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# RAIL-HIGHWAY CROSSING WARNING DEVICE LIFE CYCLE COST ANALYSIS

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FINAL REPORT



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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 improve the efficient allocation and use of these Federal funds.

The report describes the results of a study designed to collect, analyze, and document life cycle costs of active rail-highway crossing warning devices. Life cycle costs were determined from information on installation costs contained in the final billings of rail-highway crossing improvement projects and from data on maintenance costs provided by various states, railroads, and railway associations.

Life cycle costs were analyzed by cost components for each of the five Federal Railroad Administration regions. Cost components included pre-engineering, labor, material, and equipment rental costs as well as maintenance costs. Cost variability due to several factors such as number of tracks, crossing location, type of train detection system, and combinations of these variables was analyzed.


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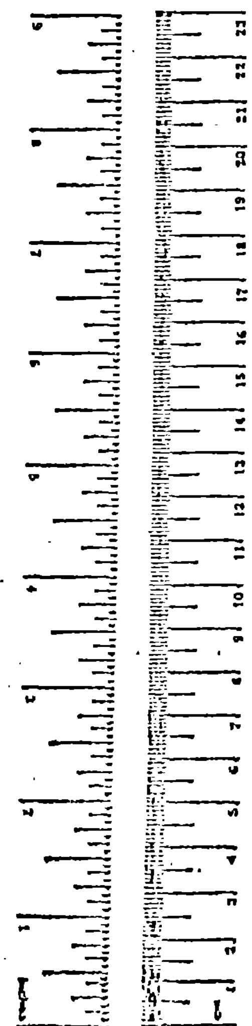
# METRIC CONVERSION FACTORS

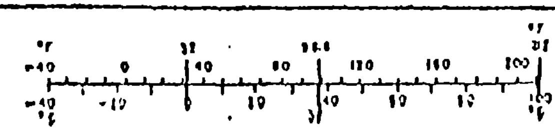
## Approximate Conversions to Metric Measures

| 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 |



# PREFACE

This study of the life cycle costs of rail-highway crossing warning devices is part of an overall rail-highway crossing safety program being conducted by the U.S. Department of Transportation. The results of this analysis will be used to support a resource allocation model being developed by the Transportation Systems Center (TSC) to improve the allocation by states and railroads of funds for improving rail-highway crossings.

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 TSC. Dr. Edwin Farr was the contract technical monitor at TSC. Under the initial direction of John M. Witten at IOCS, the research for the project was performed by Joseph Morrissey and Jennifer Heisler. Charles Erdrich served as a technical consultant for the study. Samir A. Desai, Vice President of the Systems Research and Communications Division, offered technical and managerial assistance.

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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 to improve safety at public rail-highway crossings. Safety improvements frequently consist of the installation of motorist warning devices such as crossbucks, 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 that determines how to achieve maximum safety benefits for the expenditure of a given level of funding. This computer model utilizes rail-highway crossing hazard index ratings and the effectiveness and costs of motorist warning devices as inputs. The purpose of this study is to provide life cycle cost data for active rail-highway crossing warning devices in support of the DOT-TSC resource allocation model. Life cycle costs consist of the initial costs, such as purchase and installation, and the recurring or maintenance costs.

The study included active rail-highway crossing warning systems, crossbucks, and surfaces. The costs of adding additional active warning devices to a crossing with an existing active warning system are also examined. The study includes an analysis of regional cost variability by Federal Railroad Administration (FRA) region and an analysis of the factors influencing life cycle costs. All costs are presented in 1977 dollars.

Life cycle installation costs and maintenance costs were determined for each of the active motorist warning devices, as shown in Table A.

TABLE A. INSTALLATION, MAINTENANCE, AND TOTAL LIFE CYCLE COSTS FOR MOTORIST WARNING DEVICES (IN $K)

| MOTORIST WARNING DEVICE | INSTALLATION COST | MAINTENANCE COST | TOTAL LIFE CYCLE COST |
|---|---|---|---|
| Flashing lights[1] | 26.0 | 14.1 | 40.1 |
| Cantilevered flashing lights | 29.4 | 17.4 | 46.8 |
| Flashing lights with gates | 39.2 | 23.2 | 62.4 |
| Cantilevered flashing lights with gates | 44.6 | 27.1 | 71.7 |
| Flashing lights upgraded to flashing lights with gates | 33.5 | 23.2 | 56.7 |
| Flashing lights upgraded to cantilevered flashing lights with gates | 42.7 | 27.1 | 69.8 |

[1]The term "flashing lights" refers only to post-mounted flashing lights

As Table A demonstrates, 30-year maintenance costs discounted to present value comprised 54 percent to 61 percent of the total installation costs; maintenance costs as a percentage of installation costs increased with the complexity of the motorist warning device.

Table B presents the breakdown of total installation costs into their cost components for the motorist warning devices investigated.

TABLE B. AVERAGE INSTALLATION COSTS BY MOTORIST WARNING DEVICE AND COST COMPONENTS (IN $K)

| MOTORIST WARNING DEVICE | TOTAL COST | PRE-ENGINEERING COST | LABOR COST | MATERIAL COST | EQUIPMENT COST | MISCELLANEOUS COSTS |
|---|---|---|---|---|---|---|
| Flashing lights | 26.0 | 1.4 | 7.2 | 13.8 | 0.8 | 2.8 |
| Cantilevered flashing lights | 29.4 | 1.2 | 7.9 | 17.7 | 1.1 | 1.5 |
| Flashing lights with gates | 39.2 | 1.2 | 9.7 | 25.0 | 1.2 | 2.1 |
| Cantilevered flashing lights with gates | 44.6 | 1.4 | 10.3 | 29.4 | 1.5 | 2.0 |
| Flashing lights upgraded to flashing lights with gates | 33.5 | 0.7 | 8.6 | 21.4 | 1.4 | 1.4 |
| Flashing lights upgraded to cantilevered flashing lights with gates | 42.7 | 1.1 | 9.9 | 27.6 | 1.9 | 2.2 |

The data were analyzed to determine factors influencing life cycle costs. The following trends were identified:

<u>Region</u> - No consistent regional cost trends were identified for the life cycle costs of motorist warning devices. This finding was attributed to internal railroad policies regarding the type of labor and/or equipment used, and to the fact that railroads cross regional boundaries and costs appeared to vary more by railroad than by region. Additionally, the regional samples offered a wide variety of projects with different operating and locational characteristics, such as the number of tracks and the type of existing track circuitry. The costs appeared to vary by these characteristics more than by region.

<u>Location</u> - Costs for rural installations were slightly higher than for urban ones. When the data were further subdivided by the number of tracks and the location of the crossing, the opposite cost trend was found. In both cases, the differences among average installation costs were small.

<u>Number of tracks</u> - Average costs increased as the number of tracks increased at a crossing, although the additional cost per track was dependent upon other factors as well. These include train detection type and existing track circuitry.

<u>Existence of track circuitry</u> - The data available were insufficient to perform a statistically meaningful analysis of this factor.

Track work - The electrical and communications work necessary to install or modify the track circuitry for the train detection system contributed between 8 percent and 12 percent of the signal labor costs, and between 2 percent and 5 percent of the material costs.

Train detection system - A hierarchy of train detection systems was established with respect to costs, not complexity. The hierarchy is as follows from least to most expensive: motion sensors (MS), alternating/direct current (AC-DC) track circuits, audio frequency overlay (AFO), and grade crossing predictors (GCP).

# 1. INTRODUCTION

## 1.1 BACKGROUND

This report documents a study to provide information for the U.S. Department of Transportation (DOT) to aid in improving the allocation by states and railroads of Federal funds for rail-highway crossing safety.

The Highway Safety Acts of 1973 and 1976 and the Surface Transportation Assistance Act of 1978 provide for funding to improve safety at public rail-highway crossings. In support of this program, several projects have been undertaken by DOT. First, an inventory of all rail-highway crossings was prepared by DOT and the Association of American Railroads (AAR). The inventory contains identifying and descriptive information on approximately 217,000 public at-grade crossings. The second part of the program is the development of procedures for the efficient allocation of funds for the installation of motorist warning devices. To this end, two computer models have been constructed by the Transportation Systems Center (TSC). The first computer model is a hazard prediction model.[1] This model is derived from the physical and operating characteristics of the crossings in the DOT-AAR Crossing Inventory and from actual accident data in the crossing accident history files. The hazard model determines a hazard index for each crossing which is equal to the number of expected accidents per year at the crossing; it then ranks the crossings according to their hazard index. The second model is a resource allocation model. This model uses the hazard index and the effectiveness and costs of motorist warning devices to calculate accident reduction benefit/cost ratios for each crossing. The objective of the model is to maximize the total safety benefit achieved in reduced accidents for the expenditure of a given sum of money.

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[1] Mengert, P., "Rail-Highway Crossing Hazard Prediction Research Results", Report No. FRA-RRS-80-02, U.S. Department of Transportation, Research and Special Programs Administration, Cambridge, Massachusetts, March, 1980.

## 1.2 PURPOSE AND OBJECTIVES

The purpose of this study is to provide life cycle cost data in support of the resource allocation model on rail-highway crossing warning systems and surfaces. The specific objectives of this study are listed below.

1. Determine the life cycle costs of rail-highway crossing warning devices including the documentation of the following cost components: engineering, installation, equipment, and maintenance for the first year and all other years.

2. Determine the life cycle cost variation for three general warning devices: crossbucks, all flashing lights, and all flashing lights with gates.

3. Determine the costs of upgrading existing motorist warning devices with additional warning devices. For the purposes of this study, an upgraded crossing refers to one in which an active warning device has been augmented with additional warning devices. Active warning refers to warning devices which are train-activated, such as flashing lights or gates. Passive warning refers to nonactive equipment such as crossbucks or stop signs.

4. Determine equipment scrap value and finance charges.

5. Determine regional cost variations for the various warning devices for each of the five Federal Railroad Administration (FRA) regions.[1]

[1] Effective January 29, 1980, the five FRA regions were restructured. There are currently eight FRA regions.

6. Determine and identify the factors influencing life cycle cost variations and the extent of cost variability. These factors might include the number of tracks, the location of the crossing, or the different labor costs among railroads.

7. Determine the costs to install and maintain rubberized crossing surfaces.

## 1.3 STUDY APPROACH

The study approach was to define and describe the components of rail-highway crossing warning devices, and collect historical cost data on the installation and maintenance of these devices. The cost data were analyzed with respect to variability and the sources of cost variability were determined.

The initial literature search provided information on the types of rail-highway crossing warning devices, their subsystems and subsystem components.[1] Based on this research, the two basic active motorist warning devices, flashing lights and flashing lights with gates, were divided into two categories: cantilevered and post-mounted flashing light installations. This was done to further isolate the factors influencing life cycle costs.

To obtain the necessary cost information and ensure that adequate regional sample sizes would be provided for the different types of motorist warning devices, potential sources of cost data were identified and contacted. Under the Federally funded crossing safety program, railroads installing rail-highway crossing motorist warning devices submit detailed final billings

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[1]Texas Transportation Institute, Railroad-Highway Grade Crossing Handbook, Report No. FHWA-TS-78-214, U.S. Department of Transportation, Federal Highway Administration, College Station, Texas, August 1978.

to the states. These final billings, available from both the railroads and the states, were found to be the most complete data available on the installation costs of rail-highway crossing warning devices. Maintenance cost data were compiled from a variety of sources including railroads, states, and railroad associations.[1] Additional information required to analyze cost variability and determine the factors influencing life cycle costs was obtained through the DOT-AAR Crossing Inventory maintained by FRA.

Installation costs were determined by project totals and by project subcategories of preliminary engineering, signal labor, material and material handling, and equipment rental. Maintenance costs were discounted to present value using a 10 percent discount rate over a 30-year service life. All costs were indexed to 1977 dollars using the AAR Quarterly Railroad Material Prices and Wages Index.[2] Cost variability by factors influencing life cycle costs was examined by controlling variables such as crossing location, the number of tracks, the type of train detection subsystem, and combinations of these factors. A national pooled sample of the cost data was used to determine the factors influencing life cycle costs. This was done to ensure adequate sample sizes because there are a multitude of factors influencing life cycle costs which appear in unique combinations at the various crossings.

---

[1]Average annual maintenance costs, in 1977 dollars, were distributed over the service life of the motorist warning devices using the method outlined in Circular A-94, Revised, of the Office of Management and Budget (OMB). As recommended, a 10 percent discount rate was used.

[2]Current dollars throughout this report were determined by utilizing the AAR Quarterly Materials Prices and Wages Index. The most recent quarterly index available was December 1977 (dated July 26, 1978). Therefore, all costs are presented in 1977 dollars.

# 2. COST DATA COLLECTION

## 2.1 DATA REQUIREMENTS

In order to apply the concepts of life cycle costing to rail-highway crossing warning devices and analyze the variability in costs, it was necessary to collect a wide spectrum of cost data. The requirements can best be described by considering costs and cost variability in several categories.

### Cost Elements

Initial or one-time costs - For the purpose of requesting data, initial project costs consisted of the engineering, procurement, and labor costs which were expended for the installation of the devices.

Maintenance and other recurring costs - These costs included preventive and corrective maintenance over the project life, inventory needs and labor costs. For the purposes of this study, maintenance costs were defined as the average annual cost of labor and materials for maintaining a rail-highway crossing warning device. Operating costs such as electrical power are not included in maintenance costs due to the fact that the operating costs of motorist warning devices were not available in the final billings reviewed. Other recurring costs not directly associated with the installation or maintenance of warning devices, such as train delay costs, are also not included.

Other life cycle cost elements - A complete analysis of life cycle costs required information on the salvage value of warning devices, equipment life, cost of capital, and price and wage indicators.

Types of Systems

Motorist warning devices - Listed in order of increasing complexity, cost data were required for flashing light, cantilevered flashing light, flashing light with automatic gate, and cantilevered flashing light with automatic gate installations.

Train detection systems - These included direct current (DC), alternating/direct current (AC-DC), grade crossing predictors (GCP), audio frequency overlay (AFO), and motion sensors (MS).

Passive systems - Data for the costs of crossbucks were also needed.

Regional Differences

It was expected that rail-highway crossing device costs would vary across FRA regions. Contributing factors included wages and material, differences in shipping and material handling costs, and individual railroad operating practices.

Types of Installations

Other factors contributing to differences in cost were whether a particular installation was new or an upgrading of crossing warning devices was necessary, whether there were existing track circuits, and whether surface work was needed.

Crossing Characteristics

Physical characteristics of the crossing, such as the number of tracks and highway lanes, were seen as possible factors in cost differences.

The location of the crossing, urban or rural, was used in analyzing cost variations.

## 2.2 DATA SOURCES

### 2.2.1 Identification of Sources

Several potential sources of cost data were identified early in the project. These included railroads, state agencies administering rail-highway crossing safety programs, other government agencies such as FRA and the Federal Highway Administration (FHWA), equipment suppliers, and railroad associations. Several suppliers provided valuable information and diagrams related to the components of crossing devices. The AAR supplied an important letter of introduction to railroads which is contained in Appendix A.

For each crossing project funded by a particular state, the railroad owning that crossing submitted a detailed cost estimate to the state administering agency, usually the highway department, public utilities commission, or department of transportation. After negotiation, this estimate was revised, the actual construction was performed, and final audited billings were received by the state. It was anticipated that these final billings would provide detailed cost data on engineering, procurement, and labor, as well as a description of previous equipment and crossing characteristics. The billings from both states and railroads were the only source which provided the level of detail required by this analysis.

### 2.2.2 Selection of Sources

Sources of cost data were selected mainly on the basis of coverage of the five FRA regions. Other factors, such as willingness to comply with request for data, were also considered. See Figure 2-1 for a map of the five FRA regions. In each region, one or more states and three or more Class I railroads were chosen.

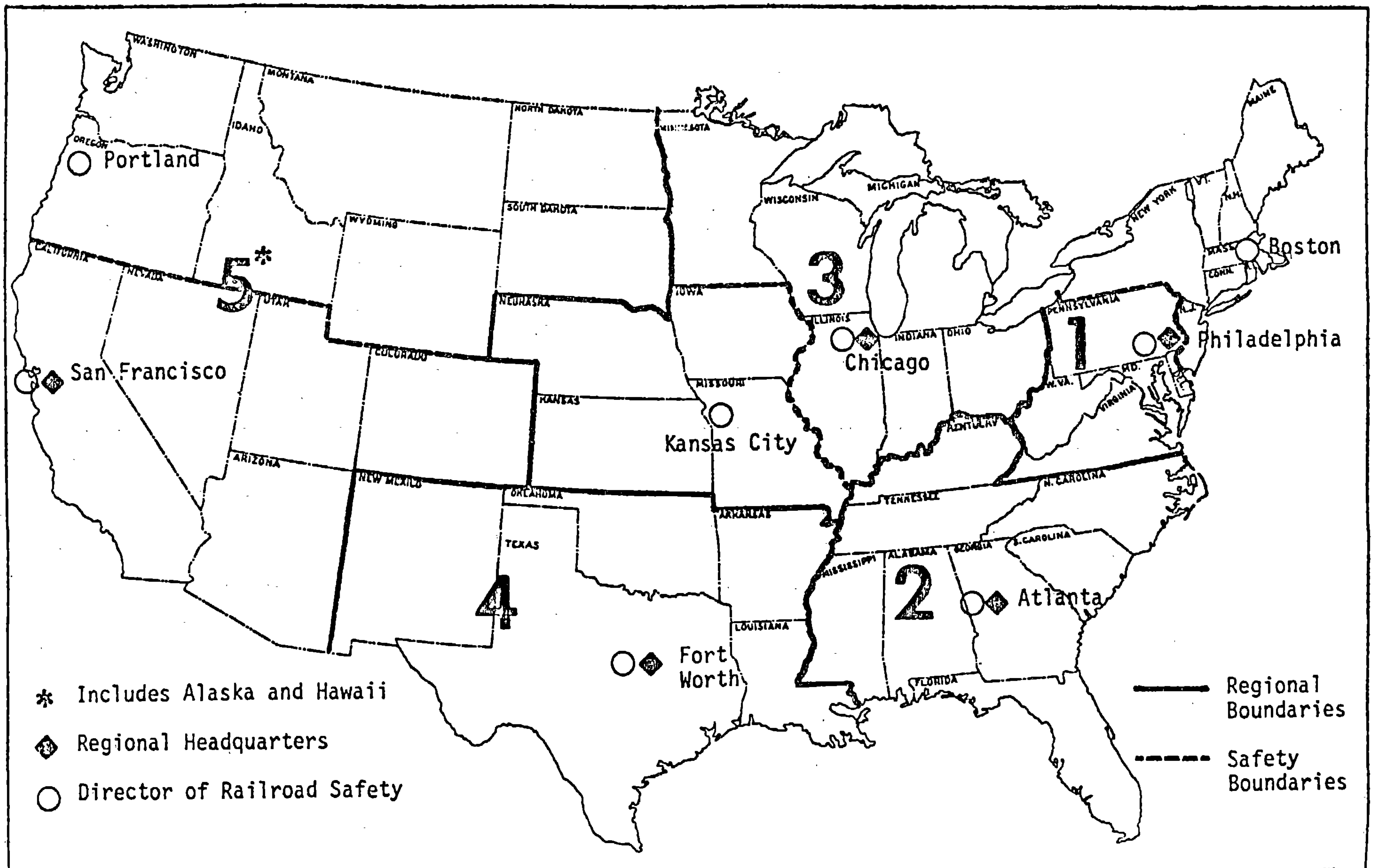


FIGURE 2-1. MAP OF FEDERAL RAILROAD ADMINISTRATION REGIONS

Other required data, such as price and wage indicators, were available from the Bureau of Labor Statistics and the AAR's Economics and Finance Department. In addition to the initial system costs, railroads were asked to provide detailed maintenance cost data for various types of crossings and installations.

After initial telephone contact was made with all sources to determine the general context and quantity of data which they could provide, letters were sent which outlined data requirements. Examples of these letters outlining data requests to the railroads are contained in Appendix A.

## 2.3 DATA RECEIVED

### 2.3.1 Description of Data Received

The billings supplied by the states and railroads detailed the initial costs of a project in nine categories.

Pre-engineering - labor and overhead to perform engineering and planning tasks (drafting, etc.)

Signal labor - by type (signal, repair, track work, and communications) and overhead

Personnel expenses - lodging, meals, and other minor expenses, if necessary

Materials - detailed listing of system components

Material handling - taxes and freight

Equipment - leased and rented machinery for performing signal and track work

Salvage - credit for equipment that was reusable by the railroads

Accounting and billing

Miscellaneous - other personal expenses, gasoline, securing permits, and other minor expenses

A cover sheet was provided. This included a general description of the work, a crossing location identifier, the name of the owning railroad, the Federal and local share of funding, and the estimated and final audited total project cost.

The format of the billings was similar for each state or railroad. It became evident that the original breakdown of initial life cycle costs by engineering, procurement, and labor was insufficient to show significant cost variations. The original categories were then expanded to pre-engineering, labor, materials (including material handling), equipment rental, and maintenance. Accounting and billing was omitted since it proved to be a small percentage of total cost, less than one percent. Miscellaneous and personal expenses were also considered negligible and were subsumed in other categories. Representative examples of the cost billings are contained in Appendix B.

Although the individual project billings were excellent sources of life cycle cost information, a number of difficulties were experienced in their use. These problems were classified in the following areas.

Cost data dealing exclusively with the installation of passive devices were only available from Kentucky. This limited the cost analysis of passive devices.

Many of the labor costs tabulated on the billings were shared costs. That is, if a combination of signal and surface work was included in a project, it was difficult to separate which components of labor were attributable to track, surface, or signal work. Additionally, in most cases it was not possible to determine to what type of work certain contracted labor expenses should be applied.

In many projects, a mixture of devices was installed at a crossing. This made it difficult to categorize a particular installation according to a specific type of motorist warning device or train detection system. In many cases, the type of train detection system was not specified. This required detailed review of the parts listing in order to make an accurate determination. It was difficult to separate the exact material comprising the train detection system. This was due primarily to the variety of materials used to install and/or modify the system and connect the device to the existing track circuitry. Since the detailed material lists found in the billings did not distinguish between signal and train detection system materials, it was not possible to itemize these costs separately. However, it was possible to distinguish costs for particular motorist warning devices by the type of train detection system.

Information specifically allocated to control logic and interconnection subsystems was not available.

Most projects did not include sufficient data describing the physical attributes of the crossing nor the DOT-AAR crossing number. Additional contacts were necessary to obtain the information on physical characteristics. For projects which were upgrading previous equipment, the type of equipment replaced was frequently not specified. This data problem was resolved by obtaining DOT-AAR crossing numbers for the final billing. The DOT-AAR Crossing Inventory was then accessed. This provided detailed crossing characteristic information such as the number of tracks, highway lanes, the location of the crossing, and the existing motorist warning device.

Other problems, such as illegibility, nonuniformity in billing format, and lack of audited cost, caused minor difficulties in data reduction.

### 2.3.2 Summary of Usable Installation Cost Data

Table 2-1 presents a summary of usable installation cost data received according to region, type of project, and source. Due to missing data, "mixed system" projects, duplicates and other data inadequacies, these numbers represent only those projects utilized for the life cycle cost analysis. The total usable sample includes 321 crossing installations out of a total received sample of approximately 450.

### 2.3.3 Maintenance Cost Data

Maintenance costs were obtained from various sources in per signal unit values or total average annual costs. Signal units are used to represent the relative complexity of the various types of equipment comprising a rail-highway crossing warning device. The signal unit measurement technique was developed by the AAR to ensure equitable division of the construction and maintenance costs of joint signal facilities and interlocking plants among railroads who shared these facilities.[1]

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[1]Association of American Railroads, "Railroad-Highway Grade Crossing Protection," American Railway Signaling Principles and Practices, Chapter 23, 1962.

TABLE 2-1. SUMMARY OF USABLE INSTALLATION COST DATA

| REGION | 1 | 2 | 3 | 4 | 5 | TOTALS |
|---|---|---|---|---|---|---|
| TOTAL NUMBER OF PROJECTS | 22 | 111 | 54 | 40 | 94 | 321 |
| TYPE OF PROJECT | | | | | | |
| Passive | 0 | 3 | 0 | 0 | 0 | 3 |
| Flashing Lights | 4 | 26 | 19 | 1 | 10 | 60 |
| Cantilevered Flashing Lights | 2 | 19 | 6 | 8 | 5 | 40 |
| Flashing Lights with Gates | 8 | 33 | 19 | 15 | 62 | 137 |
| Cantilevered Flashing Lights with Gates | 4 | 30 | 7 | 9 | 16 | 66 |
| Rubberized Surface | 4 | 0 | 3 | 7 | 1 | 15 |
| DATA SOURCE | | | | | | |
| State of Massachusetts | 12 | | | | | |
| Conrail | 2 | | | | | |
| Maine Central | 3 | | | | | |
| Seaboard Coast Line | 5 | 92 | | | | |
| State of Kentucky | | 19 | | | | |
| Missouri Pacific | | | 8 | 17 | | |
| State of Missouri | | | 16 | | | |
| Burlington Northern | | | 17 | | 10 | |
| Chicago & Northwestern | | | 13 | | | |
| State of Louisiana | | | | 10 | | |
| Southern Pacific | | | | 13 | 4 | |
| State of California | | | | | 80 | |

The basic maintenance cost data received is summarized in Table 2-2. The signal unit costs are converted to total average annual costs by using the number of signal units for the various motorist warning devices and train detection systems. Three sources, the Maine Central Railroad, Conrail, and the Texas Railway Association (TRA), provided data on actual maintenance costs. TRA's figures are based on a survey of the maintenance costs incurred at 188 public rail-highway crossings, while the other two sources represent averages of recent maintenance expenditures. The other sources provided data on amounts that were negotiated between states and railroads. These negotiated values are used as the basis for sharing the maintenance costs between the two parties. The states listed in Table 2-2 contribute 50 percent of the maintenance costs with the exceptions of Wisconsin and California which contribute 25 percent and 100 percent, respectively.

TABLE 2-2. BASIC AVERAGE ANNUAL MAINTENANCE COST DATA BY SOURCE, APPLICABLE YEAR AND MOTORIST WARNING DEVICE

| SOURCE | APPLICABLE YEAR | FLASHING LIGHTS | CANTILEVERED FLASHING LIGHTS | FLASHING LIGHTS WITH GATES | CANTILEVERED FLASHING LIGHTS WITH GATES |
|---|---|---|---|---|---|
| California[1] | 1965 | $ 440 | $ 560 | $ 909 | $1090 |
| Conrail[2] | 1977 | 2004 | 2004 | 2968 | 2968 |
| Florida DOT[1] | 1971 | 650 | 860 | 980 | 1230 |
| Iowa[1] | 1977 | 1079 | 1374 | 2233 | 2675 |
| Maine Central[2] | 1977 | 1358 | 1729 | 2809 | 3365 |
| North Carolina[1] | 1968 | 650 | 950 | 980 | 1250 |
| Texas Railway[1,2] Association | 1977 | 840 | 1080 | 1960 | 2160 |
| Virginia Railway[1] Association | 1966 | 675 | 860 | 1015 | 1230 |
| Wisconsin[1] | 1977 | 1070 | 1362 | 2214 | 2652 |

[1]Virginia, North Carolina, Florida, and Iowa contribute 50 percent of the indicated maintenance costs. Wisconsin contributes 25 percent and California 100 percent.
[2]These sources provided data on actual maintenance costs. The other sources provided data on negotiated costs of maintenance.

# 3. COST FINDINGS

## 3.1 LIFE CYCLE COST PROCEDURE

The cost information received consisted of installation costs for projects incurred over the four-year period from 1975 to 1978 and maintenance costs from 1965 to 1977. To compare these costs on an equal basis, it was necessary to convert the costs into 1977 dollars, the base year assumed for this study. The AAR Quarterly Material Prices and Wages Index was used to obtain the necessary conversion factors for this purpose.

To calculate total life cycle costs for the various types of warning devices installed, average annual maintenance costs were distributed over the service life of the device. A service life of 30 years was assumed, based upon several sources of information. An interview with an expert on railroad depreciation rates at the Interstate Commerce Commission (ICC)[1] revealed that the Depreciation Branch of the ICC periodically studies individual Class I railroads to determine the economic life of railroad signal equipment. These unpublished studies are not formally documented. However, their results indicate that the average ICC signal equipment depreciation period in 1977 for the 20 largest, by operating revenues, Class I railroads was 30 years.[2] In addition, the State of California Public Utilities Commission in its study of the effectiveness of automatic protection of rail-highway crossings, assumed a

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[1]Hostetepler, E., Depreciation Branch, Interstate Commerce Commission, Washington, D.C.

[2]*Ibid*.

30-year economic life for motorist warning devices.[1] This figure applies to both motorist warning devices and train detection systems. The average annual maintenance costs were discounted to 1977 dollars using the method outlined in the OMB Circular A-94, Revised.

## 3.2 NATIONAL LIFE CYCLE COSTS

Life cycle costs were calculated on a national basis for each of the four motorist warning devices. The results are shown in Table 3-1 as total life cycle costs comprised of the two elements, installation and maintenance costs.

TABLE 3-1. INSTALLATION, MAINTENANCE, AND TOTAL LIFE CYCLE COSTS FOR MOTORIST WARNING DEVICES (IN $K)

| MOTORIST WARNING DEVICE | INSTALLATION COST | MAINTENANCE COST | TOTAL LIFE CYCLE COST |
|---|---|---|---|
| Flashing lights | 26.0 | 14.1 | 40.1 |
| Cantilevered flashing lights | 29.4 | 17.4 | 46.8 |
| All flashing lights | 27.4 | 15.4 | 42.8 |
| Flashing lights with gates | 39.2 | 23.2 | 62.4 |
| Cantilevered flashing lights with gates | 44.6 | 27.1 | 71.7 |
| All flashing lights with gates | 40.8 | 24.3 | 65.1 |
| Flashing lights upgraded to flashing lights with gates | 33.5 | 23.2 | 56.7 |
| Flashing lights upgraded to cantilevered flashing lights with gates | 42.7 | 27.1 | 69.8 |
| All flashing lights upgraded to all flashing lights with gates | 36.7 | 24.5 | 61.2 |

[1]California Public Utilities Commission, The Effectiveness of Automatic Protection in Reducing Accident Frequency and Severity at Public Grade Crossings in California, San Francisco, California, June 30, 1974, p. 130.

### 3.2.1 Installation Cost Components

The installation cost element of the total life cycle costs for motorist warning devices are composed of five cost components which substantially contributed to the total one-time cost of installation. These components are described below.

1. Preliminary engineering - labor and overhead.

2. Signal labor - signal, track, communications, signal repair (assembly) labor costs, and the associated labor overhead.

3. Material - the total cost of all material utilized to install motorist warning devices and train detection systems. This includes track material such as ballast, as well as signal equipment. Material handling costs, such as state sales and use taxes, storage costs, and freight and transportation costs are also included.

4. Equipment lease and rental - the cost to rent or lease heavy equipment such as back hoes, tractors, or railroad cars necessary to transport or install signal equipment.

5. Miscellaneous costs - three cost components (personal expenses - signal crew meals and lodging, salvage value, and billing and accounting) were deleted from the components list. They were highly variable and comprised only 0.001 percent to 5 percent of the total initial costs. Personal expenses depended on the location of the crossing in relation to the crew's home work-base and the amount of contract labor utilized. Contract labor purchase vouchers and accounting costs differed by railroad rather than by motorist warning device installation type. This latter cost component appears to be dependent upon the type of internal railroad organization rather than the project type. Salvage value was negligible, averaging between $50 to $100 per crossing.

The final billings were grouped by motorist warning device and cost components were isolated and averaged. Table 3-2 shows these calculations for each motorist warning device.

In Table 3-2, several cost trends were identified.

As the motorist warning device installed increases in complexity, the average total cost also increases.

Signal labor, material, and equipment rental increase consistently among the component costs as the complexity of the motorist warning device increases. However, material costs increase at a faster rate than the others and account for the major cost differences among the various motorist warning devices.

Pre-engineering costs do not vary in any consistent manner. This seems to indicate that engineering costs may be dependent upon the locational characteristics

TABLE 3-2. AVERAGE INSTALLATION COSTS BY MOTORIST WARNING DEVICE AND COST COMPONENTS (IN $K)

| MOTORIST WARNING DEVICE | TOTAL COST | PRE ENGI-NEERING COST | LABOR COST | MATERIAL COST | EQUIP-MENT COST | MIS-CELLA-NEOUS COSTS |
|---|---|---|---|---|---|---|
| Flashing lights (60) | 26.0 | 1.4 | 7.2 | 13.8 | 0.8 | 2.8 |
| Cantilevered flashing lights (40) | 29.4 | 1.2 | 7.9 | 17.7 | 1.1 | 1.5 |
| Flashing lights with gates (97) | 39.2 | 1.2 | 9.7 | 25.0 | 1.2 | 2.1 |
| Cantilevered flashing lights with gates (40) | 44.6 | 1.4 | 10.3 | 29.4 | 1.5 | 2.0 |
| Flashing lights upgraded to flashing lights with gates (40) | 33.5 | 0.7 | 8.6 | 21.4 | 1.4 | 1.4 |
| Flashing lights upgraded to cantilevered flashing lights with gates (21) | 42.7 | 1.1 | 9.9 | 27.6 | 1.9 | 2.2 |

(n) = sample size

of the crossing, the type of accounting system used by the railroad to allocate these costs, or the type of contract/railroad labor employed.

Material costs, as a percentage of total costs, increase as the motorist warning device complexity increases, while labor costs as a percentage of total costs decrease. Equipment rental costs as a percentage of total costs, remain fairly constant for all types of warning devices, as shown in Table 3-3. This suggests that while total labor costs increase as the complexity of the motorist warning device increases, they proportionately comprise a smaller percentage of the total costs.

The major cost differences between cantilevered flashing lights and flashing light installations occur in the material cost component. Table 3-4 demonstrates the cost differences. The sample yielded cost differences which are very similar for flashing light and flashing light with gate installations. The material cost for installing cantilevered flashing lights with gates is higher than for nongate installations.

Upgrade projects are less expensive than new installations. Table 3-5 shows the comparative costs for upgrades and new installations.

### 3.2.2 Installation Cost Confidence Intervals

Confidence intervals at the 0.025 level (95 percent) were established for the average cost figures for each motorist warning device installation and upgrade. Table 3-6 shows these cost ranges. The method used to calculate the confidence intervals is contained in Appendix D.

TABLE 3-3. COST COMPONENTS AS A PERCENTAGE OF TOTAL MOTORIST WARNING DEVICE INSTALLATION COSTS

| | LABOR (PERCENT) | MATERIAL (PERCENT) | EQUIPMENT (PERCENT) |
|---|---|---|---|
| Flashing lights | 30 | 53 | 3 |
| Cantilevered flashing lights | 27 | 60 | 4 |
| Flashing lights with gates | 25 | 64 | 3 |
| Cantilevered flashing lights with gates | 23 | 66 | 3 |

TABLE 3-4. TOTAL INCREASE IN INSTALLATION COSTS OF MOTORIST WARNING DEVICES DUE TO CANTILEVERS (IN $K)

| | FLASHING LIGHTS WITHOUT GATES | FLASHING LIGHTS WITH GATES |
|---|---|---|
| Total cost | 3.4 | 5.4 |
| Signal labor | 0.7 | 0.6 |
| Material | 2.4 | 4.4 |
| Equipment | 0.3 | 0.4 |

TABLE 3-5. COMPARISON OF UPGRADE AND INSTALLATION COSTS FOR MOTORIST WARNING DEVICES (IN $K)

| | UPGRADE TO GATES | INSTALL GATES | UPGRADE TO CANTILEVERED FLASHING LIGHTS WITH GATES | INSTALL CANTILEVERED FLASHING LIGHTS WITH GATES |
|---|---|---|---|---|
| Total cost | 33.5 | 39.2 | 42.7 | 44.6 |
| Pre-engineering | 0.7 | 1.2 | 1.1 | 1.4 |
| Signal labor | 8.6 | 9.7 | 9.9 | 10.3 |
| Material | 21.4 | 25.0 | 27.6 | 29.4 |
| Equipment | 1.4 | 1.5 | 1.9 | 2.9 |

TABLE 3-6. 95 PERCENT CONFIDENCE INTERVALS FOR AVERAGE INSTALLATION COSTS BY MOTORIST WARNING DEVICE (IN $K)

| | CONFIDENCE INTERVAL | MEAN COST |
|---|---|---|
| Flashing lights | 25.3 - 26.7 | 26.0 |
| Cantilevered flashing lights | 27.5 - 31.3 | 29.4 |
| Flashing lights with gates | 36.8 - 41.6 | 39.2 |
| Cantilevered flashing lights with gates | 40.4 - 48.8 | 44.6 |
| Flashing lights upgraded to gates | 30.3 - 36.7 | 33.5 |
| Flashing lights upgraded to cantilevered flashing lights with gates | 38.7 - 46.7 | 42.7 |

### 3.2.3 Factors Influencing Installation Costs

The next step in the analysis was to isolate those factors which influence the total cost of an installation. It was hypothesized that three factors would be influential.

> Type of train detection system - From the initial literature search, a hierarchy of train detection systems was determined in terms of their relative complexity. This hierarchy is, from simplest to most complex: direct current, alternating/direct current, audio frequency overlay, motion sensors or detectors, and grade crossing predictors. The total costs were expected to vary according to the type of train detection system installed.
>
> Number of railroad tracks - Costs were expected to increase by the number of tracks as circuitry work would be more extensive and complicated.
>
> Location of the crossing - Costs were expected to vary depending upon whether the crossing was rural or urban. The costs of transporting the material and crew to the site and the extent of circuitry work were hypothesized as influential factors.

It was determined that the number of sample crossings required to determine the influence of each factor for each region would be approximately 34,500. This assumed a sample of 15 observations for each permutation. This is demonstrated in Figure 3-1. As shown in this tree diagram, there is a very large number of possible combinations for any one motorist warning device in each region. Since the initial analysis had indicated no regional variations in cost, the regional samples were pooled to form one national sample for analysis of the factors.

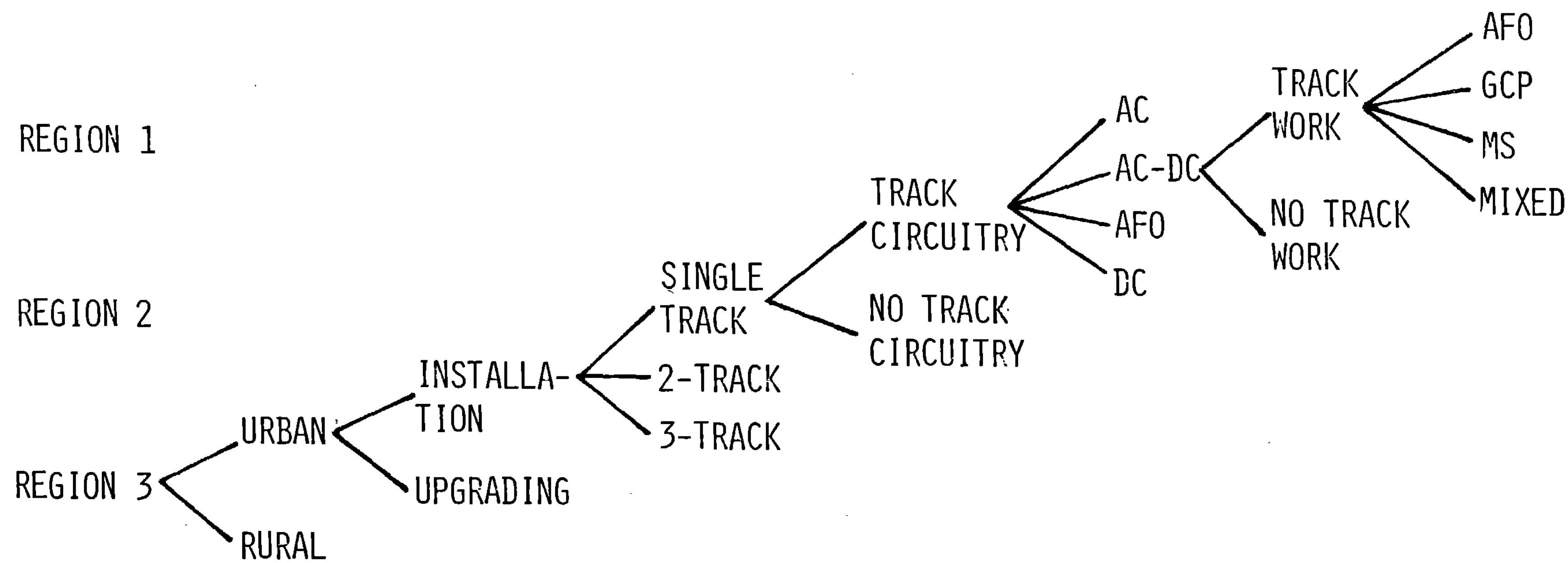


FIGURE 3-1. TREE DIAGRAM OF FACTORS INFLUENCING LIFE CYCLE COSTS

Additionally, detailed operating and locational data for each crossing were obtained by utilizing the DOT-AAR Crossing Inventory. Costs were then calculated for the crossings using the DOT-AAR Crossing Inventory data to control for cost factors.

Location - When the sample data were grouped by urban or rural location, the cost figures shown in Table 3-7 resulted. This shows that the cost differences by urban and rural location are very small and inconsistent. Confidence intervals calculated for the urban and rural costs shown in Table 3-8 also indicate considerable overlap in costs. When the number of tracks at the crossing is controlled, a similar inconsistent trend is found. Tables 3-9 and 3-10 show average costs and confidence intervals for one-track urban and rural crossings.

Number of tracks - The number of tracks at each crossing was expected to affect the total costs. As Table 3-11 demonstrates, this hypothesis was verified. The additional cost for two-track crossings ranges between 9 percent and 37 percent of a one track installation. Confidence intervals for the installation costs by track are found in Table 3-12.

Existence of track circuitry - This factor refers to whether or not the crossing was equipped with track circuitry for control of train operations or other warning devices. While none of the bills obtained for the study provided information on the type of circuitry existing at the crossing, the Seaboard Coast Line Railroad provided a list of a few crossings with track circuitry. However, the sample of crossings was not large enough to permit a statistically meaningful analysis of this factor.

TABLE 3-7. AVERAGE INSTALLATION COST FOR MOTORIST WARNING DEVICES BY LOCATION (IN $K)

| LOCATION | MOTORIST WARNING DEVICE | | | |
|---|---|---|---|---|
| | FLASHING LIGHTS | CANTILEVERED FLASHING LIGHTS | FLASHING LIGHTS WITH GATES | CANTILEVERED FLASHING LIGHTS WITH GATES |
| Urban | 28.1 (14) | 29.3 (12) | 38.0 (26) | 42.6 (22) |
| Rural | 26.5 (46) | 29.5 (28) | 39.0 (71) | 46.5 (23) |

(n) = Sample size

TABLE 3-8. 95 PERCENT CONFIDENCE INTERVALS FOR AVERAGE INSTALLATION COSTS OF MOTORIST WARNING DEVICES BY LOCATION (IN $K)

| LOCATION | MOTORIST WARNING DEVICE | | | |
|---|---|---|---|---|
| | FLASHING LIGHTS | CANTILEVERED FLASHING LIGHTS | FLASHING LIGHTS WITH GATES | CANTILEVERED FLASHING LIGHTS WITH GATES |
| Urban | 26.3-29.9 | 25.3-33.1 | 29.3-46.7 | 42.5-45.5 |
| Rural | 24.0-28.9 | 25.5-32.1 | 35.5-42.3 | 40.6-52.3 |

TABLE 3-9. AVERAGE INSTALLATION COSTS FOR MOTORIST WARNING DEVICE BY LOCATION, SINGLE TRACK (IN $K)

| | MOTORIST WARNING DEVICE | | | |
|---|---|---|---|---|
| | FLASHING LIGHTS | CANTILEVERED FLASHING LIGHTS | FLASHING LIGHTS WITH GATES | CANTILEVERED FLASHING LIGHTS WITH GATES |
| Urban - 1 Track | 26.7 | 28.3 | 33.1 | 41.6 |
| Rural - 1 Track | 23.6 | 28.8 | 32.0 | 40.5 |

TABLE 3-10. 95 PERCENT CONFIDENCE INTERVALS FOR MOTORIST WARNING DEVICE INSTALLATION COSTS BY LOCATION, SINGLE TRACK (IN $K)

| | MOTORIST WARNING DEVICE | | | |
|---|---|---|---|---|
| | FLASHING LIGHTS | CANTILEVERED FLASHING LIGHTS | FLASHING LIGHTS WITH GATES | CANTILEVERED FLASHING LIGHTS WITH GATES |
| Urban - 1 Track | 24.9-28.4 | 23.6-33.0 | 28.9-37.3 | 32.2-49.0 |
| Rural - 1 Track | 21.4-25.9 | 26.3-34.5 | 30.6-33.0 | 35.6-45.3 |

TABLE 3-11. AVERAGE INSTALLATION COSTS BY NUMBER OF TRACKS (IN $K)

| | MOTORIST WARNING DEVICE | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | FLASHING LIGHTS | | CANTILEVERED FLASHING LIGHTS | | FLASHING LIGHTS WITH GATES | | CANTILEVERED FLASHING LIGHTS WITH GATES | |
| NO. OF TRACKS | $ | PERCENT INCREASE | $ | PERCENT INCREASE | $ | PERCENT INCREASE | $ | PERCENT INCREASE |
| 1 | 24.3 | --- | 27.2 | --- | 32.1 | --- | 41.1 | --- |
| 2 | 26.5 | 9 | 31.6 | 16 | 44.1 | 37 | 48.1 | 17 |
| 3 | 34.7 | 31 | No Data | | 48.8 | 11 | 50.2 | 4 |

TABLE 3-12. 95 PERCENT CONFIDENCE INTERVALS FOR AVERAGE INSTALLATION COSTS FOR MOTORIST WARNING DEVICES BY NUMBER OF TRACKS (IN $K)

| | MOTORIST WARNING DEVICE | | | |
|---|---|---|---|---|
| TRACKS | FLASHING LIGHTS | CANTILEVERED FLASHING LIGHTS | FLASHING LIGHTS WITH GATES | CANTILEVERED FLASHING LIGHTS WITH GATES |
| 1 | 22.2-26.8 | 24.4-31.1 | 30.9-33.6 | 36.9-45.1 |
| 2 | 23.7-33.8 | 25.7-37.0 | 42.4-46.6 | 41.6-54.5 |
| 3 | Sample size not large enough for meaningful calculations | | | |

Track work - There are two types of track work which may occur during a signal installation. The first type, crossing surface work, involves the repair or replacement of the crossing surface material. The second type involves electrical and communications work necessary to install or modify the track circuitry for the train detection system, e.g., insulate joints for DC or AC-DC circuitry. The latter was hypothesized to influence costs. Many of the final billings provided signal labor and material costs itemized by track, communications, and electrical work. Track and communications costs contributed between 8 percent and 12 percent of the signal labor costs and between 2 percent and 5 percent of the material costs.

Train detection system - To determine if the type of train detection system installed affected the total installation costs, the data were divided by motorist warning device, train detection system, and number of tracks. Table 3-13 shows the variations in costs. Only the costs within each motorist warning device type should be compared to determine the hierarchy of train detection system costs, because the number of tracks for the different devices is not consistent. As Table 3-13 shows, Grade Crossing Predictors (GCP) comprise the most expensive train detection system and are frequently installed with gate devices. Audio Frequency Overlays (AFO) were the second most costly to install, followed by Alternating/Direct Current (AC/DC) in three out of four cases, and Motion Sensors (MS). It is interesting to note that although Motion Sensors are among the more sophisticated and complicated detection systems, they are consistently the least costly.

TABLE 3-13. AVERAGE INSTALLATION COSTS FOR MOTORIST WARNING DEVICES BY TRAIN DETECTION SYSTEM AND NUMBER OF TRACKS (IN $K)

| | | MOTORIST WARNING DEVICE | | | |
|---|---|---|---|---|---|
| | | FLASHING LIGHTS | CANTILEVERED FLASHING LIGHTS | FLASHING LIGHTS WITH GATES | CANTILEVERED FLASHING LIGHTS WITH GATES |
| | Tracks | 1 | 1 | 2 | 2 |
| Train Detection System | Grade Crossing Predictors (GCP) | -- | -- | 54.3 | 45.9 |
| | Audio Frequency Overlay (AFO) | 25.9 | 33.3 | 46.2 | 44.2 |
| | Alternating/Direct Current (AC-DC) | 22.6 | 26.9 | 43.6 | 44.2 |
| | Motion Sensors (MS) | 22.3 | 28.5 | 39.0 | 39.2 |
| | Direct Current (DC) | Sample size not large enough for meaningful calculations. | | | |

### 3.2.4 Maintenance Costs

The maintenance data received were not itemized by year over the life of the equipment but were expressed as total average annual costs. These costs were determined by summing the maintenance costs incurred in a year for each type of motorist warning device and dividing by the number of crossings. Motorist warning devices of varying age and condition were therefore included in the compilation of average annual costs. Although maintenance costs may increase with the age of the device, the average annual costs do not reflect this type of variation. For this reason, life-cycle 30-year maintenance costs were determined on the basis of discounting average annual cost over the life of the equipment.

The original maintenance cost data received for the study and shown in Table 2-2 were based on various years. All maintenance costs were therefore updated to 1977 dollars to provide a consistent basis for analysis. The resulting average annual and 30-year life cycle maintenance costs are shown in Table 3-14. It should be noted that the maintenance costs shown in Table 3-14 based on negotiated values do not represent the actual costs contributed by the states. In all cases, the states contribute no more than 50 percent of these amounts as shown in Table 2-2.

The resulting 30-year life cycle maintenance costs expressed as a percent of installation and total life cycle costs are shown in Table 3-15. Maintenance costs as a percentage of installation costs increased with the complexity of the motorist warning device.

## 3.3 REGIONAL COST FINDINGS

The average total installation cost and installation component costs for each active motorist warning device were compared

TABLE 3-14. AVERAGE ANNUAL AND 30-YEAR LIFE CYCLE MAINTENANCE COSTS BY DATA SOURCE AND MOTORIST WARNING DEVICE

| | FLASHING LIGHTS | | CANTILEVERED FLASHING LIGHTS | | FLASHING LIGHTS WITH GATES | | CANTILEVERED FLASHING LIGHTS WITH GATES | |
|---|---|---|---|---|---|---|---|---|
| | AVERAGE ANNUAL | 30-YEAR | AVERAGE ANNUAL | 30-YEAR | AVERAGE ANNUAL | 30-YEAR | AVERAGE ANNUAL | 30-YEAR |
| California | $ 1,173 | $11,061 | $ 1,493 | $14,077 | $ 2,426 | $22,876 | $ 2,096 | $27,401 |
| Conrail | 2,004 | 18,891 | 2,004 | 18,891 | 2,968 | 27,979 | 2,968 | 27,979 |
| Florida DOT | 1,928 | 18,175 | 2,471 | 23,299 | 2,822 | 26,602 | 3,399 | 32,050 |
| Iowa | 1,079 | 10,178 | 1,374 | 12,952 | 2,233 | 21,050 | 2,675 | 25,217 |
| Maine Central | 1,358 | 12,808 | 1,729 | 16,299 | 2,809 | 26,486 | 3,365 | 31,724 |
| North Carolina | 2,043 | 19,259 | 2,619 | 24,690 | 2,849 | 26,857 | 3,323 | 32,357 |
| Texas Railway Association | 840 | 7,919 | 1,080 | 10,181 | 1,960 | 18,468 | 2,160 | 20,362 |
| Virginia Railway Association | 1,960 | 18,476 | 2,512 | 23,686 | 2,866 | 27,021 | 3,453 | 32,555 |
| Wisconsin | 1,070 | 10,093 | 1,362 | 12,846 | 2,214 | 20,874 | 2,652 | 25,003 |
| NATIONAL AVERAGE | $ 1,495 | $14,095 | $ 1,848 | $17,435 | $ 2,460 | $23,237 | $ 2,870 | $27,055 |

TABLE 3-15. LIFE CYCLE MAINTENANCE COSTS AS A PERCENTAGE OF MOTORIST WARNING DEVICE COSTS

| MOTORIST WARNING DEVICE | PERCENT OF INSTALLATION COSTS | PERCENT OF TOTAL LIFE CYCLE COST |
|---|---|---|
| Flashing lights | 54 | 35 |
| Cantilevered flashing lights | 59 | 37 |
| Flashing lights with gates | 59 | 37 |
| Cantilevered flashing lights with gates | 61 | 40 |

on a regional basis. It was hypothesized that labor and material costs, including freight and handling charges, would vary geographically. By isolating these two component costs and comparing them by region, regional trends in installation costs were expected to be identified. To accomplish this, the final billings were grouped by FRA region and motorist warning device. Averages were then calculated for the total and component costs.

Regional variations in total and component costs did not follow any consistent patterns. No region demonstrated constant high or low costs in any of the cost component categories. One explanation for the lack of consistent variations is that the railroads cross regional boundaries and the costs appeared to vary more by railroad than by region. The results of the regional analysis are presented in Appendix C. Both maintenance and installation costs are itemized.

## 3.4 PASSIVE WARNING DEVICES

As indicated in Section 2.3.1, cost data on passive warning devices was very limited. The only available information consisted of three estimates for the costs of installing crossbucks at nine locations in Kentucky. These estimates, combined with information obtained from the material listings of the billings, indicate that the average material cost per crossbuck was approximately $72. This includes the signs, posts, and related hardware. In the Kentucky estimates, labor costs per crossing were $80 to $85.

## 3.5 RUBBERIZED CROSSING SURFACES

Rubberized crossing surfaces are a relatively new product and are not installed as frequently as other types of surfaces. The cost information received on rubberized surface installations was very limited in terms of sample size and in many cases was incomplete. This was due to the fact that most of the billings on rubberized surfaces contained cost data on other track and signal work performed at the crossing. It was difficult to isolate labor, equipment rental, and total costs for the rubberized crossing work. However, several steps were taken to determine the relevant costs.

Material costs were analyzed in two ways. First, the detailed materials listed in the billings were examined and the costs of the rubberized surface were isolated. The number of track or linear feet of rubberized surface installed at each crossing was obtained from the work description and the cost per foot of rubberized pads was then calculated. To check these calculations, manufacturers of rubberized crossing surfaces were contacted to obtain quoted sales price on their cost of rubberized surfaces per track foot. The manufacturers provided detailed information on the types of material available, the installation process, and estimates of the service life of the crossing surface. Table 3-16 shows the cost per track foot of the rubberized crossing surfaces obtained from the actual billings and the manufacturers.

The material costs per track foot are fairly consistent between manufacturers' information and the billings. The actual material costs for any given crossing will vary by the number of tracks, number of highway lanes, and the angle of the crossing. Additionally, the age and condition of the tracks, ties and ballast will affect the total cost of the project as the manufacturers recommend new tracks and ties be in place before the surface is installed.

Maintenance costs for rubberized surfaces are estimated to be almost nonexistent. For rubberized pads, preventive maintenance consists of periodic sweeping out of debris from the flangeways. Other maintenance costs may occur only once every several years when the trackage is retamped. If a rubberized pad is found to be defective at this time, a new pad may be inserted in its place. For the epoxy and rubber aggregate mixture, maintenance consists of cutting out the damaged portion of the pad, and recasting it with the rubberized material.

Labor costs for installing the rubberized surfaces also vary by the type and size of the crossing. From the final billings, labor costs were calculated per trackfoot. The sample size for labor costs was very small; only eight billings provided separate labor costs. The labor costs per track foot of rubberized surface installed ranged from $70 to $85.

Equipment rental and total costs were difficult to isolate because billings contained cost data on other types of crossing work. However, equipment rental costs vary by the type of material installed. The epoxy and rubber aggregate mixture surface requires special machinery. This equipment along with

TABLE 3-16. MATERIAL COST PER TRACK FOOT FOR RUBBERIZED CROSSING SURFACES

| SOURCE: | COST PER TRACK FOOT | SERVICE LIFE | TYPE OF MATERIAL |
|---|---|---|---|
| 1) Final billings (15) | $220 | | mixed |
| 2) Goodyear Tire Co. | $227 | 30 yr. | rubber pads with steel inserts sold in 3' pads |
| 3) Park Rubber Co. | $220 | 30 yr. | rubber pads with steel cables used instead of spikes to secure pads |
| 4) Fel-Pro, Inc. | $225 | 30 yr. | epoxy and rubber aggregate mixture molded to tracks |
| 5) Structural Rubber Products, Inc. | $225 | 30 yr. | rubber pads with steel inserts |

(n) = sample size

supervision is provided by the manufacturer. The manufacturer estimated the cost per track foot to be $295 to $300 if the equipment and personnel are included. The other rubberized surfaces require standard equipment and tools for installation. The costs for each crossing installation will vary by the amount of equipment each railroad owns.

Total costs for the installation of rubberized surfaces were also calculated per track foot. Only ten billings had a sufficient cost breakdown to determine total costs. The total costs ranged from $319 to $535 per track foot, and the mean total cost was $389 per track foot. Since the sample size was small and the costs were difficult to allocate according to the type of crossing work, these figures must be viewed as approximations. Table 3-17 summarizes the rubberized crossing surface cost data.

TABLE 3-17. SUMMARY OF RUBBERIZED CROSSING SURFACE COST DATA

| TYPE OF COSTS | COST PER TRACK FOOT |
|---|---|
| Total costs | $389 |
| Labor costs | $70 - 85 |
| Material costs | $220 - 227 |
| Maintenance costs[1] | $5 |

[1]Texas Transportation Institute, Railroad-Highway Grade Crossing Handbook, Report No. FHWA-TS-78-214, U.S. Department of Transportation, Federal Highway Administration, College Station, Texas, August, 1978.

# APPENDIX A

## SAMPLE LETTERS TO STATES AND RAILROADS

**TRANSPORTATION SYSTEMS DIVISION**

July 26, 1978

Mr. T. B. Hutcheson
Assistant Vice President of Engineering
Seaboard Coast Line Railroad
500 Water Street
Jacksonville, Florida 32202

Dear Mr. Hutcheson:

Input Output Computer Services (IOCS) of Cambridge, Massachusetts, is under contract to the Transportation Systems Center (TSC) of the U.S. Department of Transportation to collect, analyze, and document life cycle cost data on grade crossing warning systems. This research is being done for the Federal Railroad Administration.

As discussed with you in a phone conversation on Tuesday, July 25, 1978, we are looking for copies of the detailed final billings for at least twenty grade crossing warning system projects where active equipment was installed new or as an upgrading. We are interested in a package that includes each of the four active equipment configurations: namely, flashing lights, flashing lights with gates, cantilevered flashing lights, cantilevered flashing lights with gates. The package should also cover the variety of train detection systems: constant warning time devices, motion sensors, AC-DC rectified circuits, DC circuits, and Audio Frequency Overlay. A variety of projects that includes one or more sets of tracks, single lane or multi-lane roadways, and the presence of existing track circuits is desired as is the FRA crossing number. We are interested in information on projects from January 1, 1975, to the present which encompass several of the states in which Seaboard does business.

Included in the scope of our study are maintenance costs incurred by the railroads to maintain a grade crossing and its equipment. You spoke of a payment scheme whereby Florida, North Carolina, and Virginia pay Seaboard a fixed fee for maintenance per year per crossing. Please include in the package these fee schedules as well as any other information that is available on grade crossing maintenance costs.

A DIVISION OF:
**INPUT OUTPUT COMPUTER SERVICES, INC.**
689 CONCORD AVENUE, CAMBRIDGE, MA 02138, (617) 661-8700
BRANCH OFFICE: ARLINGTON, VA (703) 979-6266

Mr. T. B. Hutcheson
July 26, 1978
Page Two

Our project is of short duration and these data needs very important. We hope that you can provide the requisite information before August 14, 1978. As stated by Bob Stout of the AAR in his letter to you dated June 1, 1978 (attached), this study will be helpful to the railroad industry.

We appreciate your cooperation and hope to hear from you soon. If you have any questions, please feel free to call us.

Sincerely yours,

Joseph Morrissey

JM:mr
attachment

ASSOCIATION OF
AMERICAN RAILROADS
OPERATIONS AND MAINTENANCE DEPARTMENT . STATE-RAIL PROGRAMS DIVISION
AMERICAN RAILROADS BUILDING . WASHINGTON, D.C. 20036

J. E. MARTIN
Vice-President
Operations and Maintenance Department

C. L. AMOS
Executive Director

R. B. STOUT
Manager-Rail Highway Programs

June 1, 1978

The Transportation Systems Center of the U. S. Department of Transportation has awarded a contract to Input Output Computer Services, Inc. (IOCS), to collect, analyze, and document grade crossing warning systems life cycle cost. This research is being done for the Federal Railroad Administration.

The study has important implications regarding the future of the grade crossing warning device installation program. Of even greater importance is the impact it may have with respect to the future of maintenance responsibilities. Therefore, it is to our benefit that the study be done right. Good cost data is essential if this is to be a useful tool for public policy development and if it is to be helpful to our industry.

IOCS has selected your railroad as one of those from which they may seek to obtain data. Mr. Curtis Priest, Mr. Charles Erdrich, or other members of the OICS research team will likely be in contact with you in the near future. Since the data needed can only come from the railroad industry, I would appreciate any assistance which you can render to this team.

Sincerely,

Robert B. Stout

Robert B. Stout

S:y

cc: W. Curtiss Priest, Ph.D.

**TRANSPORTATION SYSTEMS DIVISION**

June 28, 1978

Mr. Donald Higgins
Chief of Local Assistance
California Department of Transportation
Sacramento, CA

Dear Mr Higgins:

Input Output Computer Services (IOCS) of Cambridge, Massachusetts is under contract to the Transportation Systems Center (TSC) of the U.S. Department of Transportation to collect, analyze, and document life cycle cost data on grade crossing warning systems. The data will be used as input into a computer model that TSC has developed for the Federal Railroad Administration that will improve the methods by which states prioritize and allocate funds for grade crossing improvement programs.

We intend to collect data from at least one state in each of the five FRA regions. We have selected California due to its extensive work with the railroads and its thorough oversight of the crossing improvements.

We understand that the operating railroads submit detailed cost estimates as part of the federal funding process. As discussed with you in our phone conversation on Wednesday, June 28, we would like copies of these estimates and the detailed final billings for approximately 100 grade crossing improvement projects where active equipment was installed either new or as an upgrading of an existing active system. We are interested in information on consecutive projects from January 1, 1975 to the present.

The level of detail in which we are interested includes information on engineering, procurement, installation, and labor costs for all subsystems and subsystem components of the crossing warning system. For our purposes these subsystems are: train detection, control logic,

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689 CONCORD AVENUE, CAMBRIDGE, MA 02138, (617) 661-8700
BRANCH OFFICE: ARLINGTON, VA (703) 979-6266

crossing surface, vehicle warning, and interconnection (cable and power hook-ups.) The FRA crossing number is also desired.

Our project is of short duration and these data needs quite important. We hope that you can provide the requisite data before July 24, 1978. We will gladly pay photocopying expenses.

We appreciate your cooperation and hope to hear from you soon.

Sincerely,

Joseph M Morrissey

Joseph Morrissey

JM:hw
cc: Curtis Priest, IOCS

APPENDIX B

EXAMPLE OF A COST BILLING

STATE OF ARKANSAS
STATE HIGHWAY DEPT.
P.O.BOX 2261
LITTLE ROCK ARKANSAS

BILL AUDIT NO -
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SA- G0904518

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INSTALLING CROSSING WARNING SYSTEMS AT STATE HIGHWAY 161 XING NO TCN 287-72 AT LITTLE ROCK BRANCH ARKANSAS GMO-90451

FINAL BILL PER STATEMENT ATTACHED 24274.07
DATE FIRST WORK PERFORMED JUL-1977
DATE LAST WORK PERFORMED FEB-1978

THE RECORDS SUPPORTING THE CHARGES IN THIS BILL ARE LOCATED IN THE OFFICE OF MANAGER OF DISBURSEMENTS ACCOUNTING, SAN FRANCISCO, CALIFORNIA

S U M M A R Y

| | |
|---|---|
| 1-INSTALL SIGNALS | 23455.98 |
| 2-PRELIMINARY ENGR | 681.51 |
| 3-ACCTG. & PREP. | 136.58 |
| T O T A L B I L L | 24274.07 |

STATE OF ARKANSAS
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1-INSTALL SIGNALS

LABOR

| | | | |
|---|---|---|---|
| 12 77 SYS.SIGNAL SHOP | 2.00 HRS AT 9.5098 | 19.02 | |
| 12 77 SYS.SIGNAL SHOP | 4.00 HRS AT 7.7700 | 31.08 | |
| 12 77 SYS.SIGNAL SHOP | 64.00 HRS AT 7.6600 | 490.24 | |
| 1 78 SIGNAL GANG #26 | 48.00 HRS AT 9.5094 | 456.45 | |
| 1 78 SIGNAL GANG #26 | 96.00 HRS AT 7.6600 | 735.36 | |
| 1 78 SIGNAL GANG #26 | 48.00 HRS AT 6.5800 | 315.84 | |
| 1 78 SIGNAL GANG #26 | 48.00 HRS AT 6.4900 | 311.52 | |
| 2 78 SIGNAL GANG #26 | 64.00 HRS AT10.4604 | 669.46 | |
| 2 78 SIGNAL GANG #26 | 96.00 HRS AT 7.6600 | 735.36 | |
| 2 78 SIGNAL GANG #26 | 64.00 HRS AT 6.5800 | 421.12 | |
| 2 78 SIGNAL GANG #26 | 24.00 HRS AT 6.4900 | 155.76 | |
| | | 4341.21 | |
| PLUS- 7.250% VACATION ALL | ON 4341.21 | 314.74 | |
| 3.500% PD HOLIDAY | ON 4341.21 | 151.94 | |
| 23.100% RR&UI TAXES | ON 4807.89 | 1110.62 | |
| 5.000% HEALTH & WELFARE | ON 4341.21 | 217.06 | |
| 3.000% COMP INS | ON 4655.95 | 139.68 | |
| 1.000% PL&PD INS | ON 4655.95 | 46.56 | |
| 0.125/HR EXC TAX ON 558.000 HRS | | 69.75 | 6391.56 |

MATERIAL
1.00 2C781 BLOWER FAN  2 FROM A
UNIT PRICE IS 11.4500 EA
TOTAL WEIGHT IS 0.0 LBS  11.45

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| | | | |
|---|---|---|---|
| 1.00 2E206 THERMOSTAT | | 2 FROM A | |
| | UNIT PRICE IS | 13.6400 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 13.64 |
| 46.00 SCREW BRASS RH #10X1" | | 2 FROM A | |
| | UNIT PRICE IS | 0.0600 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 2.76 |
| 10.00 SCREW BRASS RH #10X3/4" | | 2 FROM A | |
| | UNIT PRICE IS | 0.0400 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 0.40 |
| 31.00 SCREW MACHINE 1/4"X20X7/8" | | 2 FROM A | |
| | UNIT PRICE IS | 0.0500 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 1.55 |
| 140.00 FT WIRE #6 BONDSTRAND | | 2 FROM A | |
| | UNIT PRICE IS | 0.5000 FT | |
| | TOTAL WEIGHT IS | 0.0 LBS | 70.00 |
| 300.00 FT WIRE # 10 AWG FLEX | | 1 FROM A | |
| | UNIT PRICE IS | 0.0980 FT | |
| | TOTAL WEIGHT IS | 0.0 LBS | 29.40 |
| 300.00 FT WIRE FLEX #14 AWG | | 1 FROM A | |
| | UNIT PRICE IS | 0.0510 FT | |
| | TOTAL WEIGHT IS | 0.0 LBS | 15.30 |
| 2345.00 FT WIRE 1-COND #6 AWG | | 1 FROM A | |
| | UNIT PRICE IS | 0.1750 FT | |
| | TOTAL WEIGHT IS | 0.0 LBS | 410.37 |
| 1.00 CAPACITOR 3900 MFD. | | 2 FROM A | |
| | UNIT PRICE IS | 6.0000 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 6.00 |
| 1.00 CLAMP CAPACITOR #VR3 | | 2 FROM A | |
| | UNIT PRICE IS | 0.2000 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 0.20 |
| 2.00 RESISTOR 50 OHM 50 WATT | | 2 FROM A | |
| | UNIT PRICE IS | 2.6500 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 5.30 |
| 2.00 PADLOCK ASSY #49-6 | | 2 FROM A | |
| | UNIT PRICE IS | 4.7500 EA | |
| | TOTAL WEIGHT IS | 1.50 LBS | 9.50 |
| 1.00 TRANSFORMER W-800 | | 1 FROM A | |
| | UNIT PRICE IS | 238.1400 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 238.14 |

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| | | | |
|---|---|---|---|
| 1.00 RELAY DN-22A 4OHM 2FB | 2 FROM A | | |
| UNIT PRICE IS | 94.0800 EA | | |
| TOTAL WEIGHT IS | 0.0 LBS | | 94.08 |
| 2.00 RELAY PN-150B W/BASE | 1 FROM A | | |
| UNIT PRICE IS | 249.7200 EA | | |
| TOTAL WEIGHT IS | 0.0 LBS | | 499.44 |
| 1.00 RELAY PN-150HD W/BASE | 1 FROM A | | |
| UNIT PRICE IS | 297.1199 EA | | |
| TOTAL WEIGHT IS | 0.0 LBS | | 297.12 |
| 1.00 RELAY PN-150P W/BASE | 1 FROM A | | |
| UNIT PRICE IS | 251.9200 EA | | |
| TOTAL WEIGHT IS | 0.0 LBS | | 251.92 |
| 2.00 RELAY PF-256 W/BASE | 1 FROM A | | |
| UNIT PRICE IS | 356.9299 EA | | |
| TOTAL WEIGHT IS | 0.0 LBS | | 713.86 |
| 1.00 SP-19.2A SURGE PROTECTOR | 2 FROM A | | |
| UNIT PRICE IS | 36.7500 EA | | |
| TOTAL WEIGHT IS | 0.0 LBS | | 36.75 |
| 2.00 MODEL SM XING GATE W/24'F/GAR | 1 FROM A | | |
| UNIT PRICE IS | 2031.6599 EA | | |
| TOTAL WEIGHT IS | 0.0 LBS | | 4063.32 |
| 2.00 A479A 5 FLASH LIG SIG 2 WAY | 1 FROM A | | |
| UNIT PRICE IS | 731.0000 EA | | |
| TOTAL WEIGHT IS | 0.0 LBS | | 1462.00 |
| 1.00 2WAY XING ARMS W/4FA 12"LIGHT | 1 FROM A | | |
| UNIT PRICE IS | 468.0000 EA | | |
| TOTAL WEIGHT IS | 0.0 LBS | | 468.00 |
| 2.00 ALUMINUM DC XING BELL 5"MAST | 1 FROM A | | |
| UNIT PRICE IS | 144.0000 EA | | |
| TOTAL WEIGHT IS | 0.0 LBS | | 288.00 |
| 2.00 INSTRUMENT CASE 18-1/2" | 1 FROM A | | |
| UNIT PRICE IS | 33.5000 EA | | |
| TOTAL WEIGHT IS | 0.0 LBS | | 67.00 |
| 1.00 LB NC-OXIDE GREASE | 2 FROM A | | |
| UNIT PRICE IS | 6.0000 LB | | |
| TOTAL WEIGHT IS | 0.0 LBS | | 6.00 |
| 0.50 QT.PVC SOLVENT CEMENT | 2 FROM A | | |
| UNIT PRICE IS | 5.5000 QT | | |
| TOTAL WEIGHT IS | 0.0 LBS | | 2.75 |

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STATE HICHWAY DEPT.
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| | | | |
|---|---|---|---|
| 8.00 BCNC WIRE SUPPORT CLAMP | | 2 FROM A | |
| | UNIT PRICE IS | 0.2200 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 1.76 |
| 2.00 LB JUTE RCPE PACKING | | 2 FROM A | |
| | UNIT PRICE IS | 0.3800 LB | |
| | TOTAL WEIGHT IS | 0.0 LBS | 0.76 |
| 2.00 GATE FOUNDATION GALV | | 1 FROM A | |
| | UNIT PRICE IS | 146.0000 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 292.00 |
| 5.00 CONDUIT COUPLING 11/4" | | 2 FROM A | |
| | UNIT PRICE IS | 0.2400 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 1.20 |
| 40.00 FT.CONDUIT 11/4"GALV | | 2 FROM A | |
| | UNIT PRICE IS | 0.3020 FT | |
| | TOTAL WEIGHT IS | 0.0 LBS | 12.08 |
| 9.00 FD-240 BATTERIES(3CELLTRAY) | | 1 FROM A | |
| | UNIT PRICE IS | 85.4900 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 769.41 |
| 3.00 INSL.RAIL JOINTS 85 LBS | | 1 FROM A | |
| | UNIT PRICE IS | 149.0000 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 447.00 |
| 1080.00 FT.WIRE 1-COND #10 SOLID | | 1 FROM A | |
| | UNIT PRICE IS | 0.0980 FT | |
| | TOTAL WEIGHT IS | 0.0 LBS | 105.84 |
| 1.00 MOTION SENSOR #68350-156-20 | | 1 FROM A | |
| | UNIT PRICE IS | 1992.0000 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 1992.00 |
| 180.00 FT.CONDUIT 3"PVC | | 2 FROM A | |
| | UNIT PRICE IS | 1.7900 FT | |
| | TOTAL WEIGHT IS | 0.0 LBS | 322.20 |
| 6.00 ELBOW 90 3" | | 2 FROM A | |
| | UNIT PRICE IS | 13.5000 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 81.00 |
| 20.00 COUPLING 3" | | 2 FROM A | |
| | UNIT PRICE IS | 1.5600 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 31.20 |
| 1.00 POLES CREO PINE SIG 40 FT | | 2 FROM A | |
| | UNIT PRICE IS | 79.0000 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 79.00 |

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| | | | |
|---|---|---|---|
| 1.00 RL TAPE BLK FRICTION 3/4" | | 2 FROM A | |
| | UNIT PRICE IS | 0.7000 RL | |
| | TOTAL WEIGHT IS | 0.0 LBS | 0.70 |
| 4.00 RUBBER BOOTLEG | | 2 FROM A | |
| | UNIT PRICE IS | 0.5000 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 2.00 |
| 9.00 STRAND PIN RACO #624-6 | | 2 FROM A | |
| | UNIT PRICE IS | 0.5800 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 5.22 |
| 8.00 CLAMP RACO INS | | 2 FROM A | |
| | UNIT PRICE IS | 0.2600 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 2.08 |
| 400.00 BONDS CADWELD | | 2 FROM A | |
| | UNIT PRICE IS | 0.8900 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 356.00 |
| 2.00 ROD GRD 5/8'X8' | | 2 FROM A | |
| | UNIT PRICE IS | 7.2600 EA | |
| | TOTAL WEIGHT IS | 16.00 LBS | 14.52 |
| 2.00 CLAMPS GRD WIRE HUBBARD | | 2 FROM A | |
| | UNIT PRICE IS | 0.7500 EA | |
| | TOTAL WEIGHT IS | 0.90 LBS | 1.50 |
| 17.00 FT.PANDUIT DUCT COVER | | 2 FROM A | |
| | UNIT PRICE IS | 0.4100 FT | |
| | TOTAL WEIGHT IS | 0.0 LBS | 6.97 |
| 8.50 FT.UNISTRUT CHANNEL #P-6000 | | 2 FROM A | |
| | UNIT PRICE IS | 0.5000 FT | |
| | TOTAL WEIGHT IS | 0.0 LBS | 4.25 |
| 16.00 UNISTRUT NUT W/SPRING | | 2 FROM A | |
| | UNIT PRICE IS | 0.1500 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 2.40 |
| 18.00 #14-16 WIRE RECEPTACLES | | 2 FROM A | |
| | UNIT PRICE IS | 0.8000 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 14.40 |
| 36.00 #10-12 WIRE RECEPTACLES | | 2 FROM A | |
| | UNIT PRICE IS | 0.8000 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 28.80 |
| 6.00 #4 SOLDER LUG | | 2 FROM A | |
| | UNIT PRICE IS | 0.1600 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 0.96 |

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MONTHS ACCOUNT-
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DATE MADE -
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```
36.00 628-16N TERM INSL #14-16 AWG    2 FROM A
              UNIT PRICE IS       0.0800 EA
              TOTAL WEIGHT IS         0.0  LBS        2.88
36.00 628-17N INSL TERM #10-12 AWG    2 FROM A
              UNIT PRICE IS       0.0800 EA
              TOTAL WEIGHT IS         0.0  LBS        2.88
 4.00 628-1 TEST TERM #14-16AWG       2 FROM A
              UNIT PRICE IS       0.5000 EA
              TOTAL WEIGHT IS         0.07 LBS        2.00
30.00 628-2 TEST TERM #10-12 AWG      2 FROM A
              UNIT PRICE IS       0.5400 EA
              TOTAL WEIGHT IS         0.54 LBS       16.20
 3.00 320-861 API SPAD TERM #14-16    2 FROM A
              UNIT PRICE IS       0.1100 EA
              TOTAL WEIGHT IS         0.0  LBS        0.33
 2.00 628-2D FLAG TERM #14-16 AWG     2 FROM A
              UNIT PRICE IS       0.0500 EA
              TOTAL WEIGHT IS         0.0  LBS        0.10
10.00 321598 RING-TONG TERM 6 AWG     2 FROM A
              UNIT PRICE IS       0.1500 EA
              TOTAL WEIGHT IS         0.0  LBS        1.50
 5.00 CONNECTOR #839-5 12"LONG        2 FROM A
              UNIT PRICE IS       0.7900 EA
              TOTAL WEIGHT IS         0.0  LBS        3.95
 9.00 12-POST TERM STRIP #390-11      2 FROM A
              UNIT PRICE IS       4.7500 EA
              TOTAL WEIGHT IS         0.0  LBS       42.75
12.00 2-POST TERM #612-5X             2 FROM A
              UNIT PRICE IS       1.1800 EA
              TOTAL WEIGHT IS         0.0  LBS       14.16
78.00 FLEXITE PLASTIC MARKING TUBES   2 FROM A
              UNIT PRICE IS       0.0700 EA
              TOTAL WEIGHT IS         0.0  LBS        5.46
88.00 TAGS BLACK FIBER                2 FROM A
              UNIT PRICE IS       0.1040 EA
              TOTAL WEIGHT IS         0.0  LBS        9.15
 7.00 #408 INSL NUT                   2 FROM A
              UNIT PRICE IS       0.7900 EA
              TOTAL WEIGHT IS         0.0  LBS        5.53
```

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| | | |
|---|---|---|
| 1.00 #HO-221 OFF-SET NIPPLE | 2 FROM A | |
| UNIT PRICE IS | 0.3800 EA | |
| TOTAL WEIGHT IS | 0.0 LBS | 0.38 |
| 2.00 CONDUIT LOCK NUT 1/2" | 2 FROM A | |
| UNIT PRICE IS | 2.0700 EA | |
| TOTAL WEIGHT IS | 0.0 LBS | 4.14 |
| 1.00 #QO2-4AS BREAKER BOX | 2 FROM A | |
| UNIT PRICE IS | 4.7500 EA | |
| TOTAL WEIGHT IS | 0.0 LBS | 4.75 |
| 1.00 #QO BREAKER #130 30A | 2 FROM A | |
| UNIT PRICE IS | 1.8100 EA | |
| TOTAL WEIGHT IS | 0.0 LBS | 1.81 |
| 1.00 QO-115 GRD FAULT INTERUPTER | 2 FROM A | |
| UNIT PRICE IS | 28.5000 EA | |
| TOTAL WEIGHT IS | 0.0 LBS | 28.50 |
| 1.00 PK-4GTA GRD BAR KIT | 2 FROM A | |
| UNIT PRICE IS | 0.8000 EA | |
| TOTAL WEIGHT IS | 0.0 LBS | 0.80 |
| 34.00 LPC-10179 ARRESTOR | 2 FROM A | |
| UNIT PRICE IS | 8.7000 EA | |
| TOTAL WEIGHT IS | 0.0 LBS | 295.80 |
| 68.00 LPC-10181 ARRESTOR CLIP | 2 FROM A | |
| UNIT PRICE IS | 0.6000 EA | |
| TOTAL WEIGHT IS | 0.0 LBS | 40.80 |
| 1.00 ELASTIMOLD PROTECTOR | 2 FROM A | |
| UNIT PRICE IS | 0.7000 EA | |
| TOTAL WEIGHT IS | 0.0 LBS | 0.70 |
| 1.00 1230-C1 SURGE PROTECTOR | 2 FROM A | |
| UNIT PRICE IS | 42.4400 EA | |
| TOTAL WEIGHT IS | 0.0 LBS | 42.44 |
| 1.00 OUTLET BOX 2"X 3" | 2 FROM A | |
| UNIT PRICE IS | 0.7800 EA | |
| TOTAL WEIGHT IS | 0.0 LBS | 0.78 |
| 1.00 5252 DUPLEX RECEPTACLE | 2 FROM A | |
| UNIT PRICE IS | 1.4700 EA | |
| TOTAL WEIGHT IS | 0.0 LBS | 1.47 |
| 1.00 91532 RECEPTACLE COVER | 2 FROM A | |
| UNIT PRICE IS | 0.3300 EA | |
| TOTAL WEIGHT IS | 0.0 LBS | 0.33 |

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| | | | |
|---|---|---|---|
| 1.00 ALUM PRINT POCKET | | 2 FROM A | |
| | UNIT PRICE IS | 3.7500 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 3.75 |
| 3.00 U.G.CABLE RISER | | 2 FROM A | |
| | UNIT PRICE IS | 15.4000 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 46.20 |
| 1.00 CASE ALUM 61-1/4" | | 2 FROM A | |
| | UNIT PRICE IS | 520.0000 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 520.00 |
| 1.00 3AG SLC-BLC 3A FUSE FOR FAN | | 2 FROM A | |
| | UNIT PRICE IS | 0.2800 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 0.28 |
| 1.00 IN-LINE FUSE HOLDER COMP. | | 2 FROM A | |
| | UNIT PRICE IS | 0.7000 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 0.70 |
| 15.00 1/4-20 TEE NUTS | | 2 FROM A | |
| | UNIT PRICE IS | 0.0520 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 0.78 |
| 1.00 PT.PABCO #2 ACID REST.PAINT | | 2 FROM A | |
| | UNIT PRICE IS | 1.5000 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 1.50 |
| 1.00 RESISTOR 50 OHM 5 WATT | | 2 FROM A | |
| | UNIT PRICE IS | 2.6500 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 2.65 |
| 17.00 FT.PANDUIT WIRE DUCT | | 2 FROM A | |
| | UNIT PRICE IS | 1.2900 FT | |
| | TOTAL WEIGHT IS | 0.0 LBS | 21.93 |
| 4.00 BOLTS STAINLESS STEEL 11/4"X1 | | 2 FROM A | |
| | UNIT PRICE IS | 0.3000 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 1.20 |
| 16.00 NUTS STAINLESS STEEL 1/4" | | 2 FROM A | |
| | UNIT PRICE IS | 0.0600 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 0.96 |
| 13.00 STAR WASHERS STAINLESS STEEL | | 2 FROM A | |
| | UNIT PRICE IS | 0.1000 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 1.30 |
| 1.00 RUBBERMAT 58-1/4"X12" | | 2 FROM A | |
| | UNIT PRICE IS | 2.1000 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 2.10 |

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| | | | |
|---|---|---|---|
| 1.00 3/4"COPPER GRD STRAP | | 2 FROM A | |
| | UNIT PRICE IS | 2.0000 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 2.00 |
| 5.00 AMP TEST TERM.#16-14 321524 | | 2 FROM A | |
| | UNIT PRICE IS | 0.0300 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 0.15 |
| 1.00 31-251 WIRE LUBE | | 2 FROM A | |
| | UNIT PRICE IS | 0.5000 GAL | |
| | TOTAL WEIGHT IS | 0.0 LBS | 0.50 |
| 2.00 11/4 90 GALV.ELBOWS | | 2 FROM A | |
| | UNIT PRICE IS | 0.8200 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 1.64 |
| 60.00 FT.WIRE #8 THW STRAN BLACK | | 2 FROM A | |
| | UNIT PRICE IS | 0.0110 FT | |
| | TOTAL WEIGHT IS | 0.0 LBS | 0.66 |
| 60.00 FT.WIRE #8 THW STRAN WHITE | | 2 FROM A | |
| | UNIT PRICE IS | 0.0110 FT | |
| | TOTAL WEIGHT IS | 0.0 LBS | 0.66 |
| 2.00 QC 130 SQ"D"CIRCUIT BREAKER | | 2 FROM A | |
| | UNIT PRICE IS | 2.5200 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 5.04 |
| 1.00 B-125 BUSHING 11/4 RAIN TIGHT | | 2 FROM A | |
| | UNIT PRICE IS | 0.7500 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 0.75 |
| 1.00 QC 130 SQ D BOX EXTERIOR | | 2 FROM A | |
| | UNIT PRICE IS | 1.3200 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 1.32 |
| 2.00 BL 125 APPL 11/4 BUSHING | | 2 FROM A | |
| | UNIT PRICE IS | 0.1200 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 0.24 |
| 6.00 BU 125 APPL 11/4 BUSHING | | 2 FROM A | |
| | UNIT PRICE IS | 0.1200 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 0.72 |
| 6.00 114 TW-2 2 HOLE PIPECLAMP11/4 | | 2 FROM A | |
| | UNIT PRICE IS | 0.9200 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 5.52 |
| 1.00 11/4"X6"GALV NIPPLE | | 2 FROM A | |
| | UNIT PRICE IS | 0.5500 EA | |
| | TOTAL WEIGHT IS | 0.0 LBS | 0.55 |

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1.00 WEH 114 WEAVER WP ENTRANCE11/ 2 FROM A
UNIT PRICE IS 6.7500 EA
TOTAL WEIGHT IS 0.0 LBS 6.75

| | | | | |
|---|---|---|---|---|
| | | | 14798.94 | |
| 5.000% HANDLING | ON | 2388.82 | 119.43 | |
| 3.000% USE TAX | ON | 14798.94 | 443.96 | |
| 0.500% PURCHASING EXPENSE | ON | 12410.12 | 62.05 | |
| 7.000% FOREIGN LINE FREIGHT | ON | 2388.82 | 167.21 | |
| 5.000% ON-LINE FREIGHT | ON | 0.00 | 0.00 | 15591.59 |

| FREIGHT | WEIGHT | MI | TON MILES | |
|---|---|---|---|---|
| FROM A-E.ST.LOUIS | 19 | 288 | 3 | |
| TON MI AT 0.010/TM | | | 3 | 0.03 |

EQUIPMENT RENTAL

| | | | |
|---|---|---|---|
| 1 78 3662105 5 TON W/BOOM & AUGER | | | |
| | 6.000 DA AT 90.4000 DA | 542.40 | |
| 1 78 4262354 UTILITY TRLR | | | |
| | 6.000 DA AT 14.8000 DA | 88.80 | |
| 2 78 3662105 5 TON W/BOOM & AUGER | | | |
| | 8.000 DA AT 90.4000 DA | 723.20 | |
| 2 78 4262354 UTILITY TRLR | | | |
| | 8.000 DA AT 14.8000 DA | 118.40 | 1472.80 |

TOTAL INSTALL SIGNALS 23455.98

2-PRELIMINARY ENGR

LABOR

| | | |
|---|---|---|
| 7 77 M.K.KAMIYA | 4.00 HRS AT 7.9167 | 31.67 |
| 7 77 A.R.RATH | 8.00 HRS AT 9.9108 | 79.29 |

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| | | | | |
|---|---|---|---|---|
| 7 77 A.KLEMENS JR | 3.00 HRS AT 8.3929 | | 25.18 | |
| 7 77 M.R.FRANKE | 2.00 HRS AT 9.6429 | | 19.29 | |
| 10 77 E.FERNANDEZ | 14.00 HRS AT 9.8215 | | 137.50 | |
| 10 77 T.J.WRIGHT | 15.00 HRS AT 7.6191 | | 114.29 | |
| 10 77 C.D'ALRA | 1.000 DAYS AT 56.1400 | | 56.14 | |
| | | | 463.36 | |
| PLUS- 7.250% VACATION ALL | ON | 463.36 | 33.59 | |
| 3.500% PD HOLIDAY | ON | 463.36 | 16.22 | |
| 23.100% RRBUI TAXES | ON | 513.17 | 118.54 | |
| 5.000% HEALTH & WELFARE | ON | 463.36 | 23.17 | |
| 3.000% COMP INS | ON | 496.95 | 14.91 | |
| 1.000% PLBPD INS | ON | 496.95 | 4.97 | |
| 0.125/HR EXC TAX ON | 54.000 HRS | | 6.75 | 681.51 |

TOTAL PRELIMINARY ENGR 681.51

3-ACCTG. & PREP.

LABOR

| | | |
|---|---|---|
| 6 78 ACCTG & PREP | 1.500 DAYS AT 61.8400 | 92.76 |
| | | 92.76 |

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| | | | | | |
|---|---|---|---|---|---|
| PLUS- 7.250% VACATION ALL | ON | 92.76 | 6.73 | |
| 3.500% PD HOLIDAY | ON | 92.76 | 3.25 | |
| 23.100% RR&UI TAXES | ON | 102.74 | 23.73 | |
| 5.000% HEALTH & WELFARE | ON | 92.76 | 4.64 | |
| 3.000% COMP INS | ON | 99.49 | 2.98 | |
| 1.000% PL&PD INS | ON | 99.49 | 0.99 | |
| 0.125/HR EXC TAX ON 12.000 HRS | | | 1.50 | 136.58 |

TOTAL ACCTG. & PREP. 136.58

TOTAL BILL 24274.07

# APPENDIX C

## REGIONAL COST FINDINGS

MEAN INSTALLATION COSTS FOR ACTIVE MOTORIST WARNING DEVICES BY REGION

(Numbers in thousands of dollars)

| REGION | COST | | | | |
|---|---|---|---|---|---|
| | TOTAL | PRE-ENGINEERING | LABOR | MATERIAL | EQUIPMENT |
| Flashing Lights | | | | | |
| 1 | 21.1 | 0.9 | 7.1 | 11.8 | 1.1 |
| 2 | 18.9 | 1.1 | 5.2 | 11.9 | 1.0 |
| 3 | 24.7 | 0.8 | 7.5 | 14.5 | 0.6 |
| 4 | 22.3 | 1.2 | 7.8 | 12.5 | 0.8 |
| 5 | 34.5 | 1.2 | 11.3 | 19.9 | 1.2 |
| Cantilevered Flashing Lights | | | | | |
| 1 | 25.5 | 0.8 | 7.1 | 14.6 | 1.1 |
| 2 | 31.1 | 1.6 | 9.2 | 20.4 | 1.5 |
| 3 | 27.9 | 0.8 | 8.2 | 16.4 | 0.7 |
| 4 | 29.3 | 0.9 | 7.6 | 19.2 | 0.7 |
| 5 | 46.6 | 1.1 | 14.8 | 28.7 | 2.2 |
| Flashing Lights with Gates | | | | | |
| 1 | 39.7 | 1.4 | 12.5 | 29.5 | 1.6 |
| 2 | 41.1 | 1.7 | 10.9 | 25.1 | 1.7 |
| 3 | 47.9 | 1.2 | 12.3 | 29.7 | 1.8 |
| 4 | 36.0 | 1.0 | 8.3 | 24.3 | 1.4 |
| 5 | 33.7 | 0.6 | 8.3 | 21.8 | 1.6 |
| Cantilevered Flashing Lights with Gates | | | | | |
| 1 | 53.1 | 2.3 | 14.4 | 30.5 | 2.2 |
| 2 | 43.4 | 1.9 | 9.9 | 27.7 | 2.1 |
| 3 | 48.5 | 1.2 | 13.9 | 30.9 | 1.5 |
| 4 | 46.4 | 0.8 | 10.4 | 32.2 | 1.3 |
| 5 | 48.2 | 0.8 | 10.5 | 32.1 | 2.3 |

AVERAGE ANNUAL AND 30-YEAR MAINTENANCE COSTS BY REGION, DATA SOURCE AND MOTORIST WARNING DEVICE

| | FLASHING LIGHTS | | CANTILEVERED FLASHING LIGHTS | | FLASHING LIGHTS WITH GATES | | CANTILEVERED FLASHING LIGHTS WITH GATES | |
|---|---|---|---|---|---|---|---|---|
| | AVERAGE ANNUAL | 30-YEAR | AVERAGE ANNUAL | 30-YEAR | AVERAGE ANNUAL | 30-YEAR | AVERAGE ANNUAL | 30-YEAR |
| Region 1 | | | | | | | | |
| Maine Central | $ 1,358 | $12,808 | $ 1,729 | $16,299 | $ 2,809 | $26,486 | $ 3,365 | $31,724 |
| Virginia Railway Association | 1,960 | 18,476 | 2,512 | 23,686 | 2,866 | 27,021 | 3,453 | 32,555 |
| Conrail | 2,004 | 18,891 | 2,004 | 18,891 | 2,968 | 27,979 | 2,968 | 27,979 |
| Average | 1,774 | 16,725 | 2,081 | 19,625 | 2,881 | 27,162 | 3,262 | 30,752 |
| Region 2 | | | | | | | | |
| North Carolina | $ 2,043 | $19,259 | $ 2,619 | $24,690 | $ 2,849 | $26,857 | $ 3,323 | $32,357 |
| Florida DOT | 1,928 | 18,175 | 2,471 | 23,299 | 2,822 | 26,602 | 3,399 | 32,050 |
| Average | 1,985 | 18,717 | 2,545 | 23,994 | 2,835 | 26,729 | 3,361 | 32,203 |
| Region 3 | | | | | | | | |
| Iowa | $ 1,079 | $10,178 | $ 1,374 | $12,952 | $ 2,233 | $21,050 | $ 2,675 | $25,217 |
| Wisconsin | 1,070 | 10,093 | 1,362 | 12,846 | 2,214 | 20,874 | 2,652 | 25,003 |
| Average | 1,074 | 10,135 | 1,368 | 12,899 | 2,223 | 20,962 | 2,663 | 25,110 |
| Region 4 | | | | | | | | |
| Texas Railway Association | $ 840 | $ 7,919 | $ 1,080 | $10,181 | $ 1,960 | $18,468 | $ 2,160 | $20,362 |
| Region 5 | | | | | | | | |
| California | $ 1,173 | $11,061 | $ 1,493 | $14,077 | $ 2,426 | $22,876 | $ 2,096 | $27,401 |
| NATIONAL AVERAGE | $ 1,495 | $14,095 | $ 1,848 | $17,435 | $ 2,460 | $23,237 | $ 2,870 | $27,055 |

# APPENDIX D

# CONFIDENCE INTERVAL COMPUTATION

For the analysis of small samples when the population variance is unknown, the t-statistic may be used to set confidence intervals about the sample mean. This assumes that the sample is derived from a population which is normally or near-normally distributed.

The t-statistic may be written as:

$$t = \frac{\bar{x} - m}{s/\sqrt{n}}$$

Where

$\bar{x}$ = sample mean
m = population mean
s = standard deviation of the sample
n = sample size

By knowing the distribution of this statistic, a confidence interval on m can be calculated by using the following steps:

1. Write an appropriate probability statement.

$$p[- t_{\alpha/2,n-1} \leq \frac{\bar{x} - m}{s/\sqrt{n}} \leq + t_{\alpha/2,n-1}] = 1 - \alpha$$

Where

$1 - \alpha$ = level of confidence required
$n - 1$ = degrees of freedom

2. Isolate the parameter of interest.

$$p[\bar{x} - \frac{s}{\sqrt{n}} t_{\alpha/2,n-1} \leq m \leq \bar{x} + \frac{s}{\sqrt{n}} t_{\alpha/2,n-1}] = 1 - \alpha$$

3. Substitute in the inequality the observed value of the sample statistics, $\bar{x}$ and s. The (1 - α) 100 percent two-sided confidence interval on m is then

$$\bar{x} - \frac{s}{\sqrt{n}} t_{\alpha/2,n-1} \quad \text{to} \quad \bar{x} + \frac{s}{\sqrt{n}} t_{\alpha/2,n-1}$$

As an example, refer to the data below. These data represent the total initial costs of 24 projects involving the installation of flashing lights and gates with motion sensor train detection devices.

| | | |
|---|---|---|
| 33,388 | 33,303 | $\bar{x}$ = $32,266 |
| 39,025 | 39,874 | s = 7325.4 |
| 32,532 | 22,573 | n = 24 |
| 30,048 | 30,994 | |
| 31,292 | 27,046 | |
| 31,455 | 24,974 | |
| 26,630 | 29,886 | |
| 29,267 | 27,144 | |
| 53,536 | 31,072 | |
| 51 392 | 31,400 | |
| 28,502 | 27,332 | |
| 31,862 | 27,942 | |

Then, a 95 percent confidence interval on the mean would be:

$$32,266 - \frac{7325.4}{\sqrt{24}} t_{0.025,23} \leq \bar{x} \leq 32,266 + \frac{7325.4}{\sqrt{24}} t_{0.025,23}$$

From standard statistical tables, $t_{0.025,23} = 2.069$
Therefore, the 95 percent confidence interval is:

$$32,266 \pm 3,094 \quad \text{or} \quad 29,172 \leq \bar{x} \leq 35,360$$

This interval may be calculated for any desired level of confidence.

APPENDIX E

BIBLIOGRAPHY

BIBLIOGRAPHY

American National Standards Institute, "Manual on Uniform Traffic Control Devices," Report No. D 6.1-1978, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1978.

Association of American Railroads, "Railroad-Highway Grade Crossing Protection," American Railway Signaling Principles and Practices, Chapter 23, 1962.

Association of American Railroads, Economics and Finance Department, "Indexes of Railroad Material Prices and Wage Rates," Series Q-MPW, July 26, 1978.

California Public Utilities Commission, The Effectiveness of Automatic Protection in Reducing Accident Frequency and Severity at Public Grade Crossings in California, San Francisco, California, June 30, 1974.

Hitz, J.S. ed., "Summary Statistics of the National Railroad-Highway Crossing Inventory for Public At-Grade Crossings," Report No. FRA-OPPD-78-20, U.S. Department of Transportation, Transportation Systems Center, Cambridge, Massachusetts, 1978.

Mengert, P., "Rail-Highway Crossing Hazard Prediction Research Results," Report No. FRA-RRS-80-02, U.S. Department of Transportation, Research and Special Programs Administration, Cambridge, Massachusetts, March 1980.

Railway Progress Institute, "Rail-Highway Grade Crossing Warning Systems-Equipment and Application," 1977.

Texas Transportation Institute, Railroad-Highway Grade Crossing Handbook, Report No. FHWA-TS-78-214, U.S. Department of Transportation, Federal Highway Administration, College Station, Texas, August 1978.

# APPENDIX F

## REPORT OF NEW TECHNOLOGY

This report describes the results of a study designed to collect, analyze, and document life cycle costs of rail-highway crossing warning systems. Costs were analyzed by components consisting of pre-engineering, labor, material, equipment rental costs, and maintenance costs. Factors contributing to cost variability were identified and quantified. While no new inventions have resulted from this work, important new information about these life cycle costs have been obtained. The new findings include:

1. Thirty-year maintenance costs discounted to present value were found to be between 53 percent and 61 percent of the total installation costs.

2. More reliable installation cost data for flashing lights and automatic gates were determined.

3. No consistant regional variation in costs was found.

4. Average costs of warning systems increased with the number of tracks.

5. A hierarchy of train detection systems was established with respect to costs.

These results will be used by Federal, state, and railroad planners involved in the application of grade crossing warning equipment to improve rail-highway crossing safety.