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THE EFFECTIVENESS OF FLASHING LIGHTS AND FLASHING LIGHTS WITH GATES IN REDUCING ACCIDENT FREQUENCY AT PUBLIC RAIL-HIGHWAY CROSSINGS 1975-1978

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16. Abstract

The Highway Safety Acts of 1973 and 1976, and the Surface Transportation Assistance Act of 1978, provide funds to individual states to improve safety at public rail-highway crossings. This report was undertaken in support of a U.S. DOT effort to develop a resource allocation model designed to select and rank crossings, and recommend warning device improvements in a cost-effective manner.

Input to the model included the effectiveness of active warning devices, flashing lights and flashing lights with gates, in reducing accident potential. The effectiveness is defined as the percentage of accident reduction at crossings which result from the installation of warning devices. Previous effectiveness values were available from a 1974 California Public Utilities Commission study.

This report is based on inventory and accident data available from computerized FRA data bases, and computes new effectiveness values in three categories: (1) flashing lights at formerly passive crossings, (2) flashing lights with gates at formerly passive crossings, and (3) flashing lights with gates at crossings formerly equipped with flashing lights only.

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PREFACE

This study of the effectiveness factors of flashing lights and flashing lights with gates is part of an overall rail-highway crossing safety program being conducted by the U.S. Department of Transportation. This report documents the findings of Input Output Computer Services (IOCS) under Contract Number DOT-TSC-1533 to the Operations and Management Systems Branch, Intercity Systems Division, Office of Ground Systems at the Transportation Systems Center (TSC). The project is jointly sponsored by the Federal Railroad Administration (FRA) and the Federal Highway Administration (FHWA). Dr. Edwin Farr was the contract technical monitor at TSC.

The research, analysis, and documentation for the project was performed by Joseph Morrissey. Charles L. Erdrich served as a technical consultant for the study. Samir A. Desai, Vice-President of the Systems, Research, and Communications Division of IOCS, offered technical and managerial assistance.

The author thanks Dr. Richard E. Snow and Bruce F. George of the Federal Railroad Administration for making valuable statistical information available. The author is indebted to Dr. Edwin Farr, John Hitz, and Robert Coulombre, Chief of the Operations and Management Systems Branch (TSC), for their effective direction and participation in the project.

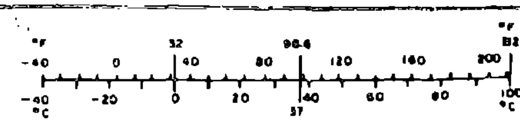
METRIC CONVERSION FACTORS

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

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	35	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

The Highway Safety Acts of 1973 and 1976, and the Surface Transportation Assistance Act of 1978, provide funding authorizations to individual states for the improvement of public rail-highway crossing safety. 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) and the Transportation Systems Center (TSC) to assist states and railroads in determining the most effective allocation of Federal funds for rail-highway crossing warning devices. One of these projects concerns the development of a resource allocation model which assists in achieving maximum safety benefits for a given level of funding. This model utilizes rail-highway crossing accident predictions, and the effectiveness and costs of motorist warning devices. The purpose of this study is to develop improved estimates of the effectiveness of active rail-highway crossing warning devices in support of the DOT resource allocation model. Effectiveness is measured as the expected percentage reduction in accidents, due to the installation of a specific warning device.

The study compares the accident rates at 2,994 rail-highway crossings nationwide, both before and after active warning devices have been installed. Necessary data for the analysis were obtained from the DOT-AAR National Rail-Highway Crossing Inventory and the Federal Railroad Administration's (FRA) Railroad Accident/Incident Reporting System (RAIRS) for the years 1975, through 1978.

The average effectiveness values resulting from the study for the three warning device upgrade categories investigated are listed below together with their 95 percent confidence intervals and the results of the California Public Utilities Commission (PUC) study.[1]

UPGRADE CATEGORY	EFFECTIVENESS FACTOR (PERCENT)	95 PERCENT CONFIDENCE INTERVAL (PERCENT)	1974 CALIFORNIA FINDINGS (PERCENT)
Passive to Flashing Lights (1165)[1]	65	57-73	64
Passive to Flashing Lights With Gates (985)[1]	84	80-89	88
Flashing Lights to Flashing Lights With Gates (844)[1]	64	56-71	66

[1]Indicates the total number of rail-highway crossings considered.

Prior to this study, the California PUC study effectiveness values have been used for the DOT resource allocation studies at TSC. This is consistent with the results of the present study, since the California study values lie within the present study's 95 percent confidence intervals. Flashing lights and flashing lights with gates are found to be significantly effective in reducing the hazards at rail-highway crossings.

[1]California Public Utilities Commission, The Effectiveness of Automatic Protection in Reducing Accident Frequency and Severity at Public Grade Crossings in California, June 1974, p. 30.

1. INTRODUCTION

1.1 BACKGROUND

In 1970, Congress issued a mandate to the U.S. Department of Transportation (DOT) for the preparation of a study concerning the number and severity of rail-highway crossing accidents. The study was to recommend steps which could be taken to reduce the accident potential at the 220,000 public crossings in the U.S.

In 1972, DOT responded with a report which was jointly authored by the Federal Highway Administration (FHWA) and the Federal Railroad Administration (FRA).[1] The report recommended that Federal funds be made available to the states for a 10-year program designed to improve rail-highway crossings. A major element of the program called for active warning device improvements at 30,000 rail-highway crossings. Specifically, the crossings were to be upgraded to flashing lights or flashing lights with automatic gates. These devices are distinguished from passive devices, such as crossbucks or stop signs, which are not set into mechanical operation by the approach or presence of a train.

The Highway Safety Act of 1973 authorized the first categorical Federal funds for individual states to implement rail-highway crossing safety improvements. The program continued with the passage of legislation in 1976 and 1978, which extended the Federal commitment to improved rail-highway crossing safety.

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[1] Federal Highway Administration/Federal Railroad Administration, Report to Congress, Railroad-Highway Safety Part II: Recommendations for Resolving the Problem, Washington, D.C.: U.S. Department of Transportation, August 1972.

In an effort to ensure cost-effective use of the Federal resources authorized for crossing safety improvement, the Transportation Systems Center (TSC) developed two models as part of a resource allocation process. These models assist in selecting and ranking crossings for the installation of warning devices. The development of these models followed the completion of the joint DOT-AAR National Rail-Highway Crossing Inventory, which numbered and collected inventory information for all public and private rail-highway crossings.

The first step in the resource allocation process uses an accident prediction formula which computes the projected number of accidents at each crossing, based on the information available in the inventory. The second step uses a resource allocation model which is designed to rank crossings for improvement and to recommend the type of warning device to be installed on a cost-effective basis. For each crossing under consideration, the resource allocation model requires the crossings' accident prediction, the life cycle costs of warning devices, the total amount of funds to be used for safety improvements, and the effectiveness factors of warning devices.

Effectiveness factors measure the expected percent reduction in accidents due to the installation of a specific warning device. Effectiveness factors have been taken from a 1974 California Public Utilities Commission (PUC) study on the effectiveness of flashing lights and flashing lights with gates in reducing accidents in that state.[1] The PUC study examined the accident history of 1,552 crossings, 44 percent of the California crossings with active devices in 1970, which were upgraded to flashing lights or flashing lights with gates during the period from January 1, 1960, to December 31, 1970. The data were separated into three categories. Table 1-1 shows the resulting effectiveness factors obtained from the PUC study.

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[1] op cit., California PUC Study, June 1974, p. 30.

TABLE 1-1. RESULTS OF CALIFORNIA PUBLIC UTILITIES COMMISSION EFFECTIVENESS STUDY

UPGRADE CATEGORY	PERCENT REDUCTION IN ACCIDENTS AFTER INSTALLATION OF ACTIVE DEVICE
Passive to Flashing Lights	64
Passive to Flashing Lights with Gates	88
Flashing Lights to Flashing Lights with Gates	66

1.2 PURPOSE AND OBJECTIVES

Since the 1974 PUC study, no other large scale study has been undertaken to assess the effectiveness of flashing lights and flashing lights with gates in reducing rail-highway crossing accidents. The effectiveness factors from the PUC study, especially for flashing lights, are frequently criticized as being too high in view of accident statistics published by the FRA.[1] Flashing light crossings have an average accident rate which is 2.7 times greater than the average of all crossings equipped with crossbucks.[2] The PUC study shows flashing lights to be 64 percent effective in reducing accidents. Therefore, to improve the quality of and confidence in the data required for use by the DOT resource allocation model, this study was designed to determine new effectiveness factors based on national statistics.

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[1]Federal Railroad Administration, Rail-Highway Crossing Accident/Incident and Inventory Bulletin, No. 1, 1978, Washington, D.C.: U.S. Department of Transportation, 1979, p. 40.

[2]ibid., p. 30.

Computerized inventory and accident data were obtained for this study from the FRA, which maintains the DOT-AAR National Railroad-Highway Crossing Inventory and the Railroad Accident/ Incident Reporting System (RAIRS). The new effectiveness factors were based on an analysis of the accident history of approximately 50 percent of the Nation's crossings which had warning device upgrades during the period from January 1, 1975, through December 31, 1978.

The specific objective of this study was to develop the necessary methodology, and compute the effectiveness of flashing lights and flashing lights with gates in three upgrade categories: passive to flashing lights, passive to flashing lights with gates, and flashing lights to flashing lights with gates. The standard deviations and 95 percent confidence intervals for the effectiveness values were determined.

2. METHOD

The study used data for the period from January 1, 1975, through December 31, 1978. Prior to 1975, the DOT-AAR Crossing Inventory was not operational and accident data was based on different reporting criteria. Three groups of warning devices were considered consistent with the categorization used in the development of the DOT accident prediction and resource allocation models. Table 2-1 provides descriptions of the three warning device groups.

TABLE 2-1. WARNING DEVICE GROUPS

GROUP	DESCRIPTION
1	All Passive Devices - Stop Signs, Crossbucks, Other Signs, or No Warning Device
2	Flashing Lights, Wigwags, Bells, Highway Signals, Special Devices
3	Flashing Lights with Gates

An effectiveness formula was developed to use the information available from the data bases. The formula was designed to determine the net reduction or increase in accidents per crossing year for each group of upgraded crossings. A crossing year for a warning device is defined as a one-year period during which the crossing was equipped with a particular warning device. For example, if a passive crossing was upgraded to flashing lights on December 31, 1976, the number of crossing years for both the passive device before the upgrade and the flashing lights after the upgrade would be two. The formula and its parameters are contained in Appendix A.

It has been estimated that over 2,000 active warning devices per year have been installed at rail-highway crossings in recent years.[1] The installations represent new and upgraded crossings. A sample of the upgraded crossing population was available directly from the DOT-AAR Crossing Inventory. Under the voluntary Federal program, both railroads and state departments of transportation submit update forms to the FRA which detail inventory information for all new and upgraded crossings. Many railroads and states are not prompt in submitting update information to the FRA. Consequently, the FRA data base contains information on approximately 50 percent of all crossings which had warning device changes since 1976. A subset of the DOT-AAR Crossing Inventory, containing the records of upgraded crossings only, was utilized. The data were segregated into the three upgrade categories. Table 2-2 shows the totals for each type of upgrade and the year.

TABLE 2-2. NUMBER OF UPGRADES FROM THE FRA DATA BASE BY TYPE AND YEAR

	1975	1976	1977	1978	TOTALS
Passive to Flashing Lights	155	359	382	269	1165
Passive to Flashing Lights with Gates	92	249	319	325	985
Flashing Lights to Flashing Lights with Gates	87	228	280	249	844
Totals	334	836	981	843	2994

[1]"Crossing Safety Has More Funds," The Signalman's Journal, November 1978, p. 9.

In addition to the data on upgraded crossings, rail-highway crossing accident data were obtained from the RAIRS. Records containing both inventory and accident information for all upgraded crossings which experienced accidents during the study period were used. FORTRAN programs were developed to access and cross-reference both the inventory upgrade and the accident data, using the DOT-AAR Crossing Inventory identification number.

In each upgrade category, crossing years were computed both before the upgrade and after the upgrade for each crossing, whether or not an accident occurred at the crossing. If a crossing experienced an accident, the accident was counted in the appropriate time frame. All parameters were summed and effectiveness factors were calculated. In addition, standard deviations and 95 percent confidence intervals for the effectiveness factors were computed. Appendix B describes the procedure and provides an example for calculating the standard deviations and confidence intervals. A comparison of crossing accident rate statistics for the three upgrade categories is presented in Appendix C.

3. RESULTS

Effectiveness factors, standard deviations, and 95 percent confidence intervals are presented in Table 3-1, as well as the values of other relevant parameters. The results indicated that flashing lights and flashing lights with gates significantly reduce the number of accidents at public crossings. In addition, gates proved to be more effective than flashing lights in accident reduction. For the 1,165 sampled crossings, the effectiveness of flashing lights at formerly passive crossings was 65 percent, given a 95 percent confidence interval of 57 percent to 73 percent. For the 985 crossings that were upgraded from passive devices to flashing lights with gates, the effectiveness factor was 84 percent, given a 95 percent confidence interval of 80 percent to 89 percent. Following the installation of flashing lights with gates at the 844 crossings previously equipped with flashing lights, the effectiveness was 64 percent with a 95 percent confidence interval of 56 percent to 71 percent. These effectiveness factors almost equal the results of the California PUC report, as shown in Table 3-1. The California results are within the 95 percent confidence intervals of this study.

TABLE 3-1. SUMMARY OF RESULTS FOR EFFECTIVENESS FACTORS

UPGRADE CATEGORY	NUMBER OF CROSSINGS	ACCIDENTS BEFORE UPGRADE	CROSSING YEARS BEFORE UPGRADE	ACCIDENTS AFTER UPGRADE	CROSSING YEARS AFTER UPGRADE	EFFECTIVENESS FACTOR (PERCENT)	STANDARD DEVIATION OF EFFECTIVENESS FACTOR (PERCENT)	95 PERCENT CONFIDENCE INTERVAL (PERCENT)	CALIFORNIA FINDINGS[1] (PERCENT)
Passive to Flashing Lights	1165	328	2539	96	2108	65	4.0	57-73	64
Passive to Flashing Lights With Gates	985	485	2380	50	1551	84	2.3	80-89	88
Flashing Lights to Flashing Lights With Gates	844	380	1963	98	1396	64	3.9	56-71	66
TOTALS	2994	1193	6882	244	5055	72	1.9	68-76	N/A

[1]California Public Utilities Commission, The Effectiveness of Automatic Protection in Reducing Accident Frequency and Severity at Public Grade Crossings in California, June 1974, p. 30.

APPENDIX A
EFFECTIVENESS FORMULA

The following formula was used to calculate the effectiveness of warning devices for the three upgrading categories.

$$E_{wdc} = \frac{\frac{N_{ab}}{N_{cb}} - \frac{N_{aa}}{N_{ca}}}{\frac{N_{ab}}{N_{cb}}}$$

E_{1-2} = Effectiveness of flashing lights at formerly passive crossings

E_{1-3} = Effectiveness of flashing lights with gates at formerly passive crossings

E_{2-3} = Effectiveness of flashing lights with gates at crossings formerly equipped with flashing lights

where: E_{wdc} = Effectiveness of a particular warning device group given the preceding group where

1 = Passive devices
2 = Flashing lights
3 = Flashing lights with gates

N_{aa} = Total number of accidents after warning device installation

N_{ca} = Total number of crossing years after warning device installation

N_{ab} = Total number of accidents before warning device installation

N_{cb} = Total number of crossing years before warning device installation

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APPENDIX B

EXAMPLE OF A COMPUTATION OF STANDARD DEVIATION AND 95 PERCENT CONFIDENCE INTERVAL FOR EFFECTIVENESS FACTORS

Equation (1) provides the formula for the standard deviation of the effectiveness factors computed by using the formula shown in Appendix A.[1]

$$(1) \qquad S(E_{wdc}) = \left(\frac{N_{aa}}{N_{ca}}\right)\left(\frac{N_{cb}}{N_{ab}}\right) \sqrt{\frac{N_{ca} - N_{aa}}{(N_{ca})(N_{aa})} + \frac{N_{cb} - N_{ab}}{(N_{cb})(N_{ab})}}$$

Using the values for the upgrade category of flashing lights to flashing lights with gates, shown in Table 3-1, results in the following:

$$S(E_{2-3}) = \left(\frac{98}{1396}\right)\left(\frac{1963}{380}\right) \sqrt{\frac{1396 - 98}{(1396)(98)} + \frac{1963 - 380}{(1963)(380)}}$$

Simplifying the equation:

$$S(E_{2-3}) = (0.0702)(5.1658) \sqrt{0.0116}$$

$$S(E_{2-3}) = 0.0391 \quad \text{or} \quad 3.91 \text{ percent}$$

A 95 percent confidence interval requires a 1.96 standard deviation from the mean. Therefore, the interval for the effectiveness factor for the upgrade category of flashing lights to flashing lights with gates is:

$$63.75 \pm (1.96)(3.91) = 56.09 \text{ to } 71.41$$

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[1]William G. Cochran, Sampling Techniques, 2nd Edition, (New York: John Wiley & Sons, 1963) p. 165.

APPENDIX C

COMPARISON OF CROSSING UPGRADE CATEGORY ACCIDENT RATE STATISTICS

The study included the development of crossing accident-rate statistics for crossings in the three upgrade categories, for both the study sample and the national inventory. This permitted a comparison of the relative hazards of each crossing category both within and between the study and the national data sets. Accident rates, expressed as accidents per crossing year, were determined by the ratio of total accidents to the total number of crossings in each upgrade category, using data from the DOT-AAR Crossing Inventory and RAIRS.

Table C-1 summarizes accident rate statistics for various categories of crossings from the DOT-AAR Crossing Inventory and the subset which comprised the study sample. The table indicates that crossings equipped with flashing lights have a higher accident rate than the average passive crossing. This conclusion applies to the study sample and for the Nation. Initially, this information may appear to conflict with the results of the study, which indicate that flashing lights and flashing lights with gates are significantly effective in reducing accidents. The explanation for this apparent contradiction is that the passive crossings which were selected for upgrading had such a high accident rate, that even after upgrading the accident rate remained higher than that of the average passive crossing. This can be demonstrated by using the data in Table C-1 in the case of upgrading passive crossings to flashing lights. The average passive crossing selected for upgrading to flashing lights during the study period had an accident rate which was 3.4 times higher than the average passive crossing. Even after flashing lights were installed at these crossings and their hazard level reduced by 65 percent, their corresponding accident rates remained higher than the average passive crossing.

TABLE C-1. ACCIDENT RATES FOR VARIOUS CATEGORIES OF RAIL-HIGHWAY CROSSINGS

CROSSING CATEGORY	CROSSING ACCIDENT RATE (ACCIDENTS PER CROSSING YEAR)
Passive[1]	0.038
Flashing Lights[1]	0.110
Flashing Lights with Gates[1]	0.088
Passive Selected for Flashing Lights[2]	0.129
Passive Selected for Flashing Lights with Gates[2]	0.204
Flashing Lights Selected for Flashing Lights with Gates[2]	0.194
Passive Upgraded to Flashing Lights[3]	0.046
Passive Upgraded to Flashing Lights with Gates[3]	0.032
Flashing Lights Upgraded to Flashing Lights with Gates[3]	0.070

[1]National average from DOT-AAR Crossing Inventory and RAIRS, 1978.

[2]Average from study sample before upgrading.

[3]Average from study sample after upgrading.

A comparison of the three crossing category exposure rates from the DOT-AAR Crossing Inventory also provides evidence of the increased hazard levels at the upgraded crossings, as shown in Table C-2. The exposure rate is the product of the average daily highway traffic times the average daily train traffic and provides a measure of the accident potential at a crossing. The exposure rates for crossings with flashing lights with gates and for crossings with just flashing lights are 17.0 and 6.7 times greater than for passive crossings respectively. In view of these exposure rates, the high accident rates at upgraded crossings which initially appear contradictory are quite reasonable. In fact, if the accident rates are normalized by exposure rates, as shown in Table C-2, the contradiction disappears. The data in Table C-2 provide an explanation for the apparent contradiction which could be used an an argument advocating that the effectiveness of warning devices is significantly less than that which was found in this study.

Other notable trends observed from Table C-1 concern the average hazard level of crossings in the study sample which were selected for upgrading. The passive crossings which were initially selected for upgrading to flashing lights with gates, had a higher accident rate than those selected for upgrading to flashing lights. In addition, flashing light crossings which were selected for upgrading to flashing lights with gates, had an initially higher accident rate than the average crossing equipped with flashing lights. These trends are consistent with the study's findings which show flashing lights with gates as more effective than flashing lights. In general, the most effective warning devices were chosen for installation at crossings which had the highest accident rates.

TABLE C-2. ACCIDENT AND EXPOSURE RATES FOR VARIOUS CATEGORIES OF CROSSINGS FROM THE DOT-AAR CROSSING INVENTORY

CROSSING CATEGORY	AVERAGE DAILY HIGHWAY TRAFFIC	AVERAGE DAILY TRAIN TRAFFIC	AVERAGE EXPOSURE	AVERAGE CROSSING ACCIDENT RATE (ACCIDENTS PER CROSSING YEAR)	AVERAGE CROSSING ACCIDENT RATE NORMALIZED BY EXPOSURE $\times 10^6$
Passive	948	5.4	5,120	0.038	7.4
Flashing Lights	3,566	9.6	34,234	0.110	3.2
Flashing Lights with Gates	4,445	19.6	87,122	0.088	1.0

APPENDIX D

REPORT OF NEW TECHNOLOGY

The work performed under this contract, while leading to no new invention, provided information on the effectiveness of active warning devices in reducing accidents at public rail-highway crossings. This work supports a U.S. Department of Transportation effort to make a computerized resource allocation model available to states and railroads. The model was designed to select and rank rail-highway crossings, and recommend safety improvements through the installation of warning devices on a cost-effective basis.

Input to the model included the effectiveness of flashing lights and flashing lights with gates in reducing accident potential at crossings. This work, based on inventory and accident data available from the FRA's data bases, computed new effectiveness factors in three categories: (1) flashing lights at crossings formerly equipped with passive devices, (2) flashing lights with gates at formerly passive crossings, and (3) flashing lights with gates at crossings which were formerly equipped with flashing lights only.

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