4. RESOURCE ALLOCATION MODEL

4.1 INTRODUCTION

The resource allocation model was developed to assist state and railroad officials in their crossing safety improvement decision process[7]. The procedure provides initial recommended lists of crossing improvements for consideration. These initial recommendations may be used by states to guide the on-site inspection of crossings by diagnostic teams. Revised results based on information obtained by the diagnostic teams provides a useful set of recommendations upon which state and railroad officials can finalize crossing safety improvement plans.

The resource allocation model principally provides safety improvement recommendations for two types of active motorist warning device upgrades; flashing lights and automatic gates. In addition, it identifies crossings that qualify for standard highway stop signs according to the FHWA guidelines[14]. The user of the resource allocation model has the option of selecting either or both sets of recommendations. Descriptions of the resource allocation model for active warning devices and stop signs are provided below in Sections 4.2 and 4.3, respectively.

4.2 RESOURCE ALLOCATION MODEL FOR ACTIVE WARNING DEVICES

4.2.1 Overview

The resource allocation model for active warning devices provides a list of crossings with recommended warning device improvements. The recommendations are based on achieving the greatest accident or casualty reduction for the available budget, given the cost and safety effectiveness of the active warning device options.

Input to the resource allocation model includes predicted accidents or casualties for the crossings being considered, costs and effectiveness of the different safety improvement options (e.g., flashing lights and gates), and the budget level available for safety improvement. Accident or casualty predictions for crossings can come from any prediction formula which computes number of accidents or casualties per year. The DOT accident and severity prediction formulas described in the previous section were developed for this purpose.

Cost data for the warning device options may include total life cycle costs (the sum of procurement, installation, and maintenance), or the costs associated with only a particular phase of a project. These costs are needed for the following categories of active warning device improvements currently considered by the model: flashing lights for a previously passive crossing, gates for a previously passive crossing, and gates for a crossing previously equipped with flashing lights. Cost data on warning device improvements which can be used for the resource allocation model are presented in Section 4.2.4.

Warning device effectiveness required by the resource allocation model is a number between 0 and 1 which determines the fraction by which accidents are expected to be reduced by installation of a warning device. Effectiveness is a relative measure involving both existing and proposed warning devices at a crossing to be upgraded. If automatic gates have an effectiveness of 0.83, when installed at a crossing with a passive warning device, the accident rate at the crossing will be reduced by 83 percent. Automatic gates installed at a crossing with flashing lights would have a lower effectiveness. An improvement which completely eliminates accidents, such as grade separations or closures, would have an effectiveness of 1.0; i.e., it is 100 percent effective. Values of effectiveness for different active warning device improvement combinations are presented in Section 4.2.5.

The budget level for crossing improvements, used as input to the resource allocation model, should include the total multi-year funding available, even though it may exceed a single year's budget. The reason for this is that the resource allocation model will produce a different and possibly conflicting set of decisions depending upon the budget level used. If, for example, the first-year budget of a 2-year program is used, a specific set of decisions will result from the model. Use of the model again for the next year's budget, incorporating the crossing improvements made the previous year, will result in a new set of decisions. Some of the new decisions may involve further improvements to crossings just upgraded the previous year, resulting in an inefficient program. The best approach would have been to use the total 2-year budget for the first application of the model, and then fund the improvement decisions over a 2-year period.

The resource allocation model is intended to assist state and railroad planners in formulating decisions on crossing improvements. There are a number of applications where the model can be useful in this role. In its primary application, the model could use the state listing of crossings, ranked by predicted accidents or casualties, to produce a list of suggested improvement projects. The project list indicates which crossings are to be upgraded and the type of upgrade to be performed. The state can then use this suggested program as a basis to select crossings for on-site inspections by diagnostic teams. The diagnostic teams can validate original data used by the model, revise the suggested program if data has changed and obtain additional information on potential crossing hazards for consideration prior to finalizing program plans. A procedure for accomplishing this evaluation process is described in Section 4.2.6.

The resource allocation model can also be used to assess the sensitivity of improvement decisions to variations in the input parameters of warning device cost and effectiveness and predicted crossing accidents. If, for a given crossing or set of crossings, these parameters are known to be different than originally assumed, the new values can be substituted into the model and new results obtained. The effect of the new parameters can be assessed by a comparison of new improvement decisions with those resulting from the previous assumptions. This type of application is useful in evaluating the impacts of known or proposed changes in crossing characteristics, such as increases in train or highway traffic on certain routes, or closures of specific crossings.

The resource allocation model is also useful for evaluating the impacts of alternative program strategies. The model can be easily modified to incorporate constraints imposed on certain improvement actions by state warrants or guidelines. An example of such a constraint would be a gates-only policy at crossings with train speeds exceeding certain values. Variations in program budgeting such as inclusion versus exclusion of warning device maintenance costs and single-year versus multi-year funding limits, can also be evaluated with the resource allocation model.

4.2.2 Description of Model Algorithm

Three categories of warning device classes are considered by the resource allocation algorithm, and are the same categories evaluated by the accident prediction formulas. Warning device classes 1 through 4 are grouped together and called "passive" warning devices, meaning that they are not train-activated devices. Classes 5, 6, and 7 are grouped together and called "flashing lights," since public crossings which are equipped with flashing lights predominate in this category. Class 8 remains as a separate warning device category called "gates". The resource allocation model only considers improvements for passive and flashing light crossings, since gates are assumed to be the most effective warning device available. Therefore, users of the model may want to obtain a list of gate crossings for the geographical area of interest, possibly ranked by the severity measure used in the resource allocation computation, to complement the resource allocation results. This will enable the user to bring all crossings into the analysis in some way.

Table 4-1 is a matrix showing the effectiveness and cost symbols for the three warning device groupings used in describing the resource allocation algorithm. The matrix reflects the possible combinations of active warning device improvements currently considered by the model. For passive crossings, single track, two upgrade options exist; flashing lights or gates. For passive, multiple-track crossings, the model allows only the gate option to be considered in accordance with Federal regulations.* For flashing light crossings, the only improvement option is gates. The model can be modified by extending the basic logic to include other options; however, it would also be necessary to determine the costs and effectiveness of any additional options that are considered.

For each combination of existing and proposed warning device, a pair of parameters (E_j,C_j), as shown in Table 4-1, must be provided for the resource allocation algorithm, where $j = 1$ for flashing lights installed at a passive crossing, $j = 2$ for gates installed at a passive crossing, and $j = 3$ for gates installed at a crossing with flashing lights. The first parameer (E_j) is the effectiveness of installing the proposed warning device at the crossing. The second parameter (C_j) is the corresponding cost of the proposed warning device. It has also been determined that E_j can vary according to the number of tracks and the number of trains per day at the crossing[11]. These results are given in Table 4-8.

The resource allocation model considers all crossings with either passive or flashing light warning devices as candidates for improvements. If, for example, a single-track

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*23 CFR 646.214(b)(3)(i)

TABLE 4-1. EFFECTIVENESS/COST SYMBOL MATRIX

	PROPOSED WARNING DEVICE			
	FLASHING LIGHTS		AUTOMATIC GATES	
EXISTING WARNING DEVICE	EQUIPMENT EFFECTIVENESS	EQUIPMENT COST	EQUIPMENT EFFECTIVENESS	EQUIPMENT COST
Passive	E_1	C_1	E_2	C_2
Flashing Lights	—	—	E_3	C_3

passive crossing, i, is considered, it could be upgraded with either flashing lights, with an effectiveness E_1, or gates, with an effectiveness E_2. The number of predicted accidents or casualties at crossing i is denoted as AC_i; hence, the reduced accidents or casualties per year is $AC_i x E_1$ for the flashing light option and $AC_i x E_2$ for the gate option. The corresponding costs for these two improvements are C_1 and C_2. The accident or casualty reduction/cost ratios for these improvements are $AC_i x E_1/C_1$ for flashing lights and $AC_i x E_2/C_2$ for gates. The rate of increase in accident or casualty reduction versus cost that results from changing an initial decision to install flashing lights with a decision to install gates at crossing i, is referred to as the "incremental accident or casualty reduction/cost rato" and is equal to $AC_i(E_2-E_1)/(C_2-C_1)$. The incremental accident or casualty reduction/cost ratio ACR/C is used by the algorithm to compare the cost-effectiveness of a decision to further upgrade a passive crossing from flashing lights to gates with an alternative decision to upgrade another crossing. If a passive multiple-track crossing, i, is considered, the only improvement option allowable would be installation of gates, with an effectiveness of E_2, a cost of C_2 and an accident or casualty reduction/cost ratio of $AC_i x E_2/C_2$. If crossing i was originally a flashing light crossing, the only improvement option available would be installation of gates, with an effectiveness of E_3, a cost of C_3, and an accident or casualty reduction/cost ratio of $AC_i x E_3/C_3$.

The resource allocation algorithm systematically computes the accident or casualty reduction/cost ratios, including incrementals, of all allowable improvement options for all crossings under consideration. The individual accident or casualty reduction/cost ratios are then sorted and selected by the algorithm so that the associated improvements result in the maximum accident or casualty reduction obtainable for the available budget. The total cost of the improvements is the sum of the individual project cost (C_1, C_2 and C_3). The total accident or casualty reduction is the sum of the individual accident or casualty reductions of the form $AC_i x E_j$.

A flow diagram describing the logic of the resource allocation algorithm is shown in Figure 4-1. The input to this program consists of the set of crossings for which the model is to apply, the accidents or casualties predicted per year for these crossings, the warning device parameters (effectiveness, C_1, C_2, C_3) and the available budget (CMAX). It should be noted that several values of E can be used to account for different crossing situations. Multiple effectiveness values for each type of upgrade, currently available for the algorithm, are discussed in more detail in Section 4.2.5.

The algorithm, described in Figure 4-1, proceeds according to the following steps in computing optimal resource allocations.

Step 1: The reasonable assumption is made for the algorithm that $E_2 > E_1$ and $C_2 > C_1$. This assumes that gates are more effective at passive crossings than flashing lights and that gates cost more. However, the effectiveness/cost ratio for flashing lights (E_1/C_1) could be greater or less than that for gates (E_2/C_2). If $E_1/C_1 > E_2/C_2$, the algorithm computes incremental accident or casualty reduction/cost ratios for all allowable improvements at each crossing according to the procedure outlined in step 2A below. Step 2A is based on the assumption that flashing lights have a greater effectiveness/cost ratio than gates. If the opposite is true--that gates have an effectiveness/cost ratio equal to or greater than flashing lights ($E_1/C_1 \leq E_2/C_2$)-- then step 2B is followed for computing the improvement accident or casualty reduction/cost ratios. Step 2B assumes that gates will always be installed at passive crossings.

Step 2A: Two accident or casualty reduction/cost ratios are calculated for each single-track passive crossing, $AC_i x E_1/C_1$ and the incremental ratio $AC_i x(E_2-E_1)/(C_2-C_1)$, where AC_i is the number of accidents or casualties predicted per year for the crossing.

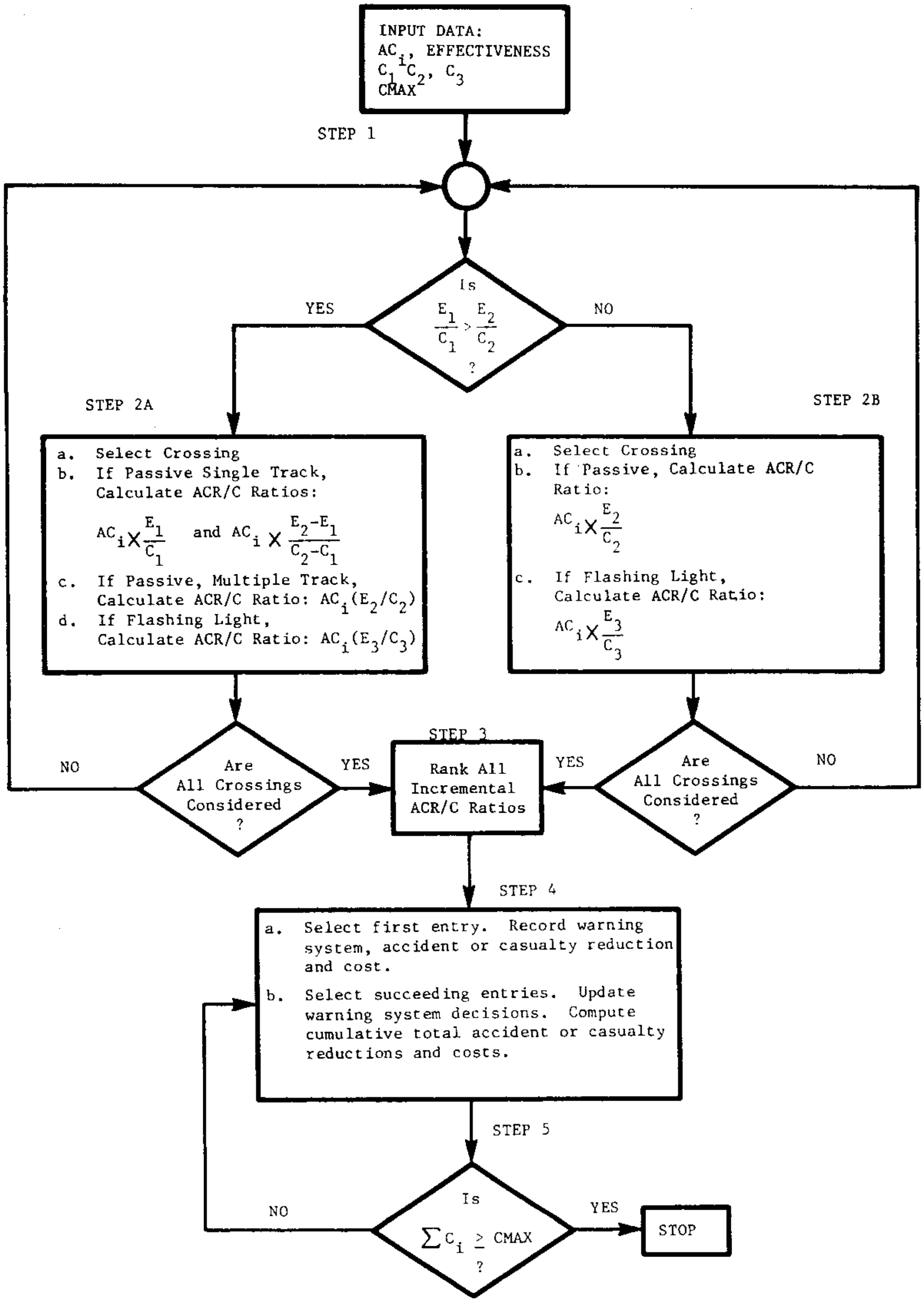

FIGURE 4-1. RESOURCE ALLOCATION ALGORITHM

These two ratios correspond to the two actions available for single-track passive crossings, either to install flashing lights or a revised decision to install gates. For multiple-track passive crossings, only the accident or casualty reduction/cost ratio for installation of gates is calculated (AC_ixE_2/C_2), to conform with Federal regulations. For each crossing equipped with flashing lights, the algorithm computes AC_ixE_3/C_3, corresponding to an upgrading from flashing lights to gates. The accident or casualty reduction/cost ratio is represented in units of accidents or casualties prevented per year per dollar.

Step 2B: The algorithm computes the accident or casualty reduction/cost ratio AC_ixE_2/C_2 for passive crossings and the ratio AC_ixE_3/C_3 for crossings with flashing lights. These accident or casualty reduction/cost ratios are associated with installing only gates at crossings. For this case, these actions are always optimal relative to the alternative of installing flashing lights, since the accident or casualty reduction/cost ratio and the absolute cost of gates are greater than for flashing lights.

Step 3: Regardless of whether step 2A or 2B is followed, all of the accident or casualty reduction/cost ratios calculated by the algorithm are ranked with the largest first. The list of accident or casualty reduction/cost ratios represents a sequence of optimal decisions starting with the top of the list.

Step 4: This step consists of a series of iterations, where the algorithm progresses down the list of ranked accident or casualty reduction/cost ratios. This process is equivalent to making the optimum decision of achieving the maximum accident or casualty reduction/cost ratio at any given step on the list is calculated as AC_ixE_1/C_1, a decision is made to install flashing lights at a passive crossing, with an accident or casualty reduction of AC_ixE_1 and cost of C_1. If the accident or casualty reduction/cost ratio is $AC_ix(E_2-E_1)/(C_2-C_1)$, a previous decision to install flashing lights is changed to install gates at a passive crossing. The incremental accident or casualty reduction of changing the previous decision is $AC_ix(E_2-E_1)$, and the incremental cost is C_2-C_1. If the accident or casualty reduction/cost ratio is AC_ixE_2/C_2, then a decision is made to install gates at a passive crossing without prior consideration of flashing lights. The accident or casualty reduction is AC_ixE_2 at a cost of C_2. If the accident or casualty reduction/cost ratio is AC_ixE_3/C_3, then a decision is made to install gates at a crossing which had flashing lights. The accident or casualty reduction is $AC_i x E_3$ at a cost of C_3. The total accident or casualty reduction at each step is the sum of the previous accident or casualty reductions and the total cost is the sum of the previous costs.

In addition to determining the total accident or casualty reduction (total benefit) and cost at each step, the algorithm also determines the particular warning systems which are to be installed at particular crossings. Since the crossings which were affected are known, the actual accidents or casualties, location, and all other information in the Inventory for those crossings are also known. Thus, the output of the program could include any of this information and any computations based on this information. Several types of output are shown in Section 5.2

Step 5: The cumulative total cost at each step, proceeding down the list of accident or casualty reduction/cost ratios, is compared with the available budget specified as input to the algorithm. When the total cost equals or exceeds the budget, the program ends. Otherwise, the sequential procedure described in step 4 continues.

4.2.3 Demonstration of Model Algorithm

To demonstrate operation of the algorithm, an example which considers the three crossings described in Table 4-2 follows. For this example predicted accidents, A_i, rather than predicted casualties will be used as the measure of crossing hazard. The predicted accidents per year and current warning device information for the crossings together with assumed warning device cost and effectiveness parameters, presented in Table 4-3, constitute the input for the algorithm. The algorithm proceeds through the following steps which were described in the previous section and in Figure 4-1.

Step 1: The effectiveness/cost ratio for flashing lights (E_1/C_1) is greater than that for gates (E_2/C_2); hence, the algorithm follows step 2A. This implies that the most effective first action which can be taken at a passive crossing is the installation of flashing lights.

TABLE 4-2. SAMPLE CROSSINGS FOR ALGORITHM DEMONSTRATION

CROSSING	CURRENT WARNING DEVICE	PREDICTED ACCIDENTS PER YEAR A_1
X_1 (single track)	Passive	$A_1 = 0.3$
X_2	Flashing Lights	$A_2 = 0.2$
X_3	Flashing Lights	$A_3 = 0.1$

TABLE 4-3. EFFECTIVENESS/COST INPUT DATA

	----- PROPOSED WARNING DEVICE -----			
	FLASHING LIGHTS		AUTOMATIC GATES	
EXISTING WARNING DEVICE	EQUIPMENT EFFECTIVENESS	EQUIPMENT COST	EQUIPMENT EFFECTIVENESS	EQUIPMENT COST
Passive	$E_1 = 0.7$	$C_1 = \$25,000$	$E_2 = 0.9$	$C_2 = \$45,000$
Flashing Lights	—	—	$E_3 = 0.667$	$C_3 = \$35,000$

Step 2A: The crossings are selected for analysis by the algorithm in the order they appear in Table 4-2. For each crossing selected, the appropriate accident reduction/cost ratios are calculated, corresponding to all the allowable warning device improvements which may be made. The results of these calculations are shown in Table 4-4.

Step 3: The accident reduction/cost ratios, as calculated in step 2A, are ranked in descending order, beginning with the largest. The warning device improvement action at each crossing, represented by the ratios and corresponding cumulative accident reduction and cost, are tabulated in Table 4-5.

Step 4: From the ranked list in Table 4-5, the first action selected by the algorithm corresonds to the first ranked accident reduction/cost ratio: installation of flashing lights at crossing X_1 with a cost of $25,000. The next action selected by the algorithm corresponds to the next ranked accident reduction/cost ratio: installation of gates at crossing X_2, resulting in a cumulative cost of $60,000 for the first two projects. The algorithm proceeds in this manner until the cumulative total cost of all improvement actions equals the available budget (CMAX). It should be noted that the third action selected by the algorithm does not involve an additional crossing, but revises an earlier decision to install gates rather than flashing lights at crossing X_1. This type of revision is typical of the algorithm for normal applications, as additional funding is made available. For the above example, if a total of $115,000 were available for improvements (CMAX = $115,000), the algorithm would proceed through the fourth item on the list involving crossing X_3. The overall improvement actions for $115,000 would result in the installation of gates at all three crossings.

TABLE 4-4. STEP 2: CALCULATION OF ACCIDENT REDUCTION/COST RATIOS

		---------------IMPROVEMENT OPTIONS---------------		
CROSSING	CURRENT WARNING DEVICE	INSTALL FLASHING LIGHTS AT PASSIVE CROSSING:	REVISE DECISION FROM INSTALLING FLASHING LIGHTS TO GATES AT PASSIVE CROSSING:	INSTALL GATES AT FLASHING LIGHT CROSSING
		$ACR/C = A_i\left(\frac{E_1}{C_1}\right)$	$ACR/C = A_i\left(\frac{E_2 - E_1}{C_2 - C_1}\right)$	$ACR/C = A_i\left(\frac{E_3}{C_3}\right)$
X_1	Passive Single Track	$ACR/C = 0.3\left(\frac{0.7}{25{,}000}\right)$ $= 8.4 \times 10^{-6}$	$ACR/C = 0.3\left(\frac{0.9 - 0.7}{45{,}000 - 25{,}000}\right)$ $= 3.0 \times 10^{-6}$	-----
X_2	Flashing Lights	-----	-----	$ACR/C = 0.2\left(\frac{0.667}{35{,}000}\right)$ $= 3.8 \times 10^{-6}$
X_3	Flashing Lights	-----	-----	$ACR/C = 0.1\left(\frac{0.667}{35{,}000}\right)$ $= 1.9 \times 10^{-6}$

TABLE 4-5. STEP 3: RANKING OF ACCIDENT REDUCTION/COST RATIOS

RANK	ACCIDENT REDUCTION/ COST RATIO	WARNING DEVICE IMPROVEMENT ACTION	E_jA_i ACCIDENTS REDUCED PER YEAR	$\sum E_jA_i$ CUMULATIVE ACCIDENTS REDUCED PER YEAR	$\sum C_j$ CUMULATIVE COSTS
1	8.4×10^{-6}	Install Flashing Lights at Crossing X_1	0.21	0.21	$25,000
2	3.8×10^{-6}	Install Gates at Crossing X_2	0.13	0.34	$25,000
3	3.0×10^{-6}	Install Gates at Crossing X_1	0.06	0.40	$80,000
4	1.9×10^{-6}	Install Gates at Crossing X_3	0.07	0.47	$115,000

4.2.4 Active Warning Device Cost Data

As described above, the resource allocation model requires data on the costs of the warning device improvement options. A study has been performed to determine average national values of these costs[8]. The costs determined include the initial installation cost (including procurement) and the net present value (NPV) maintenance costs over the life of the equipment which are added together to yield the total life cycle cost. These costs were originally determined in 1977 dollars. An additional study was performed by the Association of American Railroads (AAR) in 1982 to determine the annual maintenance costs of warning devices[9]. The AAR study results for maintenance costs were combined with the earlier study results for installation costs and updated to 1983 dollars using the procedure outlined below[11]. These 1983 warning device costs are presented in Table 4-6

TABLE 4-6. WARNING DEVICE IMPROVEMENT COSTS, 1983

IMPROVEMENT OPTION	INSTALLATION COST	NPV MAINTENANCE COST	NPV LIFE CYCLE COST
Passive to Flashing Lights, C_1	\$43,800	\$10,700	\$54,500
Passive to Gates, C_2	\$65,300	\$18,700	\$84,000
Flashing Lights to Gates, C_3	\$58,700	\$18,700	\$77,400

The category of costs that are used as input to the resource allocation model (installation, maintenance, life cycle or some combination of these) can be determined at the discretion of the user. Installation costs reflect the immediate costs to the state and Federal Government of completing the project. Maintenance costs are the long term recurring costs of the project, usually to the railroads; however, some states share in these costs. Total life cycle costs reflect the project's total cost over its useful life.

Since the costs shown in Table 4-6 have been inflating, a procedure has been developed to produce multipliers for the installation and maintenance costs that will increase their amounts to current dollars. The procedure uses the annual index of charge-out prices and wage rates from the AAR[10].

The inflation multiplier for installation costs (MI) is determined from the average increase in the "Materials and Supplies" index (MS) and the "Wage Rate" index (WR) from the year for which the latest cost information is available. The 1983 values for the MS and WR indexes are 140 and 179, respectively. The multiplier for installation costs, MI, for some future year beyond 1983 is therefore:

$$MI = \frac{(MS/140 + WR/179)}{2} \tag{9}$$

where:

MI = inflation multiplier for installation costs
MS = materials and supplies index for the subject year
WR = wage rate index for the subject year

The inflation multiplier for maintenance costs (MM) is a weighted average of 95 percent of the installation cost multiplier MI, (determined from equation (9) above) and 5 percent of the increase in the "Fuel" index (F) from the year for which the latest cost information is available. The 1983 value of the F index is 232. The multiplier for maintenance costs, MM, for some future year beyond 1983 is therefore:

$$MM = MI \times 0.95 + (F/232) \times 0.05 \tag{10}$$

where:

MM = inflation multiplier for maintenance costs
F = fuel index for the subject year

The cost values shown in Table 4-6 are national averages, and their use will produce decisions by the resource allocation model useful in formulating improvement programs. The original study to determine these costs[8] did not reveal any significant shifts in costs by region of the country, although some variation by railroad was observed. If other values for the average costs of improvements are available and are thought to more accurately reflect the application in question, these values may be substituted for those suggested here.

Use of average costs introduces the simplification of not accounting for the actual variation in costs that can occur from one project to another. Average values assume, for example, that all passive crossings upgraded to gates will cost the same. If the user can determine more accurately the actual variation in costs for improvement options on all crossings being considered, these costs could be used. To do so, however, will require modification of the model program to permit cost data to be input on an individual crossing basis. The model program currently accepts only the three cost values (C_1,C_2,C_3) as input.

Caution should be exercised in adjusting the costs of a few selected projects while assigning average costs to all other projects. If this is done, decisions regarding the adjusted crossings may be unreasonably biased by the algorithm. The effect on individual crossing decisions of changes in a crossing's cost characteristics from the average values can be determined manually, using a procedure described in Section 4.2.6. With this procedure, all other decisions by the algorithm will remain constant, while it can be determined if the decision regarding the crossing in question will change with the new cost values.

4.2.5 Active Warning Device Effectiveness Data

Three investigations have been performed to determine the effectiveness of warning devices in reducing accidents at rail-highway crossings. The most recent study performed by the U.S. Department of Transportation, used information in the Inventory and the FRA accident reporting system[11]. This study compared the accident rates at crossings both before and after warning device improvements had been made to determine their effectiveness during the period from 1975 to 1980. A similar study, also performed for the U.S. Department of Transportation used the same information sources for the years 1975 to 1978[12]. A third study was performed in 1974 by the California Public Utilities Commission[13]. This study examined accident rates before and after upgrades at 1552 California crossings over the period from 1960 to 1970. The results of these three studies are shown in Table 4-7 in terms of single "standard" effectiveness values (E_1, E_2 and E_3) for the three improvement options considered by the resource allocation model.

TABLE 4-7. STANDARD SET OF EFFECTIVENESS VALUES FOR WARNING DEVICE IMPROVEMENTS

WARNING DEVICE IMPROVEMENT OPTION	2nd DOT STUDY, 1975 to 1980 DATA	1st DOT STUDY, 1975 to 1978 DATA	CALIFORNIA STUDY, 1960 to 1970 DATA
Passive to Flashing Lights, E_1	0.70	0.65	0.64
Passive to Gates, E_2	0.83	0.84	0.88
Flashing Lights to Gates, E_3	0.69	0.64	0.66

The effectiveness values resulting from the three studies are similar but differences exist. These differences are probably a reflection of variations in crossing characteristics over time and regions of the country. The question arises as to which set of values to use for the resource allocation model. As with the cost data, any set of values which the user feels accurately reflect the situation being evaluated may be used. Without other information to the contrary, the effectiveness values from the latest DOT study are recommended, since they were most recently developed, and they used the largest data base of national scope.

The latest DOT study on warning device effectiveness determined that several crossing chracteristics, out of many investigated, had a significant influence on warning device effectiveness. Specifically, it was found that the effectiveness of warning device upgrades was less for crossings with multiple tracks and crossings with greater than 10 trains per day. These results were used to develop an "extended" set of effectiveness value shown in Table 4-8. At the option of the user, the resource allocation model has the capability to use either the extended set of values or the reduced set of standard values shown in Table 4-7. Unless otherwise specified by the user, the resource allocation model uses the extended set of values since their use results in improved performance of the model.

TABLE 4-8. EXTENDED SET OF EFFECTIVENESS VALUES FOR WARNING DEVICE IMPROVEMENTS

WARNING DEVICE IMPROVEMENT OPTION	NUMBER OF TRAINS/DAY:	SINGLE TRACK ≤ 10	SINGLE TRACK >10	MULTIPLE TRACK ≤ 10	MULTIPLE TRACK >10
Passive to Flashing Lights, E_1		0.75	0.61	0.65	0.57
Passive to Gates, E_2		0.90	0.80	0.86	0.78
Flashing Lights to Gates, E_3		0.89	0.69	0.65	0.63

4.2.6 Field Verification and Revision of Resource Allocation Results

Crossings selected for improvements by the resource allocation model should be inspected by a diagnostic team to determine the accuracy of input data and the reasonableness of the recommended improvement. The inspection may show that data from the Inventory are not correct, resulting in an inaccurate predicted accident or casualty rate. Also, the assumed warning device effectiveness and cost may be found inappropriate for the particular crossing. In addition, the diagnostic team should make note of hazardous conditions at crossings, such as limited sight distance or hazardous materials traffic, that are not included in the resource allocation model but should be considered before making a final decision. A manual procedure has been developed to evaluate the impact of changes in crossing data on the improvement decision made by the resource allocation model. This procedure can be performed without rerunning the model and is incorporated in a worksheet, shown in Figure 4-2. The worksheet guides the diagnostic team through the on-site evaluation procedure using a five-step set of instructions.

RAIL-HIGHWAY CROSSING RESOURCE ALLOCATION PROCEDURE
VERIFICATION WORKSHEET

This worksheet provides a format and instructions for use in field evaluation of crossings to determine if initial recommendations for warning device installations from the Resource Allocation Procedure should be revised. Steps 1 through 5, described below, should be followed in making the determination. In Steps 1 and 3, the intial information (left column) is obtained from office inventory data prior to the field inspection. In Step 4, the decision criteria values are obtained from the Resource Allocation Model printout.

STEP 1: VALIDATE DATA USED IN CALCULATING PREDICTED ACCIDENTS.

CROSSING CHARACTERISTICS	INITIAL INFORMATION	REVISED INFORMATION
Crossing Number		
Location		
Existing Warning Device		
Total Trains Per Day (t)		
Annual Average Daily Highway Traffic (c)		
Total Switch Trains Per Day (ts)		
Day Thru Trains (d)		
Total Thru Trains Per Day (tt)		
Number Of Main Tracks (mt)		
Total Number Of Tracks (tk)		
Is Highway Paved? (hp)		
Maximum Timetable Speed, mph (ms)		
Highway Type (ht)		
Number Of Highway Lanes (hl)		
Urban-Rural Location (ur)		
Number Of Years Of Accident History (T)		
Number Of Accidents In T Years (N)		
Predicted Accident Or Casulaty Rate (AC)		

STEP 2: CALCULATE REVISED ACCIDENT OR CASUALTY PREDICTION FROM DOT FORMULA IF ANY DATA IN STEP 1 HAS BEEN REVISED.

Revised Predicted Accidents or Casulaties (AC) = ____________________

STEP 3: VALIDATE COST AND EFFECTIVENESS DATA FOR RECOMMENDED WARNING DEVICE.

	INITIAL INFORMATION	REVISED INFORMATION
Assumed Effectivness Of Recommended Warning Device (E)		
Assumed Cost Of Recommended Warning Device (C)		
Recommended Warning Device Installation		

FIGURE 4-2. FIELD VERIFICATION WORKSHEET

STEP 4: DETERMINE IF RECOMMENDED WARNING DEVICE IS REVISED IF AC, E OR C HAS CHANGED.

Instructions for Determining If Recommended Warning Device Should Be Revised

1. Obtain Decision Criteria Values From Resource Allocation Model Output:

DC_1 = ________ DC_2 = ________ DC_3 = ________ DC_4 = ________

2. Calculate: $R = \frac{\text{Revised AC}}{\text{Previous AC}} \times \frac{\text{Revised E}}{\text{Previous E}} \times \frac{\text{Previous C}}{\text{Revised C}}$

3. Compare R with Appropriate Decision Criteria as Shown Below:

3a. Existing Passive Crossing (Classes 1, 2, 3, 4) Single Track		3b. Existing Passive Crossing (Classes 1, 2, 3, 4) Multiple Tracks		3c. Existing Flashing Light Crossing (Classes 5, 6, 7)	
Comparison	**Decision**	**Comparison**	**Decision**	**Comparison**	**Decision**
$DC_2 \leq R$	Gates	$DC_3 \leq R$	Gates	$DC_4 \leq R$	Gates
$DC_1 \leq R < DC_2$	Flashing Lights	$R < DC_3$	No Installation	$R < DC_4$	No Installation
$R < DC_1$	No Installation				

4. Revised Recommended Warning Device Installation:* ______________________________

STEP 5: DETERMINE OTHER CROSSING CHARACTERISTICS THAT MAY INFLUENCE WARNING DEVICE INSTALLATION DECISIONS.

Multiple tracks where one train/locomotive may obscure vision of another train? ________________

Percent trucks ________________

Passenger train operations over crossing? ________________

High speed trains with limited sight distance?** ________________

Combination of High Speeds and moderately high volumes of highway and rail traffic?** ________________

Either, or any combination of, high vehicular traffic volumes, high numbers of train movements, substantial numbers of school buses or trucks carrying hazardous materials, unusually restricted sight distance or continuing accident occurrences?** ________________

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*The cost and effectiveness values for the revised warning device are assumed to change by an amount proportional to the change in these values for the initial recommended warning device as determined in Step 3.

**Gates with flashing lights are the only recommended warning device per 23CFR 646.214(b)(3)(i).

FIGURE 4-2. FIELD VERIFICATION WORKSHEET (Cont.)

Steps 1 and 2 of the worksheet involve validating crossing characteristic data, and recalculating the predicted accidents or casualties if any of the data is revised. Step 3 validates the cost and effectiveness assumptions for the recommended warning device. As a result of completing steps 1, 2 and 3, three basic inputs to the resource allocation model may have changed: (1) number of predicted accidents or casualties (AC); (2) warning device effectiveness (E); and (3) warning device cost (C). Step 4 of the worksheet describes the procedure for determining if any input changes will affect the improvement decision. This procedure requires the computation of the parameter (R) using the formula below and described in part 2 of step 4:

$$R = \frac{\text{Revised AC}}{\text{Previous AC}} \times \frac{\text{Revised E}}{\text{Previous E}} \times \frac{\text{Previous C}}{\text{Revised C}} \qquad (11)$$

The value of R is the ratio of the revised to previous accident or casualty reduction/cost ratio, for the original recommended improvement action. The R value is then compared with the appropriate decision criteria values (DC_1, DC_2, DC_3, and DC_4) as described within part 3 of step 4 on the worksheet. The decision criteria values are obtained from the standard output report (see Figure 5-10) of the resource allocation model. The result of this comparison will determine if the original recommended improvement should be revised.

The decision criteria values are computed by the standard program of the resource allocation model for each crossing considered (see Section 5.2 for description of programs). The formula for computing the four decision criteria are shown below:

$$DC_1 = (ACR/C_m)/(A_i(E_1/C_1)) \qquad (12)$$

$$DC_2 = (ACR/C_m)/(A_i(E_2-E_1)/(C_2-C_1)) \qquad (13)$$

$$DC_3 = (ACR/C_m)/(A_i(E_2/C_2)) \qquad (14)$$

$$DC_4 = (ACR/C_m)/(A_i(E_3/(C_3)) \qquad (15)$$

where ACR/C_m equals the minimum accident or casualty reduction/cost ratio corresponding to the last (lowest) improvement action selected by the resource allocation model. These decision criteria represent the amount by which the accident or casualty reduction/cost ratio for a particular improvement action can be changed and still be selected by the model. The improvement actions corresponding to the decision criteria (DC_1, DC_2, DC_3 and DC_4) are, respectively, single-track passive to flashing lights, single-track passive to gates, multiple-track passive to gates, and flashing lights to gates. Comparing the R value to the decision criteria is equivalent to determining if the actual change in accident or casualty reduction/cost ratio due to revised data is still within the limits permitting selection of the same improvement action.

To demonstrate use of the revision procedure, the following hypothetical example is provided. A single-track passive crossing was selected by the resource allocation model for upgrading to gates. This crossing is listed as the second crossing (ID# 636R) on the sample standard output report of the resource allocation model shown in Figure 5-10. The crossing was inspected by a diagnostic team, and it was found that some of the data from the Inventory used in calculating the predicted accidents were incorrect. In addition, the assumed values for the installation costs and effectiveness of gates at the crossing were deemed inappropriate. Using the new data, a revised prediction of accidents was calculated according to the tabularized procedure described in Section 5.1.1. The previous and revised accident prediction, cost, and effectiveness parameters for the crossing are listed below:

	Previous	Revised
Predicted Accidents, A	0.19	0.26
Warning Device Effectiveness, E	0.90	0.87
Warning Device Cost, C	\$65,300	\$115,000

Using the above data, the R value is calculated using equation (11) (also shown on the worksheet, step 4, part 2):

$$R = (.26/.19)\,(.87/.90)\,(65{,}300/115{,}000)$$

$$= 0.751$$

The decision criteria for this crossing, obtained from the standard output report of the resource allocation model, Figure 5-10, are:

$DC_1 = 0.318$
$DC_2 = 0.780$
DC_3 = not computed since the crossing is single track
DC_4 = not computed since the crossing is passive

Comparing R with the decision criteria values, as described in step 4, part 3a of the worksheet, shows that R is greater than DC_1, but less than DC_2. This means that the original decision to install gates at this crossing should be revised to install flashing lights as the most cost-effective decision if the new data for the crossing are assumed correct.

4.3 RESOURCE ALLOCATION MODEL FOR STANDARD HIGHWAY STOP SIGNS

The most recent DOT study on warning device effectiveness[11] determined that standard highway stop signs may be effective in reducing crossing accidents. The average level of effectiveness for upgrades to standard highway stop signs from other passive devices was found to be 0.35 (95 percent confidence interval, 0.16 to 0.54). This level of effectiveness coupled with their low cost ($400 installation or $800 total 30-year life cycle cost, including "stop ahead" signs, for a two-stop sign installation) make standard highway stop signs worthy of consideration for certain crossing situations[11]. The FHWA has established the following guidelines for the selection of candidate crossings for stop signs[4,14]:

The use of the stop signs at railroad-highway grade crossings shall be limited to those grade crossings selected after need is established by a detailed traffic engineering study. Such crossings should have all of the following characteristics:

1. Highway should be secondary in character with low traffic counts.

2. Train traffic should be substantial.

3. Line of sight to an approaching train is restricted by physical features such that approaching traffic is required to reduce speed to 10 miles per hour or less in order to stop safely.

4. At the stop bar, there must be sufficient sight distance down the track to afford ample time for a vehicle to cross the track before the arrival of the train.

The engineering study may determine other compelling reasons for the need to install a stop sign. However, this should only be an interim measure until active traffic control devices can be installed. Stop signs shall not be used on primary through highways or at grade crossings with active traffic control devices.

Whenever a stop sign is installed at a grade crossing, a stop ahead sign shall be installed in advance of the stop sign.

The resource allocation model provides, at the option of the user, a list of crossings that are possible candidates for standard highway stop signs. This list is produced by selecting from the passive crossings under consideration those with less than 400 average daily traffic (ADT) counts for rural roads and less than 1500 ADT counts for urban roads, greater than 10 trains per day and single tracks. The crossings on the list are ranked by the accident or casualty prediction measure selected by the user. Unlike the resource allocation model results for active warning devices, the stop sign list is not ranked by accident or casualty reduction/cost ratios. The reason for this is two fold: (1) based on presently available information it is assumed that all stop sign upgrades have the same cost and effectiveness; hence, a ranking by accident or casualty reduction/cost ratio would be the same as that by accident or casualty prediction; and (2) since the number of crossings that are realistic candidates for stop signs are so few and their costs are so low, stop sign installation decisions will be made primarily on factors other than their accidents or casualty reduction/cost ratios relative to active warning device projects.

The stop sign candidate report can be produced either with or without the report of active warning device recommendations. If the resource allocation procedure is used to produce both reports, it is possible that the same crossing could appear on both lists; i.e., a crossing that is a possible candidate for stop signs may also be a candidate for an active warning device. To provide a means of integrating this information, the report on active warning device recommendations will indicate, at the option of the user, if a crossing is also a candidate for stop signs.