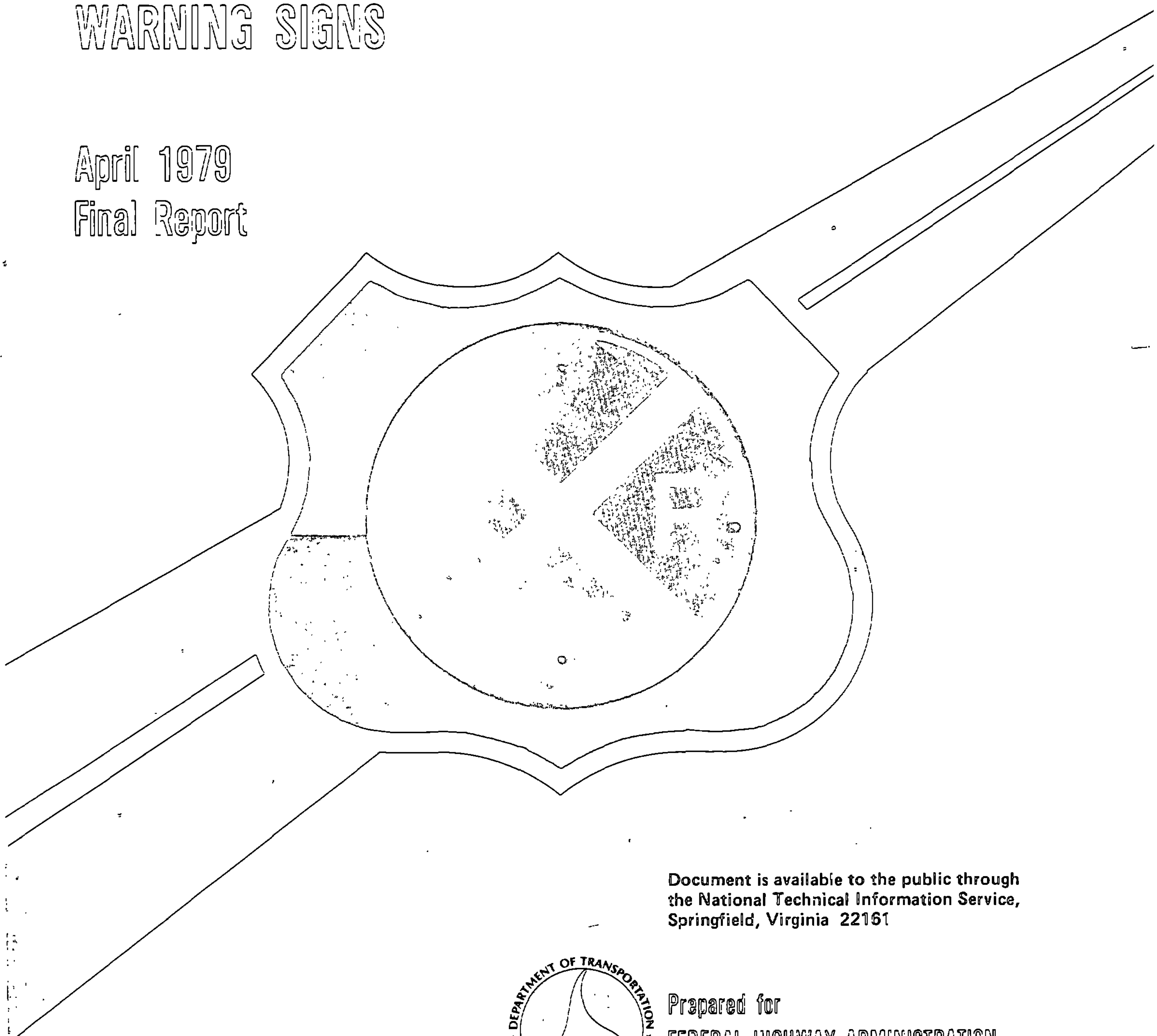
PB80-145089

Report No. FHWA-RD-79-78

EXPERIMENTAL DESIGN FOR EVALUATING THE SAFETY BENEFITS OF RAILROAD ADVANCE WARNING SIGNS

April 1979

Final Report



Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
...stems Division
..., D.C. 20590

FOREWORD

This report describes the findings of a study to develop an experimental design and analysis plan for testing and evaluating the safety benefits attributable to the use of a new railroad grade crossing advance warning sign. This research effort points out the difficulties which would be experienced in using accident reduction as a measure of effectiveness for evaluating any railroad grade crossing safety improvement. The study findings indicate that very large sample sizes would be needed to detect a significant accident reduction. The costs involved in undertaking the field testing to determine the accident reduction would, under some conditions, equal the costs of replacing all existing advance warning signs with the new advance warning signs. It was determined that field testing to determine the potential safety benefits of the new sign would be economically and experimentally impractical.

This report is primarily intended for researchers. Copies are being sent to the 25 State members of the advisory panel for the nationwide passive signing study. Additional copies may be obtained from the National Technical Information Service (NTIS), Springfield, Virginia 22161.

Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-RD-79-78		PB80-145089
4. Title and Subtitle EXPERIMENTAL DESIGN FOR EVALUATING THE SAFETY BENEFITS OF RAILROAD ADVANCE WARNING SIGNS		5. Report Date April 1979 6. Performing Organization Code 8. Performing Organization Report No.
7. Author(s) Wm. D. Berg		
9. Performing Organization Name and Address Wm. D. Berg, P.E. Consultant 1102 Chapel Hill Road Madison, Wisconsin 53711		10. Work Unit No. (TRAIS) 3101-176 11. Contract or Grant No. P.O. 8-4-0124
12. Sponsoring Agency Name and Address Offices of Research and Development Federal Highway Administration U.S. Department of Transportation Washington, D.C. 20590		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code T-0338
15. Supplementary Notes FHWA contract manager: J. Coleman (HRS-33)		

16. Abstract

This report presents the findings and conclusions of a study to develop an experimental design and analysis plan for field testing and evaluation of the accident reduction potential of a proposed new railroad grade crossing advance warning sign. Several alternative sampling frameworks were initially developed to determine which might offer the most efficient design in terms of required sample size. Because of the very large sample sizes associated with the alternative sampling frameworks, an analysis was undertaken to determine the minimum relative reduction in accident rate which would economically justify deployment of the new advance warning sign. The cost of undertaking the field studies and analyses was then evaluated so that it could be compared to the expected value or utility of the information to be derived from the study. The results indicated that the proposed accident study would be both experimentally and economically impractical. It was therefore recommended that an accident study not be undertaken. Several policy options were then examined.

17. Key Words	18. Distribution Statement
Accident Characteristics, Advance Warning Systems, Crossbucks, Economic Analysis, Grade Crossing Characteristics, Inventory, Statistics, Warrants	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72)

PREFACE

Appreciation is extended to Janet Coleman and Stanley R. Byington of the FHWA Office of Research for the guidance and assistance which they provided during the study. Special credit and recognition is also extended to Camil Fuchs who developed the statistical methods for the experimental design.

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I. INTRODUCTION

Interest in the problems of railroad-highway grade crossings having passive warning devices was heightened with the completion of NCHRP Project 3-8, "Factors Influencing Safety at Highway-Rail Grade Crossings".(1) As outlined in that investigation, when some form of active warning device is provided at a grade crossing, the motorist's decision-making process is reduced to a simple response to a clearly understood warning to bring his vehicle to a stop. Numerous researchers have shown that when this form of warning system is provided, a significant reduction in accident potential is achieved. However, there is general agreement that because of limited dollar resources, it is not economically feasible to provide this form of warning device at all grade crossings throughout the country.

Passive warning systems must continue to be utilized at the large percentage of grade crossings with low train and traffic volumes. In these situations, the passive warning devices inform the motorist that a grade crossing lies ahead, but the motorist bears the responsibility for determining whether or not a train is in the vicinity of the crossing. If an approaching train is detected, the motorist must then decide if he can proceed safely, or if he must bring his vehicle to a stop.

In recent years the Federal Highway Administration, Federal Railroad Administration, and the Association of American Railroads have supported research designed to improve the effectiveness of passive warning systems.(2,3, 4) Justification for this research has been based on the fact that even relatively small improvements in effectiveness could produce potentially significant safety benefits nationwide simply because of the extremely large number of grade crossings which offer only passive warning devices. However, the research results to date have focused almost entirely on alternate measures of safety effectiveness such as increased looking for trains (driver head movements) and reduced vehicle approach speeds.

The recent grade crossing passive signing study undertaken for the Federal Highway Administration indicated that new passive signing configurations could produce as mush as a 5-percent increase in driver head movements.(4) The 25-member State Advisory Committee to the research study generally believed that this result could be translated into a 2-3 percent reduction in average accident rate. The group subsequently recommended to the National Advisory Committee (NAC) on Uniform Traffic Control Devices that a new red and yellow advance warning sign be adopted as a national standard. The NAC denied the request for the following reasons:

1. The new sign did not reduce the speed of vehicles.

2. The significance of the 5-percent increase in head movements was not sufficient justification upon which to base a change in the national standards.

3. There were no indications of the potential safety benefits of the proposed new sign.

4. The economic impact of replacing the existing standard signs had not been determined. (5)

However, the NAC did recommend that additional experimentation with the proposed advance warning sign to determine its safety benefits be permitted.

This report presents the findings and conclusions of a study to develop an experimental design and analysis plan for field testing and evaluation of the accident reduction potential of the proposed new advance warning sign. The principal research issues were:

1. How to insure that any accident reduction attributable to the new sign would in fact be detected.

2. What type of evaluation framework would clearly reveal the potential cost-effectiveness of alternative sign deployment policies.

The scope of the study was limited to the application of the proposed advance warning sign to public grade crossings having the standard railroad crossbuck sign (R15-1) as the only warning device at the crossing. (6) These grade crossings constitute approximately 83 percent of all public grade crossings not having some form of active warning device. (7)

II. PROBLEM STATEMENT AND FORMULATION OF HYPOTHESES

The fundamental problem associated with any effort to measure the safety effectiveness of alternative railroad grade crossing warning systems is the very low expected accident rate per crossing. As comprehensively described in the 1972 Report to Congress on Railroad-Highway Safety, grade crossing accidents are rare events. (8) Based on 1970 data for all public grade crossings, the average accident rate per crossing is approximately equivalent to the occurrence of one train-involved accident every 18 years. This statistic means that any field study designed to measure a possible reduction in that accident rate would require a very large sample size and/or a very long observation period.

This problem is compounded when only those crossings with passive warning systems are considered. Historically, grade crossings having a relatively high level of exposure (the product of average daily train and highway traffic volumes) have tended to exhibit the higher accident rates. This in turn has led railroads and highway agencies to concentrate the use of active warning devices at these crossings. As a result, the remaining grade crossings with passive warning devices tend to experience an accident rate lower than the national average for all crossings.

A. Grade Crossing Accident Patterns

The national grade crossing inventory and accident data files maintained by the Federal Railroad Administration were utilized to develop descriptive statistics on current accident patterns at public grade crossings having passive warning systems. The inventory file included information on the physical characteristics of grade crossings such as:

1. Geographic location.
2. Train volume and operating speeds.
3. Types of warning devices.
4. Roadway design features and functional classification.

5. Vehicular traffic volume.

The accident file consisted of information on those grade crossing accidents which occurred during 1975 and 1976 as reported on the Highway Grade Crossing Incident Report forms filed with the Federal Railroad Administration.

Using cross-classification analysis procedures, frequency distributions and accident characteristics were tabulated for selected stratifications of grade crossings. For example, Table 1 shows the frequency distribution, and annual average accident and fatality rates for the 36,104 grade crossings having reflectorized crossbucks and advance warning signs. The data reveal that accident rates, and fatality rates to a lesser extent, tend to increase as the levels of train and traffic volume increase. Moreover, the frequency count within each cell clearly indicates that most grade crossings having reflectorized crossbucks and advance warning signs carry very low train and traffic volumes. These two fundamental patterns are graphically illustrated in Figures 1 and 2.

An unexpected result appeared when a comparison was made between crossings with and without advance warning signs. As shown in Table 2, when grade crossings were stratified by location, those crossings without an advance warning sign had a significantly lower accident rate than those with advance warning signs. The same pattern appeared again when crossings were stratified by average daily train and traffic volumes. This apparent anomaly suggests that there are one or more other causal factors whose effect is not being accounted for. Examples would include the relative amount of corner sight distance, and driver information load as indicated by the number and location of traffic control devices, advertising signs, and other roadside distractions. Another possible explanation would be that highway agencies have tended to install advance warning signs at those crossings having the greatest inherent relative hazard.

Nevertheless, the results of the cross-classification analysis did reveal the potential difficulties which would have to be confronted in the development of the experimental design. It also became clear that there were data not presently found in the national grade crossing inventory file which would have to be scheduled for field measurement within the experimental design.

Table 1. Characteristics of grade crossings with reflectorized crossbucks and advance warning signs.

Trains per day	Average daily traffic volume					
	1-250	251-500	501-1,000	1,001-5,000	>5,000	Total
0-2	10,522 0.010 -	2,516 0.025 0.002	2,233 0.043 0.004	3,054 0.057 0.003	1,009 0.071 0.002	19,334 0.026 0.002
3-5	3,867 0.027 0.003	834 0.067 0.005	645 0.086 0.007	713 0.123 0.005	218 0.167 -	6,277 0.058 0.004
6-10	3,739 0.037 0.004	709 0.076 0.010	471 0.142 0.011	546 0.213 0.009	114 0.291 0.006	5,579 0.073 0.006
11-15	1,136 0.050 0.009	148 0.114 0.025	117 0.166 0.011	142 0.185 0.004	32 0.274 -	1,575 0.082 0.010
16-20	921 0.072 0.012	186 0.088 0.020	138 0.200 0.036	113 0.376 0.017	10 0.313 -	1,368 0.115 0.016
>20	1,528 0.062 0.010	212 0.196 0.015	122 0.302 0.087	95 0.309 0.013	14 0.491 -	1,971 0.106 0.015
Total	21,713 0.025 0.003	4,605 0.054 0.006	3,726 0.081 0.009	4,663 0.102 0.005	1,397 0.115 0.002	36,104 0.049 0.004

Cell values: number of crossings
average annual accident rate
average annual fatality rate

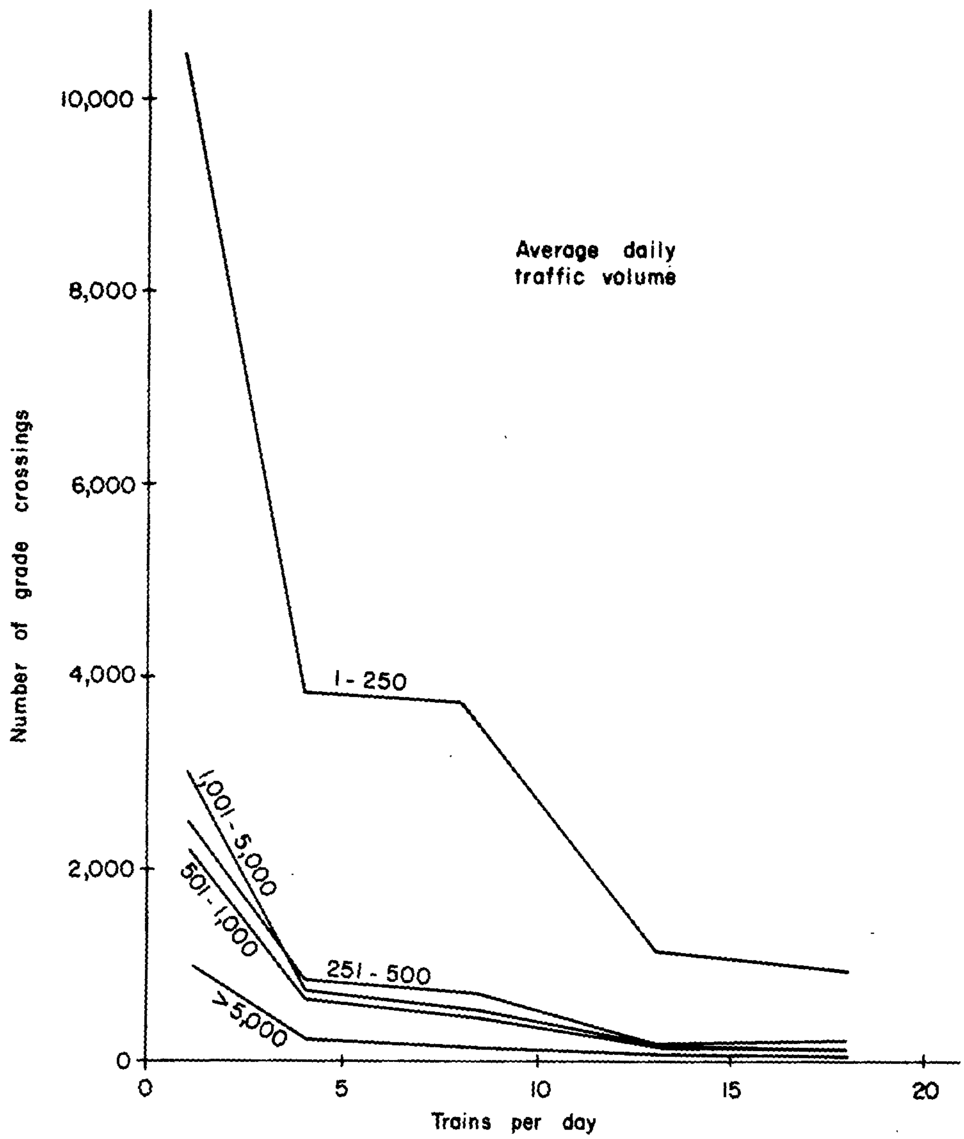

Figure 1. Frequency distribution of grade crossings with reflectorized crossbucks and advance warning signs.

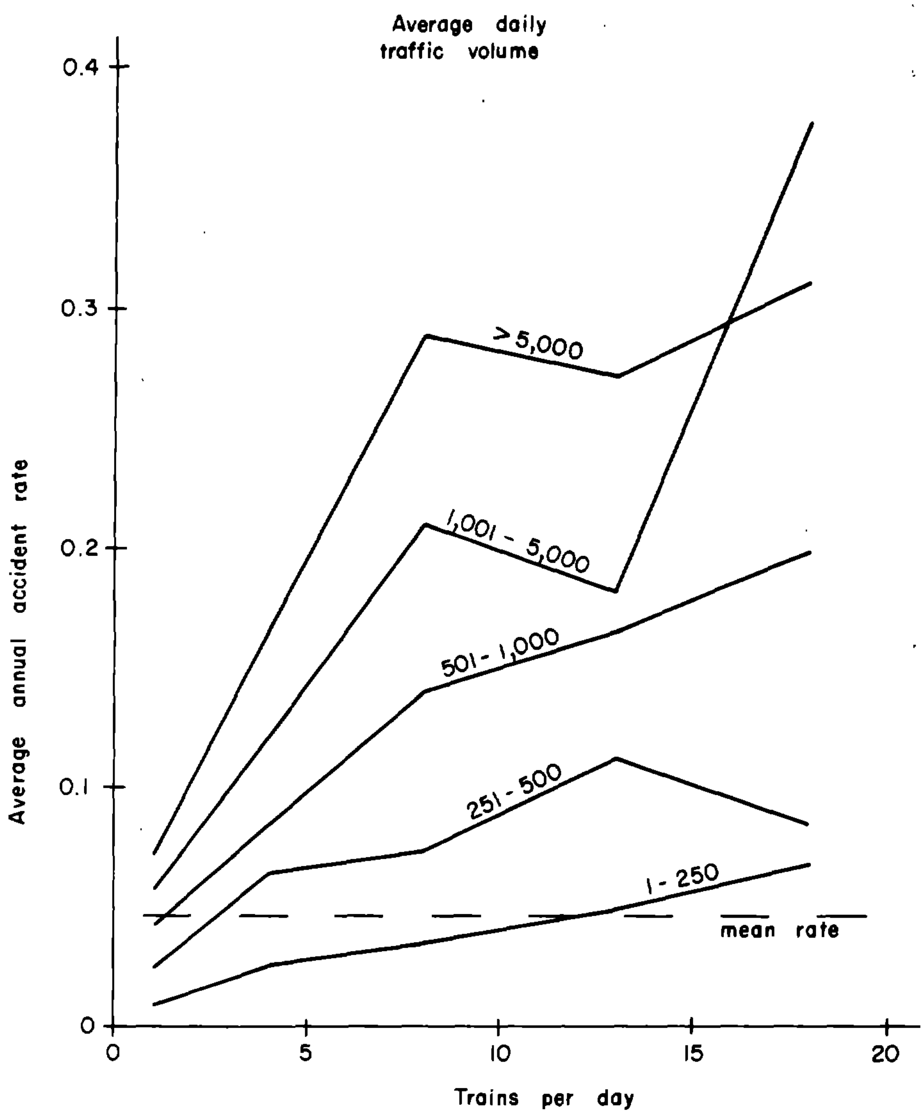

Figure 2. Accident rates at grade crossings with reflectorized crossbucks and advance warning signs.

Table 2. Characteristics of grade crossings with and without advance warning signs.

Location		Warning sign: Yes	Warning sign: No
Rural	Arterial	1,337 0.060	324 0.070
	Collector	8,822 0.050	3,689 0.037
	Local	19,050 0.029	41,232 0.019
	Total	29,209 0.037	45,245 0.021
Urban	Arterial	2,142 0.112	2,110 0.094
	Collector	1,139 0.117	1,879 0.090
	Local	3,595 0.084	11,744 0.052
	Total	6,876 0.098	15,733 0.062

Cell values: number of crossings
average annual accident rate

B. Conceptual Model of Accident Potential

The experimental design was to be structured to detect, if possible, two types of safety benefits:

1. Relatively large accident rate reductions which would occur over a small percentage of grade crossings.

2. Relatively small accident rate reductions which would occur over a large percentage of grade crossings.

Both conditions might produce a significant level of net benefits.

As with any highway environment, grade crossings can be characterized by a large array of descriptive variables. These are often generalized into the broad categories of traffic conditions, roadway design characteristics, and roadside features. The cross-tabulations of grade crossings by average daily train and highway traffic volumes, location, and functional highway classification had revealed that the population of crossings having reflectorized crossbucks tended to be concentrated on low-volume local access roads in rural areas. Therefore, it was necessary to examine the physical characteristics of these crossings more closely as a preliminary step to the formulation of hypotheses regarding which variables might be statistically significant modifiers of accident potential. Those grade crossing characteristics not exhibiting a reasonable distribution of values over the crossing population of interest would not be good candidates for control variables in the experimental design.

Influencing Variables

Extensive descriptive statistics from the national grade crossing inventory file were already available in published form. (7) These data, plus other grade crossing literature, were examined with the purpose of identifying candidate control variables for the experimental design. Those variables considered to be potentially significant modifiers of accident potential at grade crossings having reflectorized crossbucks were:

1. Average trains per day.

2. Average daily highway traffic.

3. Type of roadside development (open space, residential, commercial, industrial, institutional).

4. Maximum train speed.

5. Highway design speed, or speed limit.

6. Type and location of advance warning sign (approach zone versus nonrecovery zone).

7. Highway surface (paved versus unpaved).

8. Adequacy of corner sight distance.

9. Number of traffic control devices and roadside signs along the approach, nonrecovery, and downstream zones.

The sight distance and signing variables listed above are functional derivatives of other basic variables. Figure 2 illustrates the context in which they are measured. The concept of approach, nonrecovery, hazard, and downstream zones is defined from positive guidance principles. (9) The hazard zone is the distance corresponding to the length of the hazard, in this case the grade crossing. The nonrecovery zone is the distance required to execute an avoidance maneuver, or the point beyond which the motorist cannot avoid the hazard unless he resorts to erratic maneuvers. It is numerically equivalent to the minimum stopping sight distance for the roadway design speed. The length of the approach zone is the difference between the decision sight distance and the minimum stopping sight distance as shown in Table 3. (9) The former is defined as the distance at which a driver can detect a hazard in an environment of visual noise or clutter, recognize it, select an appropriate speed and path, and perform the required action safely and efficiently. Grade crossing advance warning signs would normally be placed in the approach zone. The downstream zone is the area used for confirming navigational choices, announcing the end of hazardous conditions, and for locating information carriers to relieve heavy driver attention load.

The adequacy of the available corner sight distance can be expressed as the ratio of the maximum clear corner

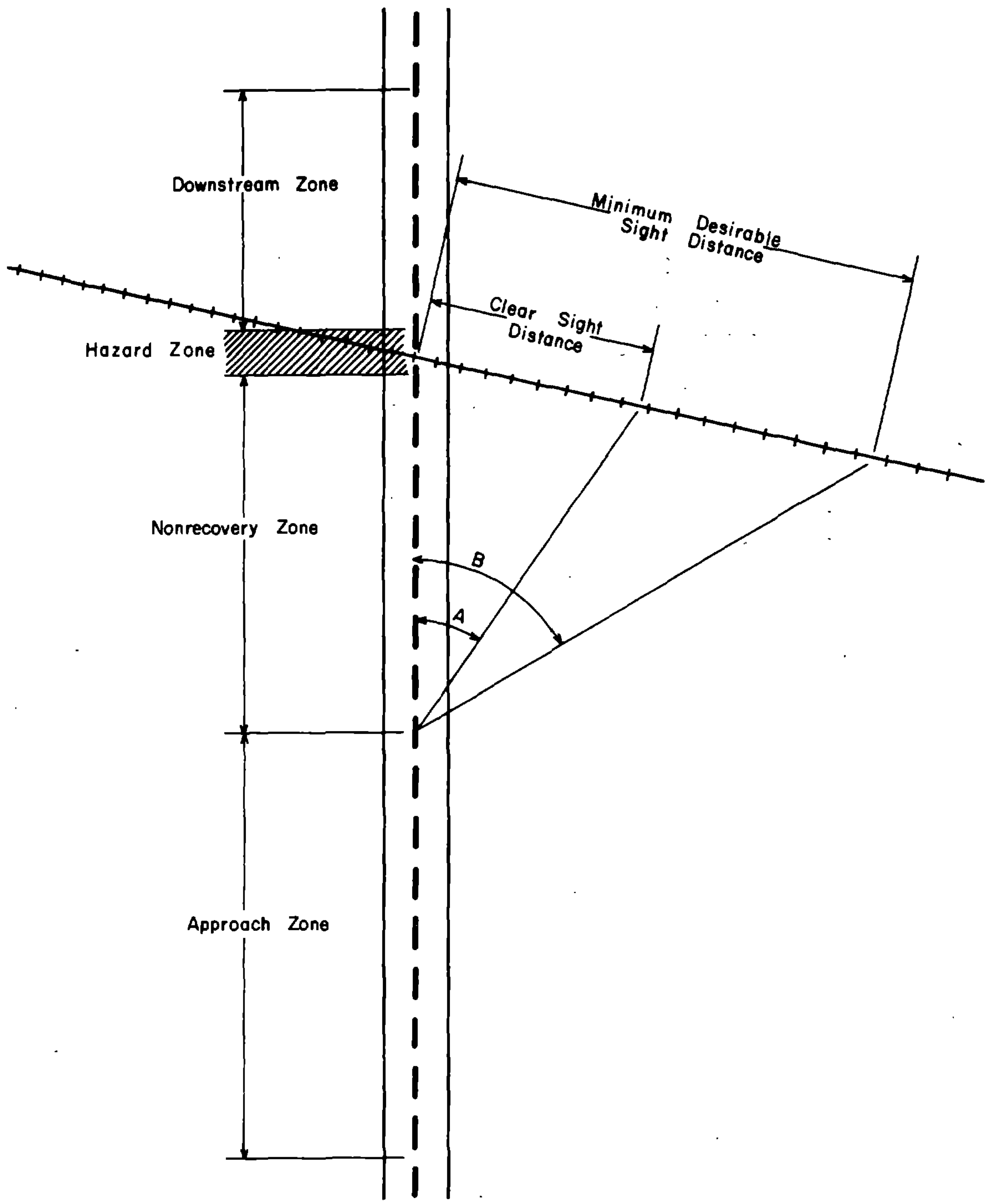

Figure 3. Geometry of information handling zones and corner sight distance parameters.

Table 3. Decision and minimum stopping sight distances.

Design speed		Sight distance			
		Decision		Minimum stopping	
mph	kph	ft	m	ft	m
30	(50)	550	(168)	200	(61)
40	(65)	750	(229)	275	(84)
50	(80)	900	(275)	350	(107)
60	(95)	1,150	(351)	475	(145)
70	(110)	1,300	(397)	600	(183)
80	(130)	1,500	(458)	750	(229)

sight angle (A) to the minimum desirable corner sight angle (B). (10) The former would be obtained from a field observation made at the beginning of the nonrecovery zone. The latter, defined at the same location, is a function of the minimum desirable sight distance along the tracks. The minimum desirable sight distance is the distance which the fastest train would travel during the time required for a vehicle, approaching at the design speed, to traverse the nonrecovery and hazard zones. With this amount of sight distance, a driver at the beginning of the nonrecovery zone would be able to either stop in advance of any approaching train which was in view, or safely clear the crossing in advance of any approaching train which was not in view. (11)

Accident Potential Model

Having identified a set of variables which would be expected to influence grade crossing safety, it was then necessary to structure a set of causal relationships which could be statistically tested. It was hypothesized that the accident and severity rates at grade crossings with reflectorized crossbucks would be causally related to a specific set of basic factors, each of which could be quantitatively or qualitatively measured by one or more of the variables described above. Table 4 presents these assumed relationships.

The accident and severity rate variables can themselves be stratified by grade crossing quadrant. For example, each grade crossing accident is associated with a unique quadrant defined by the approach direction of the involved train and vehicle. Moreover, influencing factors such as available corner sight distance are a function of the specific quadrant being considered. Driver information load and roadside distractions are similarly a function of the specific vehicle approach being considered.

If accident potential was to be defined in terms of the crossing as a single entity, then those variables defined with respect to a single quadrant or vehicular approach would have to be weighted in some reasonable way. The disadvantage of using the quadrant-based measures of accident potential is that the resulting accident and severity rates would be even lower than those observed on a per-crossing basis. This would significantly increase the difficulty of developing a cost-effective experimental design.

Table 4. Hypothesized causal relationships for an accident potential model.

Dependent variable	Influencing factor	Relationship	Independent variable
Accident frequency	Likelihood of train arrivals	Direct	Trains per day
	Frequency of exposure	Direct	Average daily traffic
	Driver information load	Direct	Number of traffic control devices and roadside signs
	Roadside distractions	Direct	Type of roadside development Urban v. rural location
	Available corner sight distance	Inverse	Ratio of clear to minimum desirable sight angles
	Driver familiarity	Inverse	Type of roadside development Highway functional classification
Accident severity	Train velocity	Direct	Maximum train speed
	Vehicle velocity	Direct	Highway speed limit

Because of the measurement problems discussed above, it was determined that the experimental design should use the annual train-involved accident rate on a per-crossing basis as the measure of safety effectiveness. The various levels of the selected influencing factors would serve to define specific grade crossing scenarios, each with a unique set of characteristics. The error associated with the effects of uncontrolled influencing variables would then be accommodated by randomizing the selection of sites within each scenario.

III. STATISTICAL ANALYSIS AND SAMPLING PROCEDURES

Due to the problems associated with temporal changes in traffic patterns and other characteristics at a grade crossing, the principal statistical analysis plan selected for the evaluation of the safety effectiveness of the proposed new advance warning sign was a treatment-control comparison. The treatment group would be randomly chosen by an appropriate procedure from the population of public grade crossings with reflectorized crossbucks and advance warning signs. This analysis would be supplemented by a before-after analysis, but its importance would be secondary because of the potential confounding effect of the temporal variations in certain grade crossing characteristics.

The proposed sampling scheme for these analyses is composed of two parts. First, the selected population of public at-grade crossings with crossbuck warning devices would be divided into k homogeneous sets, each composed of n similar crossings (where n = 2, 3, 4, or 5). Then, from each of the k sets, one of the n crossings would be randomly selected to be in the treatment group, and it would receive the new advance warning sign. All of the other n-1 crossings would be included in the control group.

There are two advantages to this sampling scheme. One, the direct comparison between the treatment crossing and the respective crossings in the control group for each set insures that the comparison is performed among crossings as homogeneous as possible (except for the form of advance warning sign), thereby permitting random fluctuations to be minimized. Two, the k sets of homogeneous grade crossings can later be consolidated into a smaller number of sets, or scenarios. Although each resulting scenario would not be as homogeneous as one of the original sets, it would still be possible to determine if the change in advance warning sign had a statistically significant effect on accident experience. The various scenarios would reflect a cross-classification of the grade crossing population in terms of parameters such as trains per day, average daily traffic, type of roadside development, or adequacy of corner sight distance.

A. Treatment-Control Analyses

The comparison of accident rates between treatment and control sites can be made on the basis of the overall accident rates for the two groups of crossings, or in terms of subsets of crossings having similar characteristics. Both approaches are described below.

Total Crossing Population

It is assumed that a sample data set has been established by randomly selecting k homogeneous sets of n grade crossings each, where one of the n crossings is randomly selected for treatment and the remaining n-1 crossings represent the control sites. Assuming that grade crossing accidents are Poisson distributed, it can be shown (see Appendix A) that using the normal approximation to the Poisson distribution and applying the correction for continuity, the statistic for testing the null hypothesis of no effect is:

$$Z = \frac{\frac{1}{k}\sum_{j=1}^{k}\left[\left(Y_j - \frac{1}{2}\right) - \left(\bar{X}_j + \frac{1}{2(n-1)}\right)\right]}{\sqrt{\frac{\sum_{j=1}^{k}\left[Y_j + (n-1)\bar{X}_j\right]}{(n-1)k^2}}} \tag{1}$$

in which Y_j is the number of accidents at the treatment crossing in set j; and $\bar{X}_j$ is the mean number of accidents for the control crossings in set j. The null hypothesis will be rejected at the 5% significance level if $Z < -1.64$, thereby concluding that the new advance warning sign has a significant effect in reducing the number of grade crossing accidents.

Crossing Subsets

Rather than analyzing all the sample crossings as a group, it may be of interest to examine subsets of crossings, each of which exhibits similar characteristics. The subsets can be identified as scenarios, $s = 1,2,\ldots m$, representing combinations of the k sets of crossings described previously. Assuming that the summations of accidents for the treatment and control crossings within each scenario are Poisson distributed, and applying the correction for continuity, it can be shown (see Appendix A) that the statistic for testing the null hypothesis of no effect is:

$$Z_s = \frac{\left[\bar{Y}_{\cdot s} - \frac{1}{2n_{s1}}\right] - \left[\bar{X}_{\cdot s} + \frac{1}{2n_{s2}}\right]}{\sqrt{\frac{(n_{s1}\,\bar{Y}_{\cdot s} + n_{s2}\,\bar{X}_{\cdot s})}{(n_{s1} + n_{s2})}}\ \sqrt{\frac{1}{n_{s1}} + \frac{1}{n_{s2}}}} \qquad (2)$$

in which $\bar{Y}_{\cdot s}$ is the mean number of accidents per crossing for the treatment group in scenario s; $\bar{X}_{\cdot s}$ is the mean number of accidents per crossing for the control group in scenario s; and n_{sg} is the number of crossings in scenario s, where g = 1 for the treatment group and g = 2 for the control group. Under the null hypothesis, Z_s^2 has a chi-square distribution with one degree of freedom, and $\sum_{g=1}^{m} Z_s^2$ has a chi-square distribution with m degrees of freedom.

The null hypothesis that the accident rates for the treatment and control crossings over all the scenarios are equal will be rejected if the value of $\sum_{s=1}^{m} Z_s^2$ exceeds the critical value in the chi-square table. Furthermore, those scenarios for which there is a statistically significant difference between the accident rates for the treatment and control groups can be identified by examining the respective values of Z_s^2. The sign of Z_s will indicate whether the treatment or the control group has the lower accident rate. If the sign is negative, it can be said that the new advance warning sign provides a statistically significant reduction in the expected accident rate.

The partitioning of accident rates by treatment and control groups and by scenario also offers the opportunity to apply a two-way analysis of variance (ANOVA). However, care must be exercised in such an analysis because the assumption of homogeniety of variances is not fulfilled:

1. In a Poisson distribution, the variance equals the mean. Therefore, the variances in the scenarios having high accident rates will be

greater than those in scenarios with low accident rates.

2. For each scenario, the means in the treatment group are based on a lower number of observations than in the control group (if $n > 2$). Because the variance of means is inversely proportional to the number of observations, this is another source of heteroscedasticity.

Notwithstanding these drawbacks, the computational procedure for the following two-way ANOVA table will be presented.

	Scenario			
	1	2	...	m
Treatment	$\bar{Y}_{\cdot 1}$	$\bar{Y}_{\cdot 2}$		$\bar{Y}_{\cdot m}$
Control	$\bar{X}_{\cdot 1}$	$\bar{X}_{\cdot 2}$		$\bar{X}_{\cdot m}$

Denoting the grand mean by G:

$$SS_{rows} = S\left[(Y_{\cdot\cdot} - G)^2 + (X_{\cdot\cdot} - G)^2\right] \tag{3}$$

$$SS_{columns} = 2\sum_{s=1}^{m}\left[\frac{\bar{Y}_{\cdot s} + \bar{X}_{\cdot s}}{2} - G\right]^2 \tag{4}$$

$$SS_{total} = \sum_{s=1}^{m}\left[\bar{Y}_{\cdot s} - G\right]^2 + \sum_{s=1}^{m}\left[\bar{X}_{\cdot s} - G\right]^2 \tag{5}$$

$$SS_{error} = SS_{total} - SS_{columns} - SS_{rows} \tag{6}$$

The usual analysis of variance can be performed by using:

$$F = \left[\frac{SS_{rows}}{\left(\frac{SS_{error}}{m-1}\right)}\right] \tag{7}$$

which is compared to the critical value of the F-statistic with (1,m-1) degrees of freedom. The row by column design has been extensively studied in the statistical literature, including analysis of residuals, transformations, and multiple comparisons.(13,14) In particular, transformations intended to improve the homogeneity of variances may be useful in this case. If the data are transformed, the variables in Equations 3 through 7 will represent the transformed observations. The need for each of the relatively sophisticated analysis techniques mentioned above can be determined after the sample data set has been collected.

B. Before-After Analyses

A before-after analysis of those crossings selected to receive the new advance warning sign can also give an indication of the potential effectiveness of the sign. However, this type of analysis is subject to a confounding effect due to the possible change in traffic volume and other parameters over time. Therefore, a before-after analysis of the treatment crossings should be complemented by a before-after analysis of the crossings in the control group.

Because the number of accidents at a specific crossing after installation of the new advance warning sign would be highly correlated with the number of accidents at the crossing before the change in signs, a paired comparison analysis is appropriate. However, because of the expected high percentage of zero observations, the normal approximation is inappropriate. Therefore, the nonparametric sign test is recommended.(15) Let:

X_i^B = the number of accidents at crossing i before the change in warning sign

and X_i^A = the number of accidents at crossing i after the change in warning sign

and $$I_i = \begin{cases} 1 & \text{if } X_i^B > X_i^A \\ 0 & \text{if } X_i^B < X_i^A \end{cases}$$

and discard all cases where $X_i^B = X_i^A$. If m is the number of remaining crossings, then under the null hypothesis of no effect, the test statistic:

$$R = \frac{\sum_{i=1}^{m} I_i - \frac{1}{2} - \frac{m}{2}}{\sqrt{\frac{m}{4}}} \qquad (8)$$

is distributed as approximately N(0,1), so that the standard hypothesis test can be performed.

Because $\sum_{i=1}^{m} I_i$ under the null hypothesis has a binomial distribution with parameters (m, 1/2), the exact p-value of the sign test can also be calculated. Thus, if:

$$\sum_{i=1}^{m} I_i = t \tag{9}$$

the probability that $\sum_{i=1}^{n} I_i \geq t$ under the null hypothesis is given by:

$$Pr\left(\sum_{i=1}^{n} I_i \geq t \mid \theta = \frac{1}{2}\right) = \frac{1}{2^m} \sum_{X=t}^{m} \binom{m}{X} \tag{10}$$

which can be computed directly with the aid of tables for the binomial distribution with $\theta = 1/2$.

C. Sampling Requirements

The sample size required for the study depends on the following parameters:

1. The desired power of the test, β.
2. The value of the overall mean accident rate, $\bar{\lambda}$.
3. The expected percentage reduction in accident rate, Δ.

The power is the probability of correctly detecting a change in accident rate, if there is a change.(15) For a fixed mean accident rate, $\bar{\lambda}$, and a fixed percentage accident rate reduction, Δ, the required sample size will vary directly with the requested power. Furthermore, there is a greater likelihood in detecting a change in accident rate when the rate of accidents is high, as opposed to when accidents are a rare event. Finally, it is clear that a larger change is more likely to be detected than a smaller one.

The required sample size for the study was derived assuming that the principal statistical analysis would be the overall comparison of all treatment and control crossings. A larger sample size would be required to achieve the same power for the analysis of crossing scenarios or for the before-after analyses. The proposed sampling scheme is designed to create k homogeneous sets of n crossings, where one crossing will be randomly selected as a treatment site and the remaining n-1 crossings will serve as control sites. Assuming that grade crossing accidents are Poisson distributed, and using the normal approximation to the Poisson distribution, it can be shown (see Appendix A) that the total number of homogeneous sets of n crossings needed to test the null hypothesis that Δ equals zero at the 5% significance level is:

$$k = \left[\Phi^{-1}(\beta) + 1.64\right]^2 \left(\frac{n}{n-1}\right)\left(\frac{1}{\bar{\lambda}\varepsilon^2}\right) \qquad (11)$$

in which $\Phi^{-1}(\beta)$ is the inverse of the standard normal distribution at point β; $\bar{\lambda}$ is the mean accident rate over all sets; and ε is the expected change in accident rate, Δ, expressed as a fraction. The value of $\Phi^{-1}(\beta)$ can be easily determined from a table of the cumulative standard normal distribution as the value of the standard variate which yields a cumulative probability of β.

The total number of sets, k, of one treatment and n-1 control crossings is in effect the desired sample size. The sample size can be seen to:

1. Increase with the desired power, β.
2. Decrease with the level of the overall mean accident rate, $\bar{\lambda}$.
3. Decrease with the square of the change in accident rate, ε.
4. Decrease slightly with the size of the sets, n.

IV. ALTERNATIVE SAMPLING FRAMEWORKS

Early in the development of the experimental design it had been determined that the testing of the new advance warning sign was to be confined to those public grade crossings presently having reflectorized crossbucks and standard advance warning signs. Because it was known that a relatively large sample size would probably be required, several alternative sampling frameworks were initially developed to determine which might offer the most efficient design in terms of required sample size.

To determine a required sample size using Equation 11, it was first necessary to select the desired power of the test, β, and the percent change in accident rate to be detected, Δ. The overall mean accident rate, $\bar{\lambda}$, would be a function of the grade crossing population to be sampled and the length of the study period in years. The size, n, of each of the k homogeneous sets of crossings could be systematically varied to determine which value would minimize the number of required treatment sites, and which would minimize the total number of treatment plus control sites. The preferred number of crossings per set would depend on the unit cost of installing the new sign at the treatment sites versus the unit cost to collect needed field data at all treatment and control sites.

A. Rural and Urban Grade Crossings

The first sampling framework to be considered was the total nationwide population of 36,104 rural and urban grade crossings having reflectorized crossbucks and standard advance warning signs as of 1976. From Table 1, the overall mean accident rate, $\bar{\lambda}$, was noted to be 0.049 accidents per crossing per year. Three- and five-year expected accident rates were then calculated to reflect the expected mean accident rates for a three-year and a five-year study. The relative change in accident rate to be detected was varied from 5 to 20 percent. The resulting required sample sizes are shown in Table 5 for a 50 percent and 80 percent power of the test, and for various ratios of the number of treatment to the number of control sites.

The results indicate that to be 50 percent confident of detecting an actual 5 percent reduction in accident rate over a three-year study period, it would be necessary

Table 5. Sample size requirements: total population of rural and urban grade crossings with reflectorized crossbucks and advance warning signs.

Power of Test	Years of Data	Acc. Rate Change (%)	Number Grade Crossings to be Sampled							
			n = 2		n = 3		n = 4		n = 5	
			Treat-ment	Control	Treat-ment	Control	Treat-ment	Control	Treat-ment	Control
0.5	3	5	14,788	14,788	11,091	22,182	-[a]	-	-	-
		10	3,698	3,698	2,773	5,546	2,459	7,376	2,310	9,243
		20	924	924	693	1,386	615	1,844	578	2,311
	5	5	8,873	8,873	6,655	13,309	5,900	17,701	5,546	22,182
		10	2,218	2,218	1,664	3,327	1,475	4,425	1,386	5,546
		20	555	555	416	832	369	1,106	347	1,386
0.8	3	5	-	-	-	-	-	-	-	-
		10	8,454	8,454	6,341	12,681	5,622	16,866	5,284	21,135
		20	2,114	2,114	1,585	3,170	1,406	4,217	1,321	5,284
	5	5	-	-	-	-	-	-	-	-
		10	5,072	5,072	3,804	7,609	3,373	10,120	3,170	12,681
		20	1,268	1,268	951	1,902	843	2,530	793	3,170

(a) A missing number indicates that the sample size exceeds the population size.

to select almost 15,000 treatment and 15,000 control sites. The required number of treatment sites could be reduced to approximately 11,000 if desired, but the number of control sites would then have to be increased to a little more than 22,000. Thus by decreasing the ratio of treatment to control sites from 1:1 to 1:2, the total number or required sites would increase from approximately 30,000 to 33,000. Of greater significance, however, is the fact that both sample sizes nearly equal the total population of 36,104 grade crossings. If the ratio of treatment to control crossings were to be reduced any further, the total required sample size would exceed the population size.

Nevertheless, the very large sample sizes noted above could be substantially reduced if either a five-year study period was selected, or if the percent change in accident rate to be detected was to be increased. A five-year study period might not be unreasonable, although the study costs would be greater, and significant variations in certain influencing factors such as train and traffic volumes would be expected to occur in some instances.

The reasonability of only being able to statistically detect accident reductions greater than or equal to 10 or 20 percent is certainly questionable. The fact that the recently completed passive signing study was only able to find a 5 percent increase in driver head movement with the new advance warning sign suggests that this might also be an upper limit on any corresponding accident rate reduction which could be achieved. The 25-member Advisory Committee to that study in fact expressed the general belief that the relative increase in looking for trains as measured by driver head movements would significantly exceed the potential reduction in vehicle-train accidents.(16)

If the power of the test were to be increased to 80 percent as a means of reducing the likelihood of not statistically detecting an actual reduction in the accident rate, then as shown in Table 5 the sample size requirements would again increase substantially. Moreover, even for a relatively long five-year data collection period, the number of available grade crossings is insufficient to meet the sampling requirements for detecting as much as a 5 percent reduction in accident rate.

B. Urban Grade Crossings

Because the required sample size varies directly with the overall mean accident rate, other grade crossing stratifications with higher mean accident rates were considered. One of these was the total nationwide set of 6,876 urban grade crossings with reflectorized crossbucks and advance warning signs. The mean accident rate for these crossings is 0.098 accidents per crossing per year. As shown in Table 6, the resulting pattern of sample size requirements is less than one-half as demanding as that based on the population of all 36,104 rural and urban grade crossings having reflectorized crossbucks and advance warning signs. Nevertheless, because the number of urban grade crossings constitutes only about one-fifth of the total population, there would actually be a decline in the ability to statistically detect possible accident rate reductions. Therefore, the use of urban grade crossings as the principal experimental data base was dropped from further consideration.

C. High Exposure Rural Grade Crossings

A third sampling stratification to receive consideration was the total nationwide set of 3,258 rural grade crossings with reflectorized crossbucks, advance warning signs, an average daily traffic volume greater than 250 vehicles, and 3 or more trains per day. The overall mean accident rate for these crossings is 0.117 accidents per crossing per year, almost 2.5 times greater than that for the total set of 36,104 grade crossings.

Once again, however, the effect of the smaller number of available sites more than offsets the potential leverage provided by the higher expected accident rate. As shown in Table 7, where sufficient sites are available, the required sample size is significantly less than the corresponding requirement found in Table 5. Nevertheless, it would generally not be possible to statistically detect accident rate reductions as large as 5 percent because the required sample size exceeds the population of available sites.

Table 6. Sample size requirements: total population of urban grade crossings with reflectorized crossbucks and advance warning signs.

Power of Test	Years of Data	Acc. Rate Change (%)	Number Grade Crossings to be Sampled: n = 2, Treatment	n = 2, Control	n = 3, Treatment	n = 3, Control	n = 4, Treatment	n = 4, Control	n = 5, Treatment	n = 5, Control
0.5	3	5	-(a)	-	-	-	-	-	-	-
		10	1,829	1,829	1,372	2,744	1,217	3,650	1,144	4,574
		20	457	457	343	686	304	913	286	1,144
	5	5	-	-	-	-	-	-	-	-
		10	1,098	1,098	823	1,647	730	2,190	686	2,744
		20	274	274	206	412	183	548	172	686
0.8	3	5	-	-	-	-	-	-	-	-
		10	-	-	-	-	-	-	-	-
		20	1,046	1,046	784	1,569	696	2,087	654	2,615
	5	5	-	-	-	-	-	-	-	-
		10	2,510	2,510	1,883	3,766	1,669	5,008	-	-
		20	628	628	471	941	417	1,252	392	1,569

(a) A missing number indicates that the sample size exceeds the population size.

Table 7. Required sample size: rural grade crossings with reflectorized crossbucks, advance warning signs, ADT > 250, and TPD > 2.

			Number of Grade Crossings to be Sampled							
			n = 2		n = 3		n = 4		n = 5	
Power of Test	Years of Data	Acc. Rate Change (%)	Treatment	Control	Treatment	Control	Treatment	Control	Treatment	Control
0.5	3	5	-(a)	-	-	-	-	-	-	-
		10	1,533	1,533	-	-	-	-	-	-
		20	383	383	287	575	255	764	239	958
	5	5	-	-	-	-	-	-	-	-
		10	919	919	690	1,379	611	1,834	575	2,299
		20	230	230	172	345	153	459	144	575
0.8	3	5	-	-	-	-	-	-	-	-
		10	-	-	-	-	-	-	-	-
		20	876	876	657	1,314	583	1,748	548	2,190
	5	5	-	-	-	-	-	-	-	-
		10	-	-	-	-	-	-	-	-
		20	526	526	394	789	350	1,049	329	1,314

(a) A missing number indicates that the sample size exceeds the population size.

V. DECISION-MAKING REQUIREMENTS

Because of the very large sample sizes associated with the alternative sampling frameworks, it was conceivable that no experimental design would be statistically sensitive to small relative changes in accident rate, be feasible in terms of site availability, and also be economically practical in terms of study costs. Therefore, an analysis was undertaken to determine the minimum relative reduction in accident rate which would economically justify deployment of the new advance warning sign. This would constitute the smallest accident reduction which the experimental design should be capable of detecting.

A. Economic Decision Model

The first step in the analysis was the formulation of an economic decision model which could be used to evaluate the trade-off between expected safety benefits, and the costs of replacing existing advance warning signs. A net present value criterion was selected for the model. (17, 18) Net present value can be expressed as:

$$NPV = PVB - PVC \tag{12}$$

in which PVB is the present dollar value of a time stream of benefits and PVC is the present dollar value of costs over the same time period. If the NPV of an investment alternative is greater than zero, then that investment is considered to be economically feasible. When comparing mutually exclusive alternatives, each with a positive NPV, that alternative with the highest NPV is preferred.

For the purposes of this study, the present value of benefits, PVB, was defined as the present dollar value of future accident rate reductions attributable to the installation of the proposed new advance warning sign at all grade crossings presently equipped with reflectorized crossbucks and standard advance warning signs. The present value of costs, PVC, was defined as the present dollar value of the differential costs associated with deploying and maintaining the proposed new advance warning sign at all grade crossings presently equipped with reflectorized crossbucks and standard advance warning signs. The benefits and costs associated with installing advance warning signs where none had previously existed were not considered because it was assumed that any increase in safety benefits at such crossings would be primarily attributable to the presence of an advance warning, not its design. Furthermore, the only cost differential associated with a new installation would be in the materials cost of the new versus the standard advance warning sign, and this would constitute a small fraction of the total sign installation cost.

Both the benefits and costs of deploying the proposed new advance warning sign would be a function of the deployment policy itself. Two alternative policies were considered:

1. Replace all existing advance warning signs at one time.

2. Replace existing advance warning signs at their normal replacement interval, or on an as-needed basis.

For an immediate replacement policy, the present value of benefits can be expressed as:

$$PVB = (AAR)(\Delta)(AC)(N)(SPW_{i,n}) \tag{13}$$

in which AAR is the present average annual accident rate per crossing; Δ is the percent reduction in the accident rate, AAR, due to the increased effectiveness of the new advance warning sign; AC is the average dollar cost of a grade crossing accident; N is the number of grade crossings at which the standard advance warning signs are replaced; and $SPW_{i,n}$ is the series present worth factor for a discount rate of i percent and an analysis period of n years. The present value of costs can be expressed as:

$$PVC = 2N\left[(\Delta C+LC+MC) + \frac{\Delta C}{m^2}(GPW_{i,m}) + \frac{\Delta C}{m}(SPW_{i,n-m})(PW_{i,m})\right] \tag{14}$$

in which ΔC is the dollar materials cost differential between the standard two-color advance warning sign and the proposed three-color sign; LC is the dollar labor cost for installing a new sign on an existing post; MC is the dollar mileage cost per sign for the truck used by the field crew; m is the average life of an advance warning sign in years; $GPW_{i,m}$ is the uniform gradient present worth factor for a discount rate of i percent over m years; $SPW_{i,n-m}$ is the series present worth factor for a discount rate of i percent over n-m years; and $PW_{i,m}$ is the present worth factor for a discount rate of i percent over m years.

For an as-needed sign replacement policy, it was assumed that grade crossings would receive the new sign at a uniform rate such that after m years (the expected life of an advance warning sign), all grade crossings presently equipped with standard signs would have received the new sign. The present value of benefits for this deployment policy can be expressed as:

$$PVB = \left[(AAR)(\Delta)(AC)\ \frac{N}{m}\ (GPW_{i,m}) \right] + \left[(AAR)(\Delta)(AC)(N)(SPW_{i,n-m})(PW_{i,m}) \right] \qquad (15)$$

with the present value of costs expressed as:

$$PVC = 2\left[(\frac{N}{m})(\Delta C)(SPW_{i,n}) \right] \qquad (16)$$

in which all variables are as previously defined. It should be noted that the analysis period is assumed to exceed the average economic life of an advance warning sign.

B. Trade-Off Analysis

The specification of the minimum relative change in accident rate which the experimental design should be capable of statistically detecting was examined by applying the economic decision model and determining the relative accident rate reduction, Δ, which would yield a net present value of zero. Any reduction in accident rate smaller than this value would be insufficient to economically justify deployment of the proposed new advance warning sign. Any accident rate reduction larger than this value would mean that deployment of the new sign could be economically justified. Thus it would be important to be able to detect accident rate reductions as small as the critical value found at the breakeven point.

The first step in the trade-off analysis was the derivation of typical values for the variables appearing in the economic decision model (see Appendix B). Using the resulting values shown in Table 8, upper and lower limits of the critical accident rate reduction were

Table 8. Input data for breakeven analysis.

Variable	Typical values
Average grade crossing accident cost, AC	\$60,000-\$75,000
Unit sign materials cost differential, C	\$1 - \$ 3
Unit labor cost for sign installation, LC	\$9 - \$12
Unit mileage cost for sign installation, MC	\$5 - \$ 8
Average useful sign life, m	7 years

computed for each alternative sign deployment policy for a 20-year analysis period and a four-percent discount rate. The four-percent discount rate represents only the real cost of capital, with no allowance for expected inflations. This approach is recommended when present values are calculated in constant dollars. (18) The grade crossing population used in this analysis was the 1976 nationwide total of 36,104 crossings having reflectorized crossbucks and standard advance warning signs. The results of these computations are presented in Table 9 below.

Table 9. Results of breakeven analysis.

Sign deployment policy	Critical accident rate reduction, Δ	
	Upper limit	Lower limit
Immediate replacement of all signs	0.14%	0.07%
As-needed replacement	0.04%	0.01%

The findings presented in Table 9 reveal that the proposed new advance warning sign, when deployed at those grade crossings presently having reflectorized crossbucks and standard advance warning signs, could be economically justified even if it only yielded on the order of a hundredth of a percent reduction in the average per crossing accident rate. This is equivalent to a reduction of about one grade crossing accident every five to six years over the total population of 36,104 grade crossings. These results clearly suggest that it might be both experimentally and economically impractical to attempt to determine if the actual safety effectiveness of the new advance warning sign would justify its deployment on a nationwide basis.

VI. COST EVALUATION

The cost of undertaking the field studies and analyses necessary to experimentally measure the accident reduction potential of the proposed new advance warning sign was an important consideration in the selection of an appropriate sampling plan. The alternative sampling frameworks described in Chapter IV incorporated an optional ratio of the number of treatment to control sites. The most appropriate ratio would depend upon the relative cost of installing the new advance warning sign at the treatment sites, versus the cost of collecting needed field data on the physical characteristics of each treatment plus control site. Furthermore, it was important to know the total expected cost of the accident study so that it might be compared to the expected value or utility of the information to be derived from the study. These evaluations would then permit a reasonable judgment to be made regarding a recommended experimental design.

A. Accident Study Costs

Typical accident study costs were developed by formulating cost models for each study task. It was assumed that four basic tasks would be required: Site Selection, Preparation of Treatment Sites, Data Processing, and Data Analysis and Evaluation.

The Site Selection task would involve three steps. First, a list of candidate treatment and control sites would be generated from the national grade crossing inventory file. Sites would then be randomly selected and visited by personnel from cooperating state highway agencies to assure compliance with the requirements of the sampling plan. The last step would be the collection of supplementary field data at the time each selected treatment and control site was inspected for compliance. These data would include the proposed corner sight distance, speed limit, and driver information load variables. The cost model formulated for this task is:

$$C_1 = \frac{N_T}{n}\left[(m)(MR) + TC\right] \qquad (17)$$

in which N_T is the total number of treatment and control sites in the experimental design; n is the number of sites visited per day; m is the mileage logged per day; MR is the vehicle mileage rate in dollars per mile; and TC is the time and per diem cost for a traffic engineering technician in dollars per day.

The second task, Preparation of Treatment Sites, would involve the installation of the new advance warning sign at each selected treatment location. Logistically, it was expected that this task would be undertaken by state highway agency maintenance crews. The cost model formulated for this task is:

$$C_2 = 2\ N_t(SC+LC+MC) \tag{18}$$

in which N_t is the total number of treatment sites in the experimental design; SC is the dollar cost of modifying each in-place standard advance warning sign; LC is the dollar labor cost for installation of the experimental sign; and MC is the dollar mileage cost per sign for the truck used by the field crew.

The third task in the accident study, Data Processing, would involve monitoring Highway Grade Crossing Incident Report forms as they are received from the railroads, and updating the site inventory file in response to any updates to the national grade crossing inventory file. The cost for this activity can be expressed as:

$$C_3 = hts \tag{19}$$

in which h is the mean number of man-hours required per year; t is the length of the accident study in years; and s is the dollar per hour salary scale, including administrative costs, for support-level personnel.

The final work task in the accident study, Data Analysis and Evaluation, would involve performing the appropriate statistical analyses and cost-effectiveness evaluations, and preparing a final study report. This task would be undertaken by professional-level staff, with the cost estimated as:

$$C_4 = yd \tag{20}$$

in which y is the number of man-years of effort; and d is the total dollar cost per man-year, including administrative costs.

Using typical cost data, parameter values for the four task cost models were specified (see Appendix B). The summation of these models constitutes the accident study cost model, and is expressed as:

$$C_T = 17N_T + 40N_t + 4400t + 30,000 \quad (21)$$

where C_T is the expected dollar cost of the accident study; N_T is the total number of treatment and control sites; N_t is the number of treatment sites; and t is the length of the data collection period in years. This model was then used to estimate the cost of undertaking each alternative experimental design identified in Tables 5 and 7.

Each experimental design alternative is specified in terms of the power of the test, the length of the data collection period, the expected percent change in accident rate, and the required number of treatment and control sites. Table 10 presents the estimated study costs for the most cost-efficient designs within the two basic sampling frameworks. The data reveal that the cost of conducting an accident study would increase significantly as the expected accident rate reduction decreases, the power of the test increases, and the data collection period decreases.

B. Value of Information

In the two-stage process of selecting the most appropriate experimental design and then determining if it should actually be undertaken, an important consideration is the trade-off between the value of the information to be derived and the estimated cost of obtaining that information. In the case of the safety effectiveness of the proposed new advance warning sign, this trade-off can be examined in two ways. First, the smallest accident rate reduction which is likely to be statistically detectable can be compared with the lowest rate that would economically justify the nationwide application of the new sign. Second, the cost of undertaking the accident study can be compared with the cost of deploying the new sign nationwide.

Figures 4 and 5 illustrate the trade-off between expected accident rate reduction, required sample size, and the accident rate reduction associated with the economic breakeven point for justifying deployment of the new

Table 10. Estimated accident study costs.

Sampling population	Expected accident change (%)	Power of test	Years of data	Sample size		Study cost ($\$ \times 10^3$)
				Treatment	Control	
36,104 rural and urban crossings	5	0.5	3	11,091	22,182	1,050
			5	6,655	13,309	660
	10	0.8	3	6,341	12,681	620
			5	3,804	7,609	400
3,258 high exposure rural crossings	10	0.5	3	1,533	1,533	160
			5	690	1,379	120

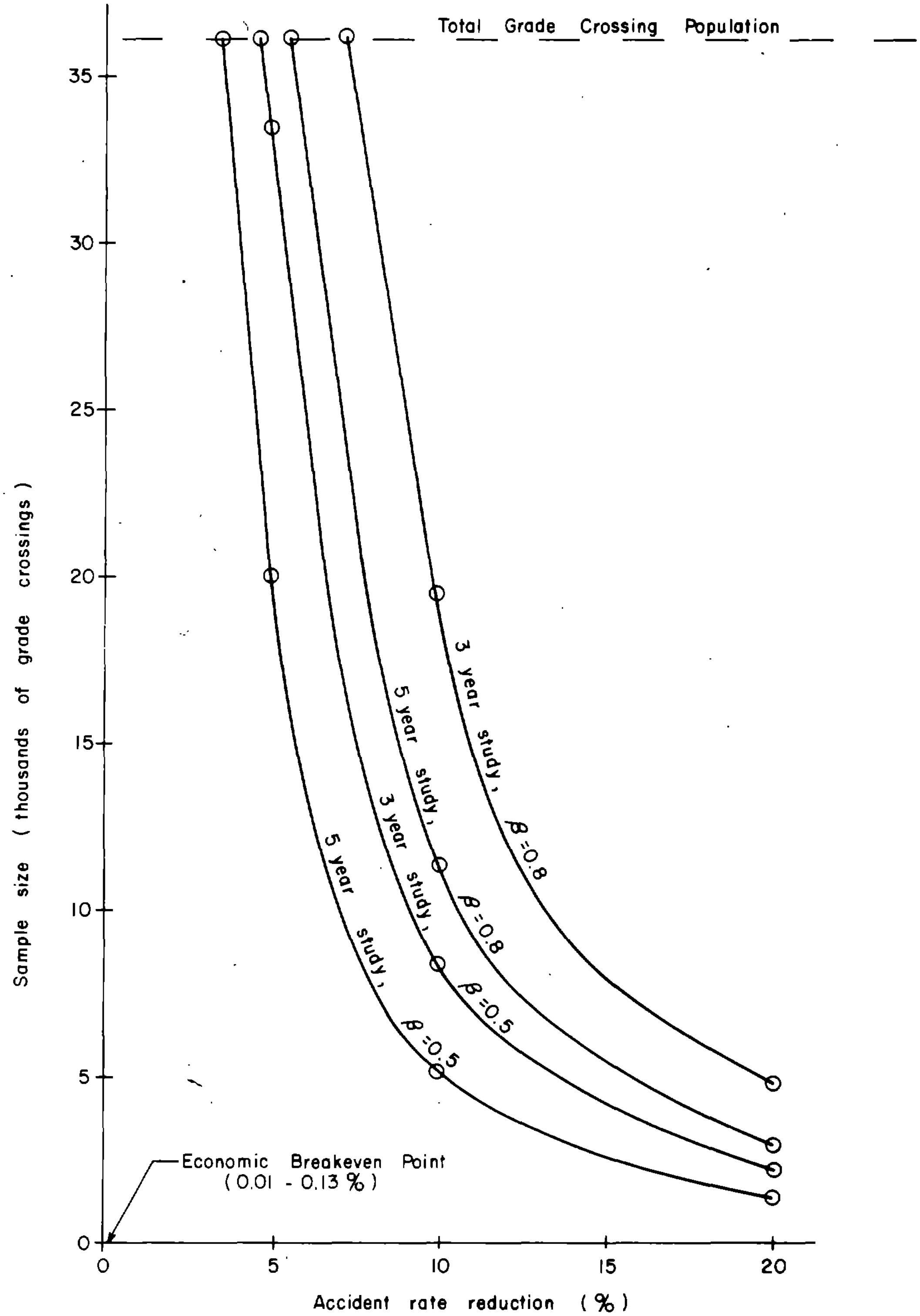

Figure 4. Sample size requirements: total nationwide population of rural and urban grade crossings with reflectorized crossbucks and advance warning signs.

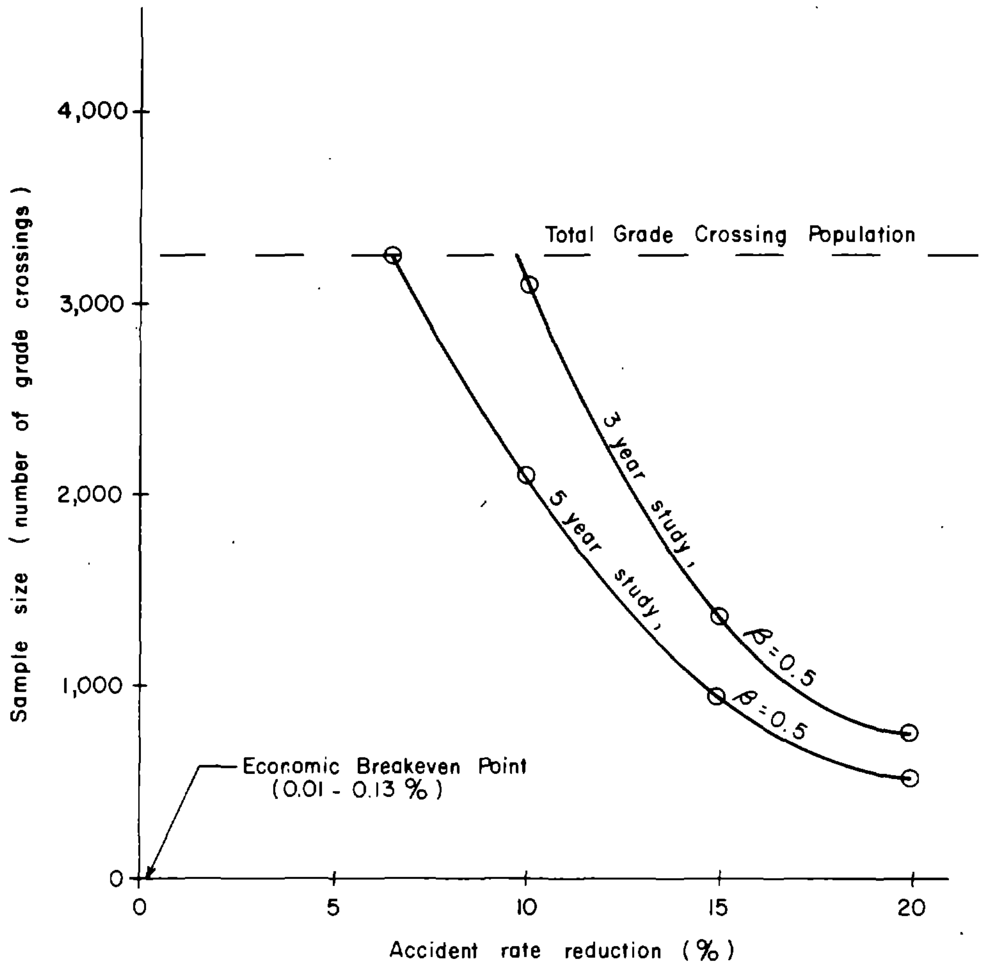

Figure 5. Sample size requirements: high-exposure rural grade crossings with reflectorized crossbucks and advance warning signs.

advance warning sign. It is clear that none of the alternative experimental designs can be expected to provide the information necessary to establish whether the potential safety benefits of the new sign would exceed the total cost of nationwide deployment. Even with a five-year data collection period and accepting only a 50-percent likelihood of detecting a true reduction in accident rate, the sample size requirements would significantly exceed the total population of grade crossings that could be selected for experimentation.

Figure 6 illustrates the trade-off between the cost of undertaking the most cost-efficient experimental design alternatives, versus the initial cost of deploying the new advance warning sign at all 36,104 rural and urban grade crossings presently equipped with both reflectorized cross-bucks and standard advance warning signs. The data which are presented reveal that study cost varies over a wide range, and that the cost of four of the six alternative experimental designs would significantly exceed the total initial cost of deploying the new sign on an as-needed basis over a seven-year period. Moreover, these study costs fall within approximately 30 to 75 percent of the total initial cost of an immediate sign replacement policy. Of the six alternative experimental designs, only the two which are based on sampling from high-exposure rural crossings would appear to be within the range of economic practicality. However, neither of these designs would provide sufficient data to determine whether or not the proposed advance warning sign would produce the accident rate reduction necessary to justify its deployment.

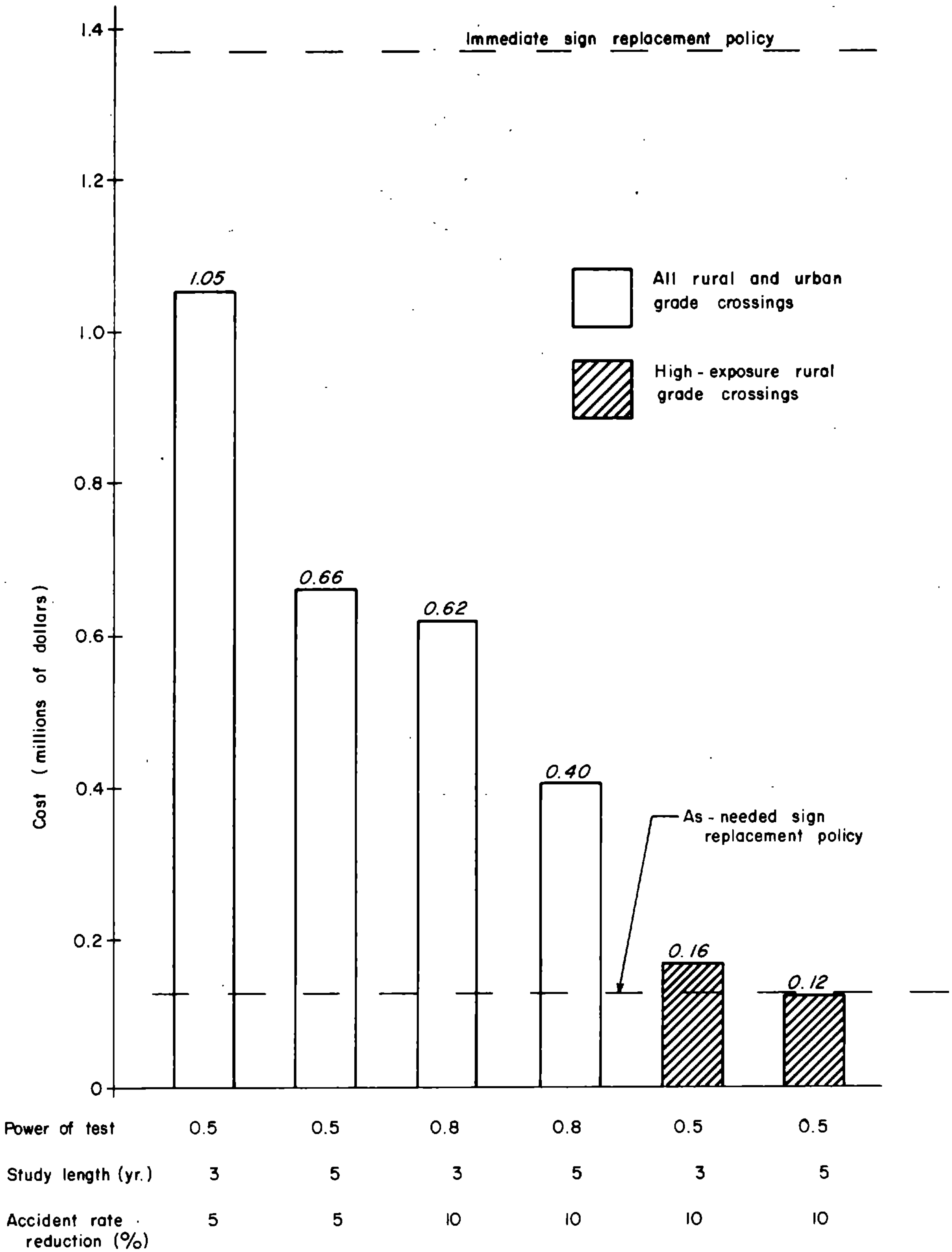

Figure 6. Comparison of accident study costs versus initial sign deployment costs.

VII. CONCLUSIONS AND RECOMMENDATIONS

The results of this study to develop an experimental design for evaluating the accident reduction potential of the proposed new grade crossing advance warning sign strongly support the conclusion that the conduct of such a field study would be both experimentally and economically impractical. The findings from the evaluation of decision-making requirements, and the comparison of the cost versus the value of the information expected from the proposed study indicate that:

1. The sample sizes necessary to detect the minimum percent accident reduction that would economically justify deployment of the new sign significantly exceed the population of available sites.

2. The estimated cost of conducting even the most cost-efficient study designs would equal or exceed the approximate total cost of deploying the new sign on an as-needed basis over a seven-year period.

3. No study design is likely to reveal a statistically significant accident reduction if in fact there was one.

These conclusions suggest that several policy options are available regarding proposals to establish the new advance warning sign as a national standard:

1. Take no further action of any type.

2. Undertake a study to experimentally measure the accident reduction potential of the new sign.

3. Undertake further study of the potential safety effectiveness of the new sign using alternative measures of effectiveness such as the frequency with which drivers look for trains.

4. Approve the use of the new sign by state and local highway agencies on an as-needed basis.

It is recommended that the first two policy options be disregarded. Previous research has demonstrated that the proposed new advance warning sign may provide increased, although unmeasured, safety benefits to the motoring public. Yet it has also been shown by this study that new research specifically designed to measure potential reductions in the grade crossing accident rate would be both experimentally and economically impractical.

Therefore, it is recommended that the latter two policy options constitute the most realistic choices facing the traffic safety community. If additional studies using alternative measures of safety effectiveness are to be undertaken, it is recommended that they incorporate the influencing variables and range of grade crossing exposure levels used in the experimental designs which were considered in this study. On the other hand, if the proposed sign were to receive approval as a national standard based on the results of this study, it would imply that the traffic safety community believes the new sign has, at a minimum, the potential for offering a marginal improvement in effectiveness compared to the current standard sign. Moreover, such a marginal improvement is all that would be required to economically justify the change in standard.

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APPENDIX A

DERIVATION OF STATISTICAL RELATIONSHIPS

The derivation of the statistical relationships for conducting hypothesis tests and determining sample size requirements ar ented below.

A. Hypothesis Tests for Treatment-Control Analyses

Total Crossing Population

The proposed sampling scheme for the accident study will create k homogeneous sets of n crossings, where one crossing will be randomly selected as a treatment site and the remaining n-1 crossings will serve as control sites. Assuming that grade crossing accidents are Poisson distributed, let:

Y_j = the observed number of accidents at the treatment crossing in set j, $j = 1,2,\ldots k$

and X_{ij} = the observed number of accidents at control crossing i in set j, $i = 1,2,\ldots n-1$, and $j = 1,2,\ldots k$

Under the null hypothesis of no accident reduction due to the new advance warning sign, assume that:

$$Y_j \sim P(\lambda_j)$$

and

$$X_{ij} \sim P(\lambda_j)$$

Namely, the number of accidents at all the crossings in set j are Poisson distributed with parameter λ_j.

For set j, the difference in accidents per crossing is expressed as:

$$D_j = Y_j - \frac{\sum_{i=1}^{n-1} X_{ij}}{n-1} = Y_j - \bar{X}_j \qquad (22)$$

For all k sets, the overall difference is:

$$\bar{D} = \sum_{j=1}^{k} \left[\frac{Y_j - \bar{X}_j}{k} \right] \tag{23}$$

Under the null hypothesis, D_j has a zero mean and variance:

$$V(D_j) = \lambda_j \left[\frac{n}{n-1} \right] \tag{24}$$

while $\bar{D}$ has a zero mean and variance:

$$V(\bar{D}) = \frac{1}{k^2} \sum_{j=1}^{k} \lambda_j \left[\frac{n}{n-1} \right] = \frac{n}{(n-1)k} \sum_{j=1}^{k} \left[\frac{\lambda_j}{k} \right] \tag{25}$$

The mean accident rate over all sets j is:

$$\bar{\lambda} = \sum_{j=1}^{k} \left[\frac{\lambda_j}{k} \right] \tag{26}$$

therefore,

$$V(\bar{D}) = \frac{n\bar{\lambda}}{(n-1)k} \tag{27}$$

Using the normal approximation to the Poisson distribution, the statistic for testing the null hypothesis is then:

$$R = \frac{\sum_{j=1}^{k} \left[\frac{Y_j - \bar{X}_j}{k} \right]}{\sqrt{\frac{n\bar{\lambda}}{(n-1)k}}} \tag{28}$$

which is approximately distributed N(0,1) under the null hypothesis. If the correction for continuity for the Poisson distribution is applied, and the overall mean accident rate, $\bar{\lambda}$, is estimated by:

$$\overline{\lambda} = \sum_{j=1}^{k} \left[\frac{Y_j + \sum_{i=1}^{n-1} X_{ij}}{nk} \right] \tag{29}$$

then the statistic for testing the null hypothesis becomes:

$$Z = \frac{\frac{1}{k} \sum_{j=1}^{k} \left[\left(Y_j - \frac{1}{2} \right) - \left(\overline{X}_j + \frac{1}{2(n-1)} \right) \right]}{\sqrt{\frac{\sum_{j=1}^{k} [Y_j + (n-1)\overline{X}_j]}{(n-1)k^2}}} \tag{30}$$

where Y_j is the number of accidents at the treatment crossing in set j, and $\overline{X}_j$ is the mean number of accidents for the control crossings in set j. The null hypothesis will be rejected at the 5% significance level if $Z < -1.64$, thereby concluding that the new advance warning sign has a significant effect in reducing the number of grade crossing accidents.

Crossing Subsets

Rather than analyzing all the sample crossings as a group, it may be of interest to examine subsets of crossings, each of which exhibits similar characteristics. The subsets can be identified as scenarios, s = 1,2,...m, representing combinations of the k sets of crossings described previously. Let:

Y_{is} = the number of accidents for crossing i in the treatment group of scenario s

and X_{is} = the number of accidents for crossing i in the control group of scenario s

and n_{sg} = the number of crossings in scenario s, where g = 1 for the treatment group and g = 2 for the control group.

Then a two-way ANOVA table can be constructed as follows.

	SCENARIO			
	1	2	...	m
Treatment	Y_{11}	Y_{12}		Y_{1m}
	$\vdots$	$\vdots$		$\vdots$
	$Y_{(n_{11})1}$	$Y_{(n_{21})2}$		$Y_{(n_{m1})m}$
Control	X_{11}	X_{12}		X_{1m}
	$\vdots$	$\vdots$		$\vdots$
	$X_{(n_{12})1}$	$X_{(n_{22})2}$		$X_{(n_{m2})m}$

The mean for each cell of this table can be computed as:

$$\bar{Y}_{\cdot s} = \sum_{i=1}^{n_{s1}} \left[\frac{Y_{is}}{n_{s1}} \right] \tag{31}$$

or

$$\bar{X}_{\cdot s} = \sum_{i=1}^{n_{s2}} \left[\frac{X_{is}}{n_{s2}} \right] \tag{32}$$

with the resulting ANOVA table being:

	SCENARIO			
	1	2	...	m
Treatment	$\bar{Y}_{\cdot 1}$	$\bar{Y}_{\cdot 2}$		$\bar{Y}_{\cdot m}$
Control	$\bar{X}_{\cdot 1}$	$\bar{X}_{\cdot 2}$		$\bar{X}_{\cdot m}$

Because the number of accidents, X_{ij} and Y_{ij} were assumed to be Poisson distributed, so are the summations of accidents for the treatment and control crossings within each scenario. Letting $\lambda_{(Y)s}$ and $\lambda_{(X)s}$ be the expected accident rates for treatment and control crossings in scenario s, then:

$$\frac{\left[\bar{Y}_{\cdot s} - \lambda_{(Y)s}\right]}{\sqrt{\frac{\lambda_{(Y)s}}{n_{s1}}}}$$

and

$$\frac{\left[\bar{X}_{\cdot s} - \lambda_{(X)s}\right]}{\sqrt{\frac{\lambda_{(X)s}}{n_{s2}}}}$$

are both approximately distributed N(0,1). Under the null hypothesis:

$$\lambda_{(Y)s} = \lambda_{(X)s} = \lambda_s \qquad (33)$$

and therefore:

$$\frac{\bar{Y}_{\cdot s} \quad \bar{X}_{\cdot s}}{\sqrt{\lambda_s\left(\frac{1}{n_{s1}} \quad \frac{1}{n_{s2}}\right)}}$$

also has a standard normal distribution. Applying the correction for continuity and estimating the overall mean accident rate for scenario j as:

$$\lambda_s = \frac{(n_{s1}\bar{Y}_{\cdot s} + n_{s2}\bar{X}_{\cdot s})}{(n_{s1} + n_{s2})} \qquad (34)$$

the statistic for testing the null hypothesis is:

$$Z_s = \frac{\left[\bar{Y}_{\cdot s} - \frac{1}{2n_{s1}}\right] - \left[\bar{X}_{\cdot s} + \frac{1}{2n_{s2}}\right]}{\sqrt{\frac{n_{s1}\bar{Y}_{\cdot s} + n_{s2}\bar{X}_{\cdot s}}{n_{s1} + n_{s2}}}\sqrt{\frac{1}{n_{s1}} + \frac{1}{n_{s2}}}} \tag{35}$$

where s = 1,2,...m. Under the null hypothesis, Z_s^2 has a chi-square distribution with one degree of freedom, and $\sum_{s=1}^{m} Z_s^2$ has a chi-square distribution with s degrees of freedom.

The null hypothesis that the accident rates for the treatment and control crossings over all the scenarios are equal will be rejected if the value of $\sum_{s=1}^{m} Z_s^2$ exceeds the critical value in the chi-square table. Furthermore, those scenarios for which there is a statistically significant difference between the accident rates for the treatment and control groups can be identified by examining the respective values of Z_s^2. For those scenarios where Z_s^2 exceeds 3.84, the sign of Z_s will indicate whether the treatment or the control group has the lower accident rate. If the sign is negative, it can be said that the new advance warning sign provides a statistically significant reduction in the expected accident rate.

B. Derivation of Sample Size Requirements

The sample size required for the accident study depends on the following parameters:

1. The desired power of the test, β.
2. The value of the overall mean accident rate, $\bar{\lambda}$.
3. The expected reduction in accident rate, Δ.

The power is the probability of correctly detecting a change in accident rate, if there is a change. For a fixed mean accident rate, $\bar{\lambda}$, and a fixed accident rate reduction, the required sample size will vary directly with the requested power. Furthermore, there is a greater likelihood in detecting a change in accident rate when the rate of accidents is high, as opposed to when accidents are a rare event. Finally, it is clear that a larger change is more likely to be detected than a smaller one. The derivation presented below quantifies these qualitative assessments in terms of the overall comparison of all treatment and control crossings.

Using the notation of the previous section, assume that:

$$X_{ij} \sim P(\lambda_j)$$

$$Y_j \sim P(\lambda_j - \varepsilon\lambda_j)$$

This implies that the treatment (i.e., the new advance warning sign) reduces the accident rates by an amount proportional to the original rate. Under this assumption, the statistic $\bar{D}$ (Equation 23) no longer has a zero mean, rather:

$$E(\bar{D}) = \frac{1}{k} E(\bar{Y}_j - \bar{X}_j)$$

$$= \frac{1}{k} \sum_{j=1}^{k} (\lambda_j - \varepsilon\lambda_j - \lambda_j) = -\varepsilon\bar{\lambda} \qquad (36)$$

and

$$V(\bar{D}) = \frac{1}{k^2(n-1)} \sum_{j=1}^{k} \lambda_j[(n-1) - \varepsilon(n-1) + 1]$$

$$= \frac{[n - \varepsilon(n-1)]\bar{\lambda}}{(n-1)k} \qquad (37)$$

Moreover, the statistic R (Equation 28) no longer has a N(0,1) distribution, but has a mean of

$$-\frac{\varepsilon\bar{\lambda}}{\sqrt{\frac{[n - \varepsilon(n-1)]\bar{\lambda}}{(n-1)k}}}$$

and a variance of: $\frac{n - \varepsilon(n-1)}{n}$

Compared to the N(0,1) distribution, this represents a slight shift in the variance, but the main effect is on the mean of R.

The probability of rejecting the null hypothesis, H_0, that ε equals zero (at $\alpha = 0.05$) is:

$$\Pr(R < -1.64) =$$

$$\Pr\left[\left(R + \frac{\varepsilon\bar{\lambda}}{\dfrac{n\bar{\lambda}}{(n-1)k}}\right) \cdot \frac{1}{\sqrt{\dfrac{n - \varepsilon(n-1)}{n}}} < -1.64\left(\frac{1}{\dfrac{n - \varepsilon(n-1)}{n}}\right) + \frac{\varepsilon\sqrt{\bar{\lambda}}}{\sqrt{\dfrac{n - \varepsilon(n-1)}{(n-1)k}}}\right] \qquad (38)$$

or

$$\Pr\left[Z < \frac{-1.64}{\sqrt{\dfrac{n - \varepsilon(n-1)}{n}}} + \frac{\varepsilon\sqrt{\bar{\lambda}}\ \sqrt{(n-1)k}}{\sqrt{n - \varepsilon(n-1)}}\right] \qquad (39)$$

where: $Z \sim N(0,1)$

If the effect on the variance is ignored, then:

$$\Pr(R < -1.64) \approx \Pr\left[Z < -1.64 + \frac{\varepsilon\sqrt{\bar{\lambda}}\ \sqrt{(n-1)k}}{\sqrt{n}}\right] \qquad (40)$$

which is a much simpler relationship.

If the required power is now fixed at some level β, then from Equation 40:

$$\Phi^{-1}(\beta) = \left[-1.64 + \frac{\varepsilon\sqrt{\bar{\lambda}}\ \sqrt{(n-1)k}}{\sqrt{n}} \right] \qquad (41)$$

where $\Phi^{-1}(\beta)$ is the inverse of the normal distribution at point β. Solving for k, the total number of sets of one treatment and n-1 control crossings:

$$k = \left[\Phi^{-1}(\beta) + 1.64 \right]^2 \left[\frac{n}{n-1} \right] \left[\frac{1}{\bar{\lambda}\varepsilon^2} \right] \qquad (42)$$

The total number of sets, k, is in effect the desired sample size, which:

1. Increases with the desired power, β.
2. Decreases with the overall mean accident rate, $\bar{\lambda}$.
3. Decreases with the square of the change in accident rate, ε.
4. Decreases slightly with the size of the sets, n.

Similar results can be obtained by using the more complex Equation 11.

Although the above derivation is presented in terms of sets of crossings (j = 1,2,...k), it is also directly applicable to separate scenarios, s.

APPENDIX B

ESTIMATION OF COSTS

The data and methodology used to estimate parameter values for the economic decision model (Chapter V), and the accident study cost model (Chapter VI) are described below.

A. Economic Decision Model

The average cost per grade crossing accident, AC, was estimated by updating accident costs cited in the 1972 Report to Congress on Railroad-Highway Safety. (8) In that study, unit costs for fatal and personal injury accidents at rail-highway grade crossings were developed from estimates of the total economic loss to society for various injury categories. Property damage costs were derived from information reported on state accident report forms. Then using data on the distribution of fatal, personal injury, and property damage accidents by rural versus urban area, composite accident costs were computed. These costs were reported as \$60,000 per accident for rural areas, and \$25,000 per accident for urban areas. To update these costs to 1979 dollars, the above values were weighted by the proportion of grade crossing accidents occurring in rural and urban areas, and then expanded using an 8 percent inflation rate:

$$AC = [0.4(\$60,000) + 0.6(\$25,000)](1.08)^7$$

$$= \$66,800 \text{ per accident}$$

For use in the economic decision model, the average cost of a grade crossing accident was assumed to range between \$60,000 and \$75,000 per accident.

The materials cost differential between the standard advance warning sign and the proposed three-color sign, ΔC, was estimated to range between \$1 and \$3 per sign. This was based upon data reported by state highway agencies in Texas and Wisconsin, as well as a major materials supplier. (16)

The estimated unit labor cost, LC, for installing a new advance warning sign on an existing post was determined from assumed values for the number of signs which could be installed per day, and the wage rate per hour for the sign crew. It was assumed that one crew could install an average of twelve signs per day, and that the crew would be paid at the rate of $16 per hour for an eight-hour day. Therefore:

$$LC = \left[\frac{\text{day}}{12 \text{ signs}}\right] \left[\frac{8 \text{ hr}}{\text{day}}\right] \left[\frac{\$16}{\text{crew-hr}}\right] = \$10.67 \text{ per sign}$$

Allowing for variability in the above estimates, the typical unit cost was assumed to be within the range of $9 to $12 per sign.

The estimated mileage cost per sign, MC, for the vehicle used by the sign crew was based upon the assumption that approximately 200 miles would be traveled in a typical day in which an average of 12 signs could be installed. Using cost per mile data reported by the Wisconsin Department of Transportation, the unit mileage cost for a sign truck was estimated as:

$$MC = \left[\frac{\text{day}}{12 \text{ signs}}\right] \left[\frac{200 \text{ miles}}{\text{day}}\right] \left[\frac{\$0.35}{\text{mile}}\right] = \$5.83 \text{ per sign}$$

As with the other cost parameters, it was assumed that the typical value for unit mileage cost would fall within a range of $5 to $8 per sign.

Finally, the typical economic life of an advance warning sign was assumed to be seven years. This estimate was based upon the experience reported by the Wisconsin Department of Transportation.

B. Accident Study Cost Model

The accident study cost model is composed of four components, each associated with a basic work task. It was assumed that four basic tasks would be required: Site Selection, Preparation of Treatment Sites, Data Processing, and Data Analysis and Evaluation.

The Site Selection cost model was formulated as:

$$C_1 = \frac{N_T}{n}\left[(m)(MR) + TC\right]$$

in which N_T is the total number of treatment and control sites in the experimental design; n is the number of sites visited per day; m is the mileage logged per day, MR is the vehicle mileage rate in dollars per mile; and TC is the time and per diem cost for a traffic engineering technician in dollars per day. It was assumed that it would require about one-half hour to collect the necessary data at each site, and an average of one-half hour to travel to the next candidate site. Allowing time for meals, it was therefore assumed that an average of eight sites could be visited over a 10-hour day. It was further assumed that an average day would involve 150 miles of travel at $0.17 per mile. Time and per diem costs were estimated at $8 per hour for a 10-hour day and $30 per day, respectively, for a total cost of $110 per day. Using these parameter values, the Site Selection cost model could then be expressed as:

$$C_1 = \left[\frac{N_T}{\left(\frac{8 \text{ sites}}{\text{day}}\right)}\right]\left[\left(\frac{150 \text{ miles}}{\text{day}}\right)\left(\frac{\$0.17}{\text{mile}}\right) + \frac{\$110}{\text{day}}\right] \approx 17\ N_T$$

where C_1 is the cost of this task in dollars.

The cost model for the second task, Preparation of Treatment Sites, was expressed as:

$$C_2 = 2\ N_t(SC+LC+MC)$$

in which N_t is the total number of treatment sites in the experimental design; SC is the dollar cost of modifying each in-place standard advance warning sign; LC is the dollar labor cost for installation of the experimental sign; and MC is the dollar mileage cost per sign for the truck used by the field crew. Using the cost data developed for the economic decision model, the Preparation of Treatment Sites cost model was specified as:

$$C_2 = 2\ N_t\left[\frac{\$3}{\text{sign}} + \frac{\$11}{\text{sign}} + \frac{\$6}{\text{sign}}\right] \approx 40\ N_t$$

where C_2 is the cost of this task in dollars.

The cost model for the Data Processing task was defined as:

$$C_3 = hts$$

in which h is the mean number of man-hours required per year; t is the length of the accident study in years; and s is the dollar per hour salary scale, including administrative costs, for support-level personnel. It was assumed that this task would require one man-month, or 176 hours, per year. At a salary rate, including fringe benefits and administrative costs, of $25 per hour, this cost model could then be expressed as:

$$C_3 = \left[\frac{176 \text{ hours}}{\text{year}}\right]\left[\frac{\$25}{\text{hour}}\right] t \approx 4400 \ t$$

where C_3 is the cost of this task in dollars.

Finally, the cost model for the Data Analysis and Evaluation task was defined as:

$$C_4 = yd$$

in which y is the number of man-years of effort; and d is the total dollar cost per man-year, including administrative costs. This task was assumed to require one-half man-year of effort at $60,000 per man-year, including all administrative costs. The resulting estimate for the cost of this task was then expressed as:

$$C_4 = \left[\frac{1}{2} \text{ man-year}\right]\left[\frac{\$60,000}{\text{man-year}}\right] = 30,000$$

where C_4 is expressed in dollars.

Adding the cost models for the four study tasks, the cost model for the entire accident study becomes:

$$C_T = 17 \ N_T + 40 \ N_t + 4400 \ t + 30,000$$

where C_T is the expected dollar cost of the accident study; N_T is the total number of treatment and control sites; N_t is the number of treatment sites; and t is the length of the data collection period in years.

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