown in Table 3-26. However, the characteristics of the crossings and special warning devices in these two groups may be quite different and could explain much of this inconsistency. Effectiveness estimates for Class 6 warning devices are therefore inconclusive on the basis of this analysis. It should be noted that these results generally do not reflect the effectiveness of highway signals since there were so few upgrade records for these devices.

TABLE 3-27. EFFECTIVENESS OF CLASS 7, FLASHING LIGHTS UPGRADED FROM CLASS 6, HIGHWAY, SIGNALS, WIGWAGS, AND BELLS

UPGRADE CASE	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
Class 6, No Highway Signals to Class 7	.62	.43 to .81
Class 6, Highway Signals to Class 7	Not enough cases	
Combined	.62	.43 to .81

See Appendix A, Table A-29 for data.

*Effectiveness, Passive to Class 6 = $1 - \frac{(1\text{-Effectiveness, Passive to Class 7})}{(1\text{-Effectiveness, Class 6 to Class 7})}$

3.10 EFFECTIVENESS OF CONSTANT WARNING TIME DEVICES

The presence of constant warning time devices at crossings with flashing lights or gates is denoted on the Inventory form as the answer to the question: "Does Crossing Signal Provide Speed Selection for Trains"? Two crossing upgrade cases were examined: (a) flashing lights (Class 7) without constant warning time upgraded to flashing lights (Class 7) with constant warning time, and (b) gates (Class 8) without constant warning time upgraded to gates (Class 8) with constant warning time. The data, however, included only 39 upgrades for case (a) and 80 upgrades for case (b). The confidence intervals produced by this data were too large to provide any meaningful estimates of effectiveness. The data for these results are contained in Appendix A, Table A-30.

The variation in train speed at a crossing was examined as a surrogate for warning time constancy to determine if it influenced effectiveness. The measure of this factor is the ratio of the two numbers given in the Inventory under the designation "Typical Speed Range Over Crossing from X to Y mph". Thus Y/X is the parameter used to measure speed varation. The results, shown in Table 3-28, indicate a trend of diminishing effectiveness with increased train speed variation, particularly for the case of passive upgrades to flashing lights. This trend, however, is not statistically significant for any of the upgrade cases; hence, no conclusions can be made regarding its influence on effectiveness.

TABLE 3-28. EFFECTIVENESS BY RATIO OF MAXIMUM SPEED TO MINIMUM SPEED (Y/X)

MAXIMUM SPEED (Y) / MINIMUM SPEED (X)	EFFECTIVENESS	95 PERCENT CONFIDENCE INTERVAL
Passive (Classes 1 to 4) to Flashing Lights (Class 7)		
$1 \le Y/X < 2$	.76	.69 to .82
$2 \le Y/X < 3$	.76	.66 to .85
$3 \le Y/X < 6$	.65	.53 to .77
$6 \le Y/X$	.60	.43 to .77
Combined	.70	.66 to .75
Passive (Classes 1 to 4) to Gates (Class 8)		
$1 \le Y/X < 2$	.84	.80 to .89
$2 \le Y/X < 3$	.83	.76 to .90
$3 \le Y/X < 6$	.83	.76 to .90
$6 \le Y/X$	.79	.72 to .86
Combined	.83	.80 to .85
Classes 5, 6, 7 to Gates (Class 8)		
$1 \le Y/X < 2$	.69	.63 to .76
$2 \le Y/X < 3$	.62	.50 to .74
$3 \le Y/X < 6$	.70	.62 to .78
$6 \le Y/X$	.69	.60 to .78
Combined	.69	.65 to .73

See Appendix A, Table A-31 for data.

4. REVISION OF DOT RAIL-HIGHWAY CROSSING RESOURCE ALLOCATION PROCEDURE

This study has produced important results which should be considered as possible improvements to the DOT Procedure. Stop signs were shown to be an effective warning device option that could be added to the procedure. In addition, refined effectiveness values were obtained for the active warning devices currently included in the procedure. The following sections provide information and guidance for incorporating results of this study in potential revisions of the procedure. Actual revisions should be subject to further investigation and coordination with Federal, state and private users of the procedure.

4.1 NEW EFFECTIVENESS VALUES

The first revision to consider for the DOT Procedure should be to substitute the new effectiveness values determined for flashing light and gate upgrades, summarized in Table 3-1 (Section 3.2). These values reflect more recent performance of active warning devices and are more accurate than previous values.

Crossing characteristics that were found to have the greatest influence on active warning device effectiveness are: number of tracks and number of trains per day. Considering these two characteristics independently, effectiveness values for single and multiple tracks, and less than and greater than 10 trains per day were determined, as shown in Table 3-25. In practice, if these two factors are to be included in the DOT Procedure they must be considered together; i.e., separate values of effectiveness are required for each combination of tracks and trains. This results in a total of 12 effectiveness values which were determined as shown in Table 4-1, for the three active warning device upgrades included in the current procedure. The values for upgrades to flashing lights from passive multiple track crossings would normally not be used since FHWA guidelines (Ref. 7) recommend gates for these situations.

The effect of urban versus rural location is not presently defined in sufficient detail to make its inclusion possible in the DOT Procedure. To properly include this parameter, each of the 12 cases listed in Table 4-1 would have two values (one for urban and one for rural), making 24 values that must be calculated. Nevertheless, since the urban-rural factor significantly influences the effectiveness of flashing lights, it should be considered further for possible inclusion in the procedure.

TABLE 4-1. NEW EFFECTIVENESS VALUES FOR DOT PROCEDURE

Number of Tracks	Total Trains Per Day	Effectiveness Passive (Cl 1 to 4) to Fl Lights (Cl 7)	Effectiveness Passive (Cl 1 to 4) to Gates (Cl 8)	Effectiveness Fl Lights (Cl 5, 6, 7) to Gates (Cl 8)
Single	0 - 10	.75	.90	.89
Single	≥ 11	.61	.80	.69
Multiple	0 - 10	.65	.86	.69
Multiple	≥ 11	.57	.78	.63

*FHWA guidelines (Ref. 7) recommend gates for warning device upgrades at multiple track crossings.

4.2 STOP SIGNS

In Section 3.6, standard highway stop signs were shown to effectively reduce accidents at crossings. Therefore, these devices should be considered for possible inclusion in the DOT Procedure. However, because stop signs require all highway vehicles to come to a complete stop, not all crossings are practical sites for stop signs. The FHWA has established guidelines for the selection of candidate crossings for stop signs (Ref. 8,9). Any final decision on stop sign installation should, furthermore, be based on a demonstrated need as determined by a detailed traffic engineering study. As suggested by the FHWA guidelines, crossings considered for installation of stop signs should be limited to the following situations:

1. The highway must be secondary in character with low average daily traffic (ADT) counts (less than 400 ADT-rural and 1500 ADT-urban).
2. Train traffic must be substantial (greater than 10 trains per day).
3. The crossing must be single track.
4. A restricted line of site must exist such that approaching traffic is required to reduce speed to 10 mph or less in order to stop safely.
5. There must be adequate sight distance at the stop bar to provide sufficient time for a stopped vehicle to start and cross the tracks before the arrival of a train.
6. Stop signs must not be used at crossings with active warning devices.
7. A "Stop Ahead" sign must be installed in advance of the stop sign.

Because of the unique nature of stop sign applications, the decision process for stop signs is different than, and generally independent of, decisions for active warning device installations. It may, therefore, be inappropriate to incorporate stop signs as an option considered by the DOT Procedure in combination with active warning device projects. A more useful approach might be for the DOT Procedure to prepare a separate list of candidate passive crossings for standard stop signs that meets criteria 1, 2, 3 and 6 above. These three criteria can be easily determined from data in the

Inventory. This list of candidate crossings could also be ranked by the predicted accident rate of the crossing. These crossings could then be examined in more detail in order of their rank to determine if any meet the other guidelines, and whether they should receive stop signs.

At the same time that the list of candidate crossings for stop signs is prepared, the DOT Procedure can prepare the usual listing for active warning devices for the given funding level. A passive crossing could appear on both the stop sign and active warning device lists, and judgment would have to be used to decide which warning device to use, if any.

4.3 NEW WARNING DEVICE COSTS

Rail-highway crossing warning device costs consist of installation (including procurement) and maintenance costs, with the sum of these two costs being the total life cycle cost. Estimates of these values were originally obtained in 1977 dollars (Ref 10). Any revisions to the DOT Procedure should utilize an update of these costs.

To revise installation costs to 1983 dollars, an inflation factor must be applied to the 1977 installation costs. Such a factor was determined using a procedure described in Reference 1 and data on wage and price indexes published by the Association of American Railroads (Ref 11).

To revise maintenance costs, new data were used that have been prepared by the Association of American Railroads (Ref 12) and are considered more accurate than those determined by the original study. The average values produced by the AAR data in 1982 dollars are as follows:

Flashing Lights, $1,114 per year

Gates, $1,946 per year

Assuming a 30-year life for active warning devices and a 10 percent discount rate, the net present value of the maintenance costs for these warning devices was calculated as described in Appendix D. The net present value maintenance costs were then updated to 1983 dollars using the procedure described in Reference 1. The resulting net present value maintenance costs are listed below:

Flashing Lights, $10,500

Gates, $18,300

When included in the DOT Procedure, the costs for standard highway stop signs, as well as "stop ahead" signs, are also required. A pair of each costs about $200 to install, resulting in a total stop sign installation cost of $400.* The only maintenance costs for stop signs are assumed to result from their replacement every seven years (Ref. 13). Over the same 30-year life cycle assumed for active warning devices, stop sign installations would be replaced at intervals of 7, 14, 21 and 28 years resulting in a net present value (10 percent discount rate) maintenance cost of $392.

The resulting installation, maintenance and life cycle costs of warning devices, including stop signs, in 1983 dollars, are shown in Table 4-2. For comparison purposes, the active warning device costs in 1977 dollars are also included. The 1983 values should be used as the basis for any future revisions of the procedure.

*Private communication with A. Churchill, Federal Highway Administration, Kendall Square, Cambridge MA 02142.

TABLE 4-2. WARNING DEVICE COSTS FOR 1977 AND 1983 ($1000)

Warning Device Upgrade	Installation	Maintenance	Life Cycle
	— 1977 —		
Passive to Flashing Lights	27.4	15.4	42.8
Passive to Gates	40.8	24.3	65.1
Flashing Lights to Gates	36.7	24.5	61.2
	— 1983 —		
Passive to Flashing Lights	43.8	10.7	54.5
Passive to Gates	65.3	18.7	84.0
Flashing Lights to Gates	58.7	18.7	77.4
Standard Stop Signs	0.4	0.4	0.4

APPENDIX A

WARNING DEVICE EFFECTIVENESS DATA

TABLE A-1. EFFECTIVENESS DATA FOR PASSIVE, FLASHING LIGHT AND GATE WARNING DEVICES-USED FOR TABLE 3-1

WARNING DEVICE UPGRADE FROM	TO	NUMBER OF RECORDS	ACCIDENTS BEFORE UPGRADE, B_a	CROSSING MONTHS BEFORE UPGRADE, B_m	ACCIDENTS AFTER UPGRADE, A_a	CROSSING MONTHS AFTER UPGRADE, A_m
Passive (1-4)*	- Flashing Lights (7)	2003	884	82383	191	59830
Passive (1-4)	- Flashing Lights (5-7)	2151	924	87450	220	64632
Passive (1-4)	- Gates (8)	2027	1357	85221	163	58699
Flashing Lights (5-7)	- Gates (8)	1873	1428	78427	311	54556

*Numbers in parentheses designate FRA warning device classes.

TABLE A-2. EFFECTIVENESS DATA FOR FRA WARNING DEVICE CLASSES - USED FOR TABLE 3-2

WARNING DEVICE UPGRADE FROM	TO	NUMBER OF RECORDS	ACCIDENTS BEFORE UPGRADE, B_a	CROSSING MONTHS BEFORE UPGRADE, B_m	ACCIDENTS AFTER UPGRADE, A_a	CROSSING MONTHS AFTER UPGRADE, A_m
Class 1	- Class 2	6	5	314	1	112
	- Class 3	31	5	1678	0	523
	- Class 4	1608	121	86656	39	27512
	- Class 5	12	1	506	2	346
	- Class 6	5	5	178	0	177
	- Class 7	58	26	2648	6	1470
	- Class 8	27	11	1125	2	859
Class 2	- Class 3	1	0	50	0	21
	- Class 4	53	5	2904	2	859
	- Class 5	2	0	51	0	91
	- Class 6	1	0	21	0	50
	- Class 7	12	0	427	1	425
	- Class 8	7	5	420	0	77
Class 3	- Class 4	2090	616	130655	81	17735
	- Class 5	2	0	69	0	73
	- Class 6	0	0	0	0	0
	- Class 7	11	4	522	0	259
	- Class 8	2	0	63	0	79
Class 4	- Class 5	78	15	2319	29	3219
	- Class 6	48	26	2278	5	1130
	- Class 7	1922	847	78431	177	57392
	- Class 8	1991	1214	75549	147	52322
Class 5	- Class 6	3	1	104	0	109
	- Class 7	130	43	5672	32	3558
	- Class 8	69	36	3263	7	1636
Class 6	- Class 7	203	89	9220	19	5191
	- Class 8	200	98	7567	29	6633
Class 7	- Class 8	1604	1294	67597	275	46287

TABLE A-3. EFFECTIVENESS DATA FOR FLAGMAN - USED IN SECTION 3.2

WARNING DEVICE FROM	UPGRADE TO	NUMBER OF RECORDS	ACCIDENTS BEFORE UPGRADE, B_a	CROSSING MONTHS BEFORE UPGRADE, B_m	ACCIDENTS AFTER UPGRADE, A_a	CROSSING MONTHS AFTER UPGRADE, A_m
Passive (1-4)	- Class 5	94	16	2945	31	3729
Passive (1-4)	- Class 5 Flagman	26	2	1124	1	722
Class 5 Flagman	- Class 7	88	26	3770	23	2478

TABLE A-4. EFFECTIVENESS DATA FOR ILLUMINATION - USED FOR TABLE 3-3

WARNING DEVICE FROM	UPGRADE TO	NUMBER OF RECORDS	ACCIDENTS BEFORE UPGRADE, B_a	CROSSING MONTHS BEFORE UPGRADE, B_m	ACCIDENTS AFTER UPGRADE, A_a	CROSSING MONTHS AFTER UPGRADE, A_m
Passive (1-4)*	- Illumination	53	14	1304	28	2459
Special (5) without Illumination	- Special (5) with Illumination	54	14	1326	28	2508

* Numbers in parentheses designate FRA warning device class.

TABLE A-5. EFFECTIVENESS DATA FOR CANTILEVERED AND MAST-MOUNTED FLASHING LIGHTS - USED FOR TABLE 3-4

WARNING DEVICE UPGRADE FROM	TO	NUMBER OF RECORDS	ACCIDENTS BEFORE UPGRADE, B_a	CROSSING MONTHS BEFORE UPGRADE, B_m	ACCIDENTS AFTER UPGRADE, A_a	CROSSING MONTHS AFTER UPGRADE, A_m
Passive (1-4)*	- Cantilevered Flashing Lights	701	354	27,091	94	22,680
Passive (1-4)	- Mast-Mounted Flashing Lights	1285	514	54,565	89	36,670

*Numbers in parentheses designate FRA warning device classes.

TABLE A-6. EFFECTIVENESS DATA FOR UPGRADES TO GATES WITH CANTILEVERED AND MAST-MOUNTED FLASHING LIGHTS - USED FOR TABLE 3-5

WARNING DEVICE UPGRADE FROM	TO	NUMBER OF RECORDS	ACCIDENTS BEFORE UPGRADE, B_a	CROSSING MONTHS BEFORE UPGRADE, B_m	ACCIDENTS AFTER UPGRADE, A_a	CROSSING MONTHS AFTER UPGRADE, A_m
Passive (1-4)*	- Gates with Cantilevered Flashing Lights	440	327	18,336	30	12,904
Passive (1-4)	- Gates with Mast-Mounted Flashing Lights	1389	902	58,605	119	40,014

*Numbers in parentheses designate FRA warning device classes.

TABLE A-7. EFFECTIVENESS DATA FOR MAST-MOUNTED FLASHING LIGHTS BY BASIC ACCIDENT RATE - USED FOR TABLE 3-6

ACCIDENT RATE BASIC FORMULA	NUMBER OF RECORDS	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
0 to .10	883	282	38042	47	24651
.10 to .15	251	121	10307	12	7514
.15 to .20	81	55	3412	14	2339
.20 to .25	38	45	1603	10	1095
.25 to .30	20	11	799	6	621
> .30	8	6	319	0	249
Total	1281	520	54482	89	36469

TABLE A-8. EFFECTIVENESS DATA FOR CANTILEVERED FLASHING LIGHTS BY BASIC ACCIDENT RATE - USED FOR TABLE 3-6

ACCIDENT RATE BASIC FORMULA	NUMBER OF RECORDS	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
0 to .10	367	141	13681	37	12376
.10 to .15	167	91	6916	18	4941
.15 to .20	99	68	3821	23	3208
.20 to .25	38	32	1552	9	1148
.25 to .30	18	15	718	6	560
>.30	4	1	100	2	184
Total	693	348	26786	95	22417

TABLE A-9. EFFECTIVENESS DATA FOR CANTILEVERED FLASHING LIGHTS INSTALLED AT CROSSINGS WITH MAST-MOUNTED FLASHING LIGHTS - USED FOR TABLE 3-7

UPGRADE CLASS	NUMBER OF RECORDS	ACCIDENTS BEFORE UPGRADE B_a	MONTHS BEFORE UPGRADE B_m	CROSSING ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
Class 7 Mast to Class 7 Cantilevers	433	280	18444	190	12299

TABLE A-10. EFFECTIVENESS DATA FOR CANTILEVERED FLASHING LIGHTS INSTALLED AT GATED CROSSINGS WITH MAST-MOUNTED FLASHING LIGHTS - USED FOR TABLE 3-7

PLACEMENT OF CANTILEVERS	NUMBER OF RECORDS	ACCIDENTS BEFORE UPGRADE B_a	MONTHS BEFORE UPGRADE B_m	CROSSING ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
Class 8 Mast to Class 8 Cantilevers	101	78	4692	26	2479

TABLE A-11. EFFECTIVENESS DATA FOR CANTILEVERED FLASHING LIGHTS BY HIGHWAY LANE AND PLACEMENT OF CANTILEVERS - USED FOR TABLE 3-8

PLACEMENT OF CANTILEVERS	LANES	NUMBER OF RECORDS	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
Over Traffic Lane	2	259	134	11499	71	6890
Over Traffic Lane	>2	145	131	5649	103	4646
Over Traffic Lane	all	404	265	17148	174	11536
Not Over Traffic Lane	2	15	3	599	7	466
Not Over Traffic Lane	>2	4	3	219	1	65
Not Over Traffic Lane	all	19	6	818	8	531

TABLE A-12. EFFECTIVENESS DATA FOR CANTILEVERED AND MAST-MOUNTED FLASHING LIGHTS BY HIGHWAY LANES AND PLACEMENT OF CANTILEVERS - USED FOR TABLE 3-9

UPGRADE CASE	LANES	NUMBER OF RECORDS	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
Cantilevers Over Traffic Lane	2	547	248	21448	65	17389
Cantilevers Over Traffic Lane	>2	103	83	3999	24	3314
Cantilevers Not Over Traffic Lane	2	14	3	418	2	576
Cantilevers Not Over Traffic Lane	>2	0	-	---	-	---
All	2	561	251	21866	67	17965
Mast	2	1170	468	49833	81	33237
Mast	>2	12	21	473	4	379

TABLE A-13. EFFECTIVENESS DATA FOR REFLECTORIZED AND NON-REFLECTORIZED CROSSBUCKS - USED FOR TABLE 3-10

UPGRADE CASE	NUMBER OF RECORDS	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
Class 1 to Class 4 Reflectorized Crossbucks	1483	110	80143	36	25150
Class 1 to Class 4, Non-Reflectorized Crossbucks	90	9	4710	1	1680
Class 4, Non-Reflectorized Crossbucks to Class 4, Reflectorized Crossbucks	3390	506	178516	171	62174

TABLE A-14. EFFECTIVENESS DATA FOR CROSSBUCKS UPGRADED FROM STOP SIGNS - USED FOR TABLE 3-11

UPGRADE CASE	NUMBER OF RECORDS	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
Class 4, Crossbucks added to Class 3, Standard Stop Signs*	71	20	4014	4	1027
Class 4, Crossbucks added to Class 3** other Stop Signs	837	265	53346	38	6081
Class 4, Crossbucks replaced Class 3, Standard Stop Signs	49	22	3030	1	449
Class 4, Crossbucks replaced Class 3** other Stop signs	1055	279	65450	33	9455

* Other Stop Signs excluded

** Standard Stop Signs Excluded

TABLE A-15. EFFECTIVENESS DATA FOR STOP SIGNS* - USED FOR TABLE 3-12

UPGRADE CASE	NUMBER OF RECORDS	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
Class 4, Crossbucks only to Class 4, Standard Stop signs	543	160	27547	47	11006
Class 1 to Class 3, Standard Stop Signs	23	5	1228	0	405
Class 4, Crossbucks and Standard Stop Signs to Class 4, Crossbucks only**	69	10	3729	8	1170
Class 3, Standard Stop signs to Class 1**	9	2	545	1	94
Combined (Data Reversed for Class Marked **)	644	174	30039	59	15685

*Standard Stop Signs

**Calculation based on procedure described in Appendix C

TABLE A-16. EFFECTIVENESS DATA BY NUMBER OF TRACKS - USED FOR TABLE 3-13

NUMBER OF TRACKS	NUMBER OF RECORDS	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
	Passive (Classes 1 to 4) to Flashing Lights (Class 7)				
Single	1586	719	65697	143	46309
Multiple	409	165	16408	47	12631
	Passive (Classes 1 to 4) to Gates (Class 8)				
Single	958	537	39743	55	28275
Multiple	1068	820	45412	108	30416
	Classes 5, 6, 7 to Gates (Class 8)				
Single	793	592	32441	101	23862
Multiple	1077	833	45858	210	30609

TABLE A-17. EFFECTIVENESS DATA FOR CLASS 7, FLASHING LIGHTS BY CROSSING SURFACE - USED FOR TABLE 3-14

CROSSING SURFACE	NUMBER OF RECORDS	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
1 - Section Timber	387	193	16317	35	11160
2 - Full Wood Plank	190	65	7093	18	6397
3 - Asphalt	1320	586	54287	123	39433
4 - Concrete Slab	6	2	127	3	299
5 - Concrete Pavement	6	1	141	0	285
6 - Rubber	35	18	1851	7	634
7 - Metal Sections	3	3	135	0	78
8 - Other Metal	5	3	314	0	41
9 - Unconsolidated	35	8	1398	2	1087
0 - Other	16	5	720	3	416
Combined	2003	884	82383	191	59830

TABLE A-18. EFFECTIVENESS DATA FOR CLASS 7, FLASHING LIGHTS BY TRAIN SPEED - USED FOR TABLE 3-15

MAXIMUM TIMETABLE SPEED (MS)	NUMBER OF UPGRADES	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
0 ≤ MS < 20	414	226	17980	41	11414
20 ≤ MS < 40	866	347	35753	83	25733
40 ≤ MS < 60	568	249	22568	49	17760
60 ≤ MS < 80	152	60	5951	18	4841
80 ≤ MS	3	2	131	0	82
Combined	2003	884	82383	191	59830

TABLE A-19. EFFECTIVENESS DATA FOR CLASS 7, FLASHING LIGHTS BY CROSSING ANGLE - USED FOR TABLE 3-16

CROSSING ANGLE	NUMBER OF UPGRADES	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
0 - 29	223	131	10210	19	5623
30 - 59	356	141	14529	29	10747
60 - 90	1424	612	57644	143	43460
Combined	2003	884	82383	191	59830

TABLE A-20. EFFECTIVENESS DATA FOR CLASS 7, FLASHING LIGHTS BY HIGHWAY PAVING - USED FOR TABLE 3-17

HIGHWAY PAVED?	NUMBER OF UPGRADES	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
Yes	1861	838	76143	180	55988
No	141	46	6175	11	3836
Combined	2003	884	82383	191	59830

TABLE A-21. EFFECTIVENESS DATA FOR CLASS 7, FLASHING LIGHTS BY AADT - USED FOR TABLE 3-18

AADT INTERVAL	NUMBER OF UPGRADES	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
0 - 1700	1351	481	54809	104	41112
1700 - 3100	268	136	11314	22	7714
3100 - 5000	157	87	6877	20	4270
5000 - 6500	84	33	3666	12	2298
6500 - 7800	40	40	1649	11	1191
7800 ≤	128	128	5392	25	3696
Combined	2003	884	82383	191	59830

TABLE A-22. EFFECTIVENESS DATA FOR CLASS 7, FLASHING LIGHTS BY TOTAL TRAINS PER DAY - USED FOR TABLE 3-19

TRAINS PER DAY	NUMBER OF UPGRADES	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
	Passive (Classes 1 to 4) to Flashing Lights (Class 7)				
0*	121	10	4827	6	3764
1 - 2	536	220	22170	42	15886
3 - 5	430	175	18360	31	12170
6 - 10	542	269	21783	49	16699
11 ≤	374	210	15243	63	11311
Combined	2003	884	82383	191	59830
	Passive (Classes 1 to 4) to Gates (Class 8)				
0*	59	12	2301	4	1888
1 - 2	232	103	10338	5	6134
3 - 5	242	139	10482	7	6700
6 - 10	405	280	16532	27	12223
11≤	1089	823	45568	120	31751
Combined	2027	1357	85221	163	58696
	Flashing Lights (Classes 5, 6, 7) to Gates (Class 8)				
0*	17	5	826	0	381
1 - 2	144	49	5939	9	4285
3 - 5	186	118	8697	10	4509
6 - 10	369	280	15650	38	10549
11≤	1157	976	47315	254	34832
Combined	1873	1428	78427	311	54556

* Less than one train per day

TABLE A-23. EFFECTIVENESS DATA FOR CLASS 7, FLASHING LIGHTS BY FRACTION OF DAY TRAINS - USED FOR TABLE 3-20

FRACTION OF DAY TRAINS (R)	NUMBER OF UPGRADES	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
Passive (Classes 1 to 4) to Flashing Lights (Class 7)					
0*	121	Not Applicable			
$0 < R \le .25$	137	95	6276	8	3451
$.25 < R \le .50$	728	364	29307	83	22381
$.50 < R \le .75$	500	224	20265	53	15235
$.75 < R \le 1.00$	517	191	21708	41	14999
Combined	2003	884	82383	191	59830
Passive (Classes 1 to 4) to Gates (Class 8)					
0*	59	Not Applicable			
$0 < R \le .25$	107	47	4983	4	2614
$.25 < R \le .50$	939	627	38389	81	28180
$.50\ R \le .75$	690	524	29157	62	19833
$.75 < R \le 1.00$	232	147	10291	12	6181
Combined	2027	1357	85221	163	58696
Flashing Lights (Classes 5, 6, 7) to Gates (Class 8)					
0*	17	Not Applicable			
$0 < R \le .25$	57	33	2486	2	1561
$.25 < R \le .50$	780	628	30698	155	24682
$.50 < R \le .75$	803	637	34818	127	22195
$.75 < R \le 1.00$	216	125	9599	27	5737
Combined	1873	1428	78427	311	54556

*This consists of crossings with less than one train per day

TABLE A-24. EFFECTIVENESS BY NUMBER OF SWITCH TRAINS AND NUMBER OF THRU TRAINS-USED FOR TABLE 3-21

SWITCH TRAINS PER DAY	THRU TRAINS PER DAY	NUMBER OF UPGRADES	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
	Passive (Classes 1 to 4) to Flashing Lights (Class 7)					
0	0	121	10	4827	6	3764
0	1-10	835	335	34539	50	24746
0	≥ 11	139	78	5257	26	4612
0	Combined	1095	423	44623	82	33122
1-10	0	293	139	12159	34	8644
≥11	0	23	28	1077	3	556
Combined	0	437	177	18063	43	12964
All Crossings		2003	884	82383	191	59830
	Passive (Classes 1 to 4) to Gates (Class 8)					
0	0	59	12	2301	4	1888
0	1-10	406	242	16985	16	11841
0	≥ 11	496	306	20064	55	15152
0	Combined	961	560	39350	75	28881
1-10	0	169	92	7563	6	4436
≥ 11	0	25	15	1165	1	610
Combined	0	253	119	11029	11	6934
All Crossings		2027	1357	85221	163	58696
	Flashing Lights (Classes 5, 6, 7) to Gates (Class 8)					
0	0	17	5	826	0	381
0	1-10	300	150	12461	12	8839
0	≥ 11	383	212	14296	76	12897
0	Combined	700	367	27583	88	22117
1-10	0	145	82	6234	11	4061
≥ 11	0	26	36	962	3	884
Combined	0	188	123	8022	14	5326
All Crossings		1873	1428	78427	311	54556

TABLE A-25. EFFECTIVENESS DATA BY URBAN-RURAL LOCATION - USED FOR TABLE 3-22

UPGRADE CASE	NUMBER OF UPGRADES		ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
Passive (Class 1 to 4) To Class 7, Flashing Lights	Urban	693	417	29538	105	19665
	Rural	1310	467	52845	86	40165
	Combined	2003	884	82383	191	59830
Passive (Class 1 to 4) to Class 8, Gates	Urban	813	713	34339	82	23384
	Rural	1214	644	50882	81	35312
	Combined	2027	1357	85221	163	58696
Classes 5, 6, 7 to Class 8, Gates	Urban	1080	1041	45778	218	30902
	Rural	793	387	32649	93	23654
	Combined	1873	1428	78427	311	54556

TABLE A-26. EFFECTIVENESS DATA FOR CLASS 7, FLASHING LIGHTS, BY ACCIDENT RATE CALCULATED WITH BASIC FORMULA - USED FOR TABLE 3-23

ACCIDENT RATE BASIC FORMULA	NUMBER OF UPGRADES	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
0 to .10	1268	429	52366	85	37662
.10 to .15	426	218	17546	32	12700
.15 to .20	181	123	7293	37	5558
.20 to .25	77	77	3171	23	2296
.25 to .30	39	30	1588	12	1181
>.30	12	7	419	2	433
Combined	2003	884	82383	191	59830

TABLE A-27. EFFECTIVENESS OF FLASHING LIGHTS (CLASS 7) AND GATES (CLASS 8) BY NUMBER OF TRACKS AND TRAIN SPEED, UPGRADES FROM PASSIVE (CLASSES 1 to 4) WARNING DEVICES - USED FOR TABLE 3-24

NUMBER OF TRACKS	MAX TRAIN SPEED (MPH)	NUMBER OF RECORDS	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
		Passive (Classes 1 to 4) to Flashing Lights (Class 7)				
Single	< 50	1332	612	55841	121	38731
Single	≥ 50	254	107	9856	22	8178
Multiple	< 50	365	134	14703	37	11212
Multiple	≥ 50	52	31	1983	11	1709
		Passive (Classes 1 to 4) to Gates (Class 8)				
Single	< 50	598	375	25626	29	16832
Single	≥ 50	360	162	14117	26	11443
Multiple	< 50	572	426	23995	60	16617
Multiple	≥ 50	497	394	21483	48	13804

TABLE A-28. EFFECTIVENESS BY NUMBER OF TRACKS AND TOTAL TRAINS PER DAY (T) USED FOR TABLE 3-25

NUMBER OF TRACKS	T	NUMBER OF RECORDS	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
Passive (Classes 1 to 4) to Flashing Lights (Class 7)						
Single	0-10	1311	575	54493	101	38588
Single	≥ 11	275	144	11204	42	8321
Multiple	0-10	318	99	12647	27	9931
Multiple	≥ 11	99	66	4039	21	2990
Combined	---	2003	884	82383	191	59830
Passive (Classes 1 to 4) to Gates (Class 8)						
Single	0-10	561	317	23956	21	15875
Single	≥ 11	397	220	15787	34	12400
Multiple	0-10	377	217	15697	22	11070
Multiple	≥ 11	692	603	29781	86	19351
Combined	---	2027	1357	85221	163	58699
Flashing Lights (Classes 5, 6, 7) to Gates (Class 8)						
Single	0-10	405	267	16966	21	11786
Single	≥ 11	388	325	15472	80	12076
Multiple	0-10	311	185	14143	36	7938
Multiple	≥ 11	769	651	31843	174	22756
Combined	---	1873	1428	78427	311	54556

TABLE A-29. EFFECTIVENESS DATA FOR HIGHWAY SIGNALS, WIGWAGS, AND BELLS - USED FOR TABLES 3-26 and 3-27

UPGRADE BASE	NUMBER OF UPGRADES	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
Passive (Class 1 to 4) to Class 6	54	31	2477	5	1357
Passive (Class 1 to 4) to Wig-wags or Bells	47	14	2143	5	1194
Passive (Class 1 to 4) to High-way Signals Only	6	17	282	0	144
Class 6, No High-way Signals to Class 7	195	86	8920	18	4925
Class 6 High-way Signals to Class 7	8	3	302	1	266
Class 6 to Class 7	203	89	9222	19	5191

TABLE A-30. EFFECTIVENESS DATA FOR CONSTANT WARNING TIME DEVICES - USED IN SECTION 3.10

UPGRADE CASE	NUMBER OF UPGRADE	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
Class 7 without constant warning time to Class 7 with constant warning time	39	22	1411	30	1358
Class 8 without constant warning time to class 8 with constant warning time	80	16	2561	23	3119

TABLE A-31. EFFECTIVENESS DATA FOR RATIO OF MAXIMUM TO MINIMUM SPEED (Y/X) USED FOR TABLE 3-28

MAX SPEED (Y) / MIN SPEED (X)	NUMBER OF UPGRADES	ACCIDENTS BEFORE UPGRADE B_a	CROSSING MONTHS BEFORE UPGRADE B_m	ACCIDENTS AFTER UPGRADE A_a	CROSSING MONTHS AFTER UPGRADE A_m
Passive (Classes 1 to 4) to Flashing Lights (Class 7)					
1≤Y/X 2	895	370	37698	62	25847
2≤Y/X 3	351	155	14313	28	10608
3≤Y/X 6	281	149	11109	42	8842
6≤Y/X	233	90	9447	27	7096
Combined	1760	884	82383	191	59830
Passive (Classes 1 to 4) to Gates (Class 8)					
1≤Y/X 2	783	510	32595	57	22998
2≤Y/X 3	310	243	13531	26	8479
3≤Y/X 6	322	180	12738	24	10124
6≤Y/X	427	278	17758	41	12559
Combined	1842	1357	85221	163	58696
Classes 5, 6, 7 to Gates (Class 8)					
1≤Y/X 2	669	528	27904	114	19595
2≤Y/X 3	279	201	12352	46	7457
3≤Y/X 6	354	292	14079	69	11055
6≤Y/X	400	244	15943	59	12457
Combined	1702	1428	78427	311	54556

APPENDIX B

U.S. DOT-AAR CROSSING INVENTORY FORM

OMB-004-R4039

U.S. DOT — AAR CROSSING INVENTORY FORM

A. INITIATING AGENCY
☐ RAILROAD ☐ STATE

B. CROSSING NUMBER [ ]

C. REASON FOR UPDATE:
☐ CHANGES IN EXISTING CROSSING DATA
☐ NEW CROSSING
☐ CLOSED CROSSING

D. EFFECTIVE DATE
M D Y

Part I Location and Classification of All Crossings (Must Be Completed)

1. Railroad Operating Company
2. Railroad Division or Region
3. Railroad Subdivision or District
4. State
5. County
6. County Map. Ref. No.
7. City
8. Nearest City
9. Highway Type and No.
10. Street or Road Name
11. RR I. D. No
12. Nearest RR Timetable Station
13. Branch or Line Name
14. Railroad Mile Post

DO NOT WRITE IN THIS SPACE: State, County, City, Nearest City, RR Code, Timetable Station

15. Pedestrian Crossing
☐ 1 at grade
☐ 2 RR under
☐ 3 RR over

16. Private Vehicle Crossing
A ☐ 1 Farm ☐ 2 Residential ☐ 3. Recreational ☐ 4. Industrial
B ☐ 5 at grade ☐ 6 RR under ☐ 7. RR over
C ☐ 8 signs-specify ☐ 9 signals-specify ☐ 0 none

17. Public Vehicle Crossing
☐ 1. at grade
☐ 2 RR under
☐ 3. RR over

COMPLETE REMAINDER OF FORM ONLY FOR PUBLIC VEHICLE CROSSINGS AT GRADE

Part II Detailed Information for Public Vehicular at Grade Crossing

1A Typical Number of Daily Train Movements

Daylight (6 AM to 6 PM)		Night (6 PM to 6 AM)	
thru trains	switching	thru trains	switching
1	2	3	4

1B Check if Less Than One Movement Per Day ☐ 5

2. Speed of Train at Crossing
A. Maximum time table speed 1
B. Typical Speed Range Over Crossing from 2 to 3 mph

3. Type and Number of Tracks
main 1 other 2 If other specify 3

4. Does Another RR Operate a Separate Track at Crossing?
☐ Yes 1 ☐ No Specify RR 2

5. Does Another RR Operate Over Your Track at Crossing?
☐ Yes 1 ☐ No Specify RR 2

6. Type of Warning Device at Crossing

A. Signs

Crossbucks		Standard Highway Stop Sign	Other Stop Signs	Other Signs Specify
reflectorized	non-reflectorized			
01 Number	02 Number	03 Number	04 Number	05 Number, 06; 07 Number, 08

B Train Activated Devices

Gates		Cantilevered Flashing Lights		Mast Mounted Flashing Lights	Other Flashing Lights Specify	Highway Traffic Signals	Wigwags	Bells
red & white reflectorized	other colored	over traffic lane	not over traffic lane					
09 Number	10 Number	11 Number	12 Number	13 Number	14 Number, 15	16 Number	17 Number	18 Number

C Specify Special Warning Device not Train Activated 19

D No Signs or Signals ☐ 20

7. Is Commercial Power Available? ☐ Yes ☐ No

8. Does Crossing Signal Provide Speed Selection for Trains? ☐ Yes ☐ No ☐ N/A

9. Method of Signalling for Train Operation Is Track Equipped with Signals? ☐ Yes ☐ No

Part III Physical Data

1. Type of Development ☐ 1 Open Sp ☐ 2 Res ☐ 3 Comm ☐ 4 Ind ☐ 5 Inst
2. Smallest Crossing Angle ☐ 0°-29° ☐ 30°-59° ☐ 60°-90°
3. Number of Traffic Lanes Crossing Railroad Number
4. Are Truck Pullout Lanes Present? ☐ Yes ☐ No
5. Is Highway Paved ☐ Yes ☐ No
6. Pavement Markings ☐ Stoplines ☐ RR Xing Sym. ☐ None
7. Are RR Advance Warning Signs Present? ☐ Yes ☐ No
8. Crossing Surface ☐ 1 Sec Timber ☐ 2 Full Wd Plank ☐ 3 Asphalt ☐ 4 Concrete Slab ☐ 5 Concrete Pave ☐ 6 Rubber ☐ 7 Metal Sections ☐ 8 Other Metal ☐ 9 Unconsolidated ☐ 0 Other Specify
9. Does Track Run Down A Street? ☐ Yes ☐ No
10. Nearby Intersecting Highway? ☐ Yes ☐ No

Part IV Highway Department Information

1. Highway System
2. Is Crossing on State Highway System? ☐ Yes ☐ No
3. Functional Classification of Road over Crossing
4. Estimate AADT
5. Estimate Percent Trucks

I. D Number

APPENDIX C

EFFECTIVENESS OF REVERSE INSTALLATION

Let E be the effectiveness of warning device X when installed at a crossing which had warning device Y. This means that warning device Y is removed when X is installed. Thus:

$$E = 1 - \frac{\text{accident rate with X}}{\text{accident rate with Y}} \tag{C1}$$

What is the effectiveness E_R of the reverse installation as a function of E? The reverse installation assumes Y is installed at a crossing which had X. Thus, the following:

$$E_R = 1 - \frac{\text{accident rate with Y}}{\text{accident rate with X}} \tag{C2}$$

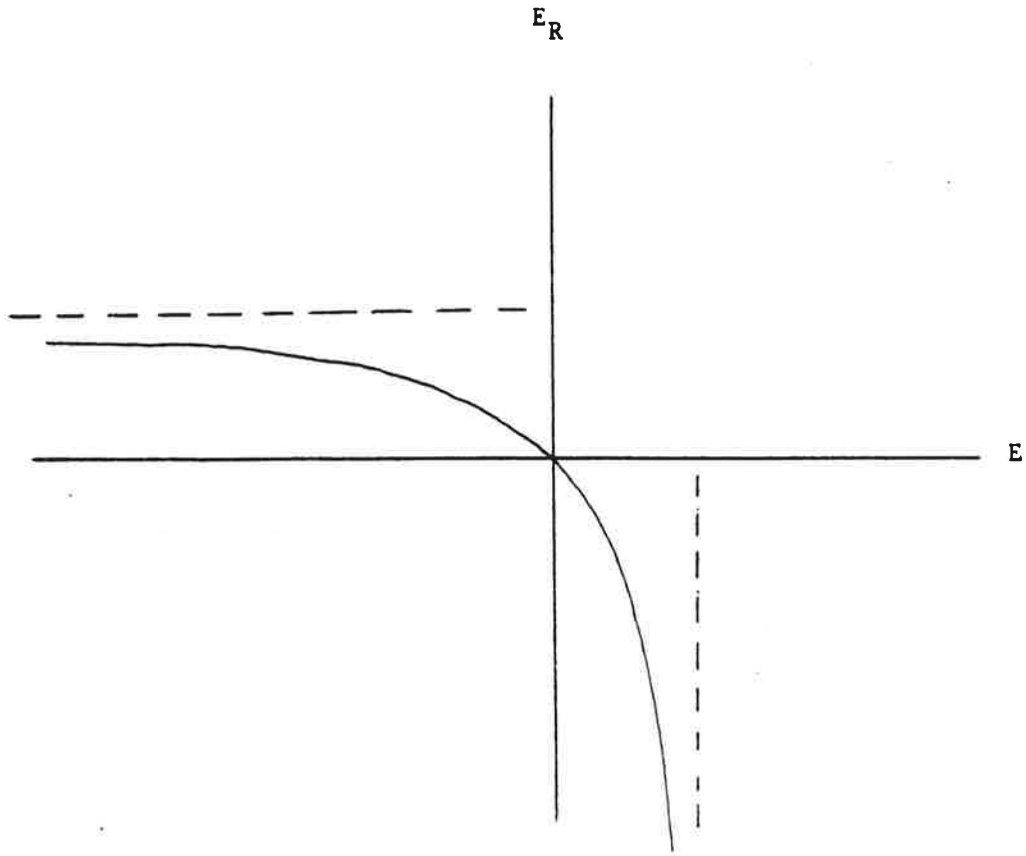
Substituting from Equation C1 into C2 yields:

$$E_R = 1 - \frac{1}{1-E}$$

Thus,

$$E_R = \frac{-E}{1-E}$$

A plot of this function is shown below:



From this graph it is seen that when E is negative, E_R is positive and when E is positive, E_R is negative. In fact, a symmetry exists for E and E_R in that for any point (E, E_R) that satisfies the formula, the point (E_R, E) also satisfies it.

As an example, for one case of stop signs, E was calculated to be -1.55. This produces the result $E_R = 0.61$.

APPENDIX D

CALCULATION OF NEW COSTS

The Association of American Railroads has compiled the following yearly maintenance cost data from 353 crossings throughout the country. (Ref. 12):

Standard Flashing Light Signals, Single Track, $1,172

Cantilever Type Signals, Single Track, $1,056

Standard Flashing Light Signals, With Gates, Single Track, $1,512

Cantilever Type Signals, With Gates, Single Track, $2,081

Standard Flashing Light Signals, With Gates, Two Main Tracks, $1,880

Cantilever Type Signals, With Gates, Two Main Tracks, $2,311

Using the first two numbers, the average maintenance cost for flashing lights is $1,114.

Using the last four numbers, the average maintenance cost for gates is $1,946.

To convert these yearly costs to net present values, assuming a 30-year equipment life and a 10 percent discount rate, it is necessary to divide by .106079. This gives:

$$\text{Flashing Lights} \quad \frac{1114}{.106079} = \$10,500$$

$$\text{Gates} \quad \frac{1946}{.106079} = \$18,300$$

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