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Title: The Evaluation and Selection of Highway Safety Improvements for Local Jurisdictions

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Many hazardous locations exist on our local and street highway systems. Such hazards contribute to the frequency and severity of traffic accidents. The elimination and mitigation of the hazards reduces accident frequency and severity, as measured by the number of fatalities, injuries and property damage resulting from the accidents.

The accident potential and the accident severity for the existing situation and for improvements are estimated to determine the number of fatal, injury and property damage only accidents. The reduction in accidents because of the safety improvement are used to measure the safety benefits. These benefits are compared with the costs of the improvements using economic analyses techniques. A decision making framework is developed which employs economic evaluation methods and takes account of budget limitations, to rank safety improvements. This approach leads to the selection of the most cost-effective safety improvement alternatives for highways and streets in local jurisdictions.

The Evaluation and Selection of Highway Safety Improvements for Local Jurisdictions

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CHAPTER 1 INTRODUCTION

1.1 Problem Identification

The current annual highway accident toll in the U.S. is approximately 50,000 deaths, two million injuries and 17 million accidents. A significant part of these accidents are on low volume and low speed highways and streets.

Local highway agencies are faced with the problem of identifying safety hazards and establishing priorities for the improvements necessary to eliminate the safety hazards. Funds are usually not sufficient to finance all improvements. Therefore, an economic evaluation to determine the most cost-effective safety countermeasure would aid decision makers in establishing highway improvement programs.

1.2 Purpose

The purpose of this study is to develop a process that evaluates and sets priorities on safety improvements for the street and highway system of local jurisdictions.

The specific objectives of this study are to:

(1) Estimate the probability of fatal, injury and property damage only accidents for various types of hazards and at different vehicle speeds.

(2) Present methods to assess the costs of fatal, injury and property damage only accidents.

(3) Discuss various countermeasures and their contribution to

a decrease of fatal, injury and property damage accidents.

(4) Compare the reduction in accident costs, that is increase in benefits, with the cost of countermeasures on an economic basis.

(5) Take account of budget constraints and develop a technique to set priorities for safety improvements within budget limitations.

(6) Prepare a decision-making approach to select and implement safety improvements.

1.3 Scope

This study treats the economic evaluation of highway safety improvements. The procedures developed are for use in local jurisdictions to rank highway safety improvements and establish safety programs. Non-safety benefits of countermeasures are not treated in detail.

This study is the second part of research to develop a method to rank highway safety improvements. The first part of this research developed a priority rating system for highway safety improvements that emphasized the accident potential and severity of different hazards. Hazards are ranked according to their accident potential with severity taken into account. Part I dealt with safety conditions for railroad crossings, intersections, roadway condition of the geometrics and roadside obstacles.

In Chapter II of this report the study framework, the accident potential which is based on an earlier study (31), accident severity and weightings, and speed and safety relationships stated as the probabilities of fatal, injury and property damage accidents are presented. The remaining chapters deal primarily with the monetary evaluation of safety improvements. Chapter III discusses the evaluation framework which includes a discussion of accident costs, safety benefits, improvement costs, accident reduction, estimation of the number of different types of accidents, and countermeasures. Chapter IV elaborates the evaluation criteria for safety improvements and economic analysis methods to prepare economic measures for the economic evaluation. Chapter V deals with the evaluation approach, independent and mutually exclusive alternatives, and the different methods of economic analysis with examples. Chapter VI discusses the elements of a decision making approach for selecting and implementing countermeasures, the comparison of independent and mutually exclusive alternatives on a common basis, the comparison of all the elements involved in two separate projects and the inclusion of budgetary constraints. Conclusions and recommendations for further research are presented in Chapter VII.

CHAPTER II BACKGROUND

This chapter presents the study framework for selecting highway safety improvements. The initial study which dealt with accident potential, and the ranking of hazards based on accident potential and severity is discussed. The accident severity for various hazards and vehicle speeds is presented, and relationships from the existing literature are used to develop a relationship between obstacle severity, vehicle speeds, and the probability of fatal, injury or property damage only accidents.

2.1 Study Framework

Remedial measures must be evaluated to obtain the most cost effective safety improvement programs. The safety funds are usually insufficient to improve all potential hazards.

This report presents procedures to evaluate proposed remedial measures at hazardous locations. Figure 2.1 illustrates the analytical and evaluation framework of the methodology for evaluating safety improvements.

The analysis and evaluation of highway safety improvements are divided into the following steps.

Step 1 - Hazard Categories. The factors contributing to accidents differ for various types of hazards. The hazards are classified into four categories:

1. Rail-Highway Grade Crossings,
2. Intersections,
3. Geometrics, and
4. Roadside Obstacles

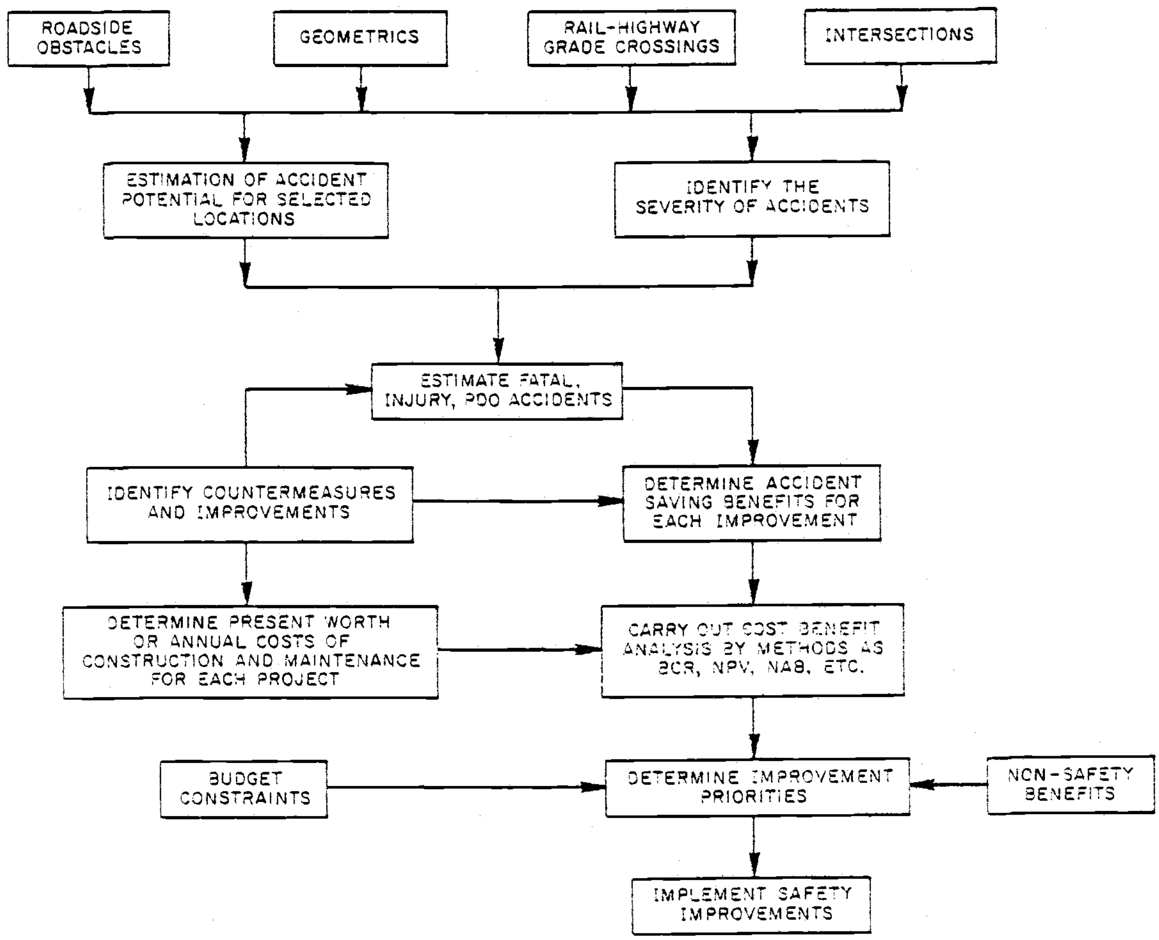

Figure 2.1 Study Framework

Step 2. Estimation of accident potential for hazardous locations and estimation of the severity of accidents: The accident potential for hazardous locations is estimated in accidents per year. The severity of the accidents is estimated based on the obstacle characteristics and the normal roadway speed.

Step 3. Estimation of fatal, injury and property damage only accidents: In this step the number of fatal, non-fatal injury and property damage only accidents among the total accidents are estimated.

Step 4. Identify countermeasures and improvements: The possible countermeasures for different hazard types are identified so that all possible safety improvement alternatives are considered.

Step 5. Determine accident saving benefits for each improvement: Accident reduction factors for countermeasures are used to determine accident saving benefits for each improvement. The benefits are obtained by multiplying the accident reduction by the accident costs and converting to present worth or equivalent uniform annual benefits.

Step 6. Determine present worth or equivalent uniform annual costs of safety improvements: The initial costs, yearly maintenance costs and salvage values of safety improvements are converted to present worth or equivalent uniform annual costs.

Step 7. Evaluate safety improvements by economic analysis: Cost benefit analysis of countermeasures is performed by methods such as benefit/cost ratio, net present worth, and net annual benefit. The alternative may be either independent or mutually exclusive.

Step 8. Final decision making: This is the final stage in evaluating alternatives. The independent and mutually exclusive alternatives are compared simultaneously by the use of benefit/cost ratio and incremental benefit/cost ratio methods. Two projects are evaluated in entirity. The budget constraints are also taken into account as the alternatives are ranked and the most cost-effective safety improvements are selected.

2.2 Accident Potential

A highway safety obstacle is defined as "any natural or man-made feature of the road environment which affects the frequency and the severity of accidents" (45). A hazardous roadside obstacle is defined as one projecting above the ground surface, any surface depressions, or any terrain feature that produces a vector change in vehicle acceleration.

The causes of accidents are so complex that they cannot be readily related to physical conditions. There are three major elements that contribute directly or indirectly to the occurrence of accidents, and these elements all have potential for improvement. These three elements are the (45):

driver,

vehicle, and

road and its environment.

The means of improvement for drivers include information, education and enforcement. The extent of driver improvements is limited. No matter what precautions are taken in design and control, a driver can lose control of his vehicle as a result of loss of attention, an incorrect maneuver, excessive speed or numerous other reasons.

Vehicle improvements achieve greater occupant safety through improved vehicle design. Safety belts and other passenger restraint devices are proving effective (9). Attempts are being made to develop restraint devices that can absorb the shock of a collision with a rigid obstacle with greatly reduced severity.

The hazards from a road and its environment include geometrics, operations and roadside obstacles. Improvements for the road and its environment typically include better layout and design. There is great potential for increased safety through roadway and roadside improvements. They can be the most effective in reducing accidents and their severity. Some improvements can only be implemented on new roads. Others can be introduced on existing roads, where action can be undertaken and often at low cost. This report deals only with potential improvements to the roadway and its environment.

Many hazardous locations and situations that create safety problems exist in our local street and highway system. These hazards have to be identified properly and appropriate improvements implemented to reduce fatalities, injuries, and property damage. Factors contributing to accidents differ for various types of hazards. Hazards are classified into four categories (31):

1. Rail-Highway Grade Crossings,
2. Intersections,
3. Geometrics, and
4. Roadside obstacles

2.2.1 Rail-Highway Grade Crossings

Rail-highway grade crossings account for less than 0.1 percent of all motor vehicle accidents, but the number of people killed and injured is high. This is illustrated by the fact that each year approximately 2.5 percent of all motor vehicle deaths occur at railroad crossings (46). Although accidents at railroad crossings are infrequent, the accidents always attract much public attention.

Gates and flashing lights reduce the number of accidents at railroad crossings, but these improvements are expensive (5). Railroad crossings where major safety improvements are warranted are those in urban areas or locations with high vehicle and train volumes. Effective analysis and evaluation techniques are needed to select and implement appropriate and economic countermeasures.

2.2.2 Intersections

Intersection accidents account for 25 percent of all reported accidents, about 50 percent of all fatal accidents in urban areas, and 10 to 15 percent of fatal accidents in rural areas (43).

Inadequate sight distance due to obstructions is a major cause of accidents at intersections. The removal of sight obstructions and improvement of sign visibility reduces the number of accidents. However, the cost of removing sight obstructions is generally high. Analysis and economic evaluation are needed to select the most cost effective safety improvement.

2.2.3 Geometrics

Highway geometrics and design have a very significant influence on safety. Accident potential exists for any highway alignment even if it is designed for "ideal" conditions. If a highway is designed that does not provide ideal conditions, accident potential is increased. Inadequate and deficient geometrics are a major cause of highway accident frequency and severity. Geometric features, such as, horizontal and vertical alignment, the presence of structures, pavement width, shoulder widths, sight distances and cross-slopes, are closely related to highway safety.

It is not possible to have ideal design conditions for all types of highways. However, very deficient highways and streets need improvements. The most cost-effective design for the expected highway conditions should be attempted. Where possible, the design should more than meet minimum standards and criteria for safety. However, a consistent standard of design over a section of highway is also important for safety.

2.2.4 Roadside Obstacles

A National Safety Council study published in 1974 reports that 6.7 percent of urban accidents and 21.4 percent of rural accidents involve fixed objects along the roadway. These roadside obstacles account for 17.5 percent of the urban fatalities and 22.5 percent of the rural fatalities (2). Obviously these hazards account for a significant portion of the total accidents and must be analyzed and evaluated for improving safety.

Most fixed object accidents involve a single vehicle. The probability of occupant injury in "single vehicle fixed object" accidents is significantly higher than in other accidents (20). Unyielding objects, such as, bridge and overpass entrances, when struck result in fatality rates four times the average rate. Trees, field approaches, culverts, and embankments also have high fatality and injury rates. Guardrails, fences, and small sign posts cause less severe accidents (40). The single object type that presents the most serious hazard, in injuries and deaths, is single trees.

Guardrails because of their common use placement near the road and size contribute to high accident frequency, but the severity of the accident is generally less. Also guardrails are designed to protect vehicles from more hazardous conditions, and if installed properly, they reduce the severity of accidents.

2.3 Accident Severity

Accident severity measures the consequence or the seriousness of an impact if an object is struck. Different types of obstacles produce varying degrees of impact severity. The combined effect of the rigidity of the obstacle, its mass and the vehicle speed determine the severity of an accident. The accident severity for an obstacle is typically measured by a severity index that takes into account the fatalities, injuries and property damage which result from a collision with the obstacle.

Generally, any safety program is aimed at reducing the severity and the total number of fatal, non-fatal injury, and property damage accidents. Different schemes of assigning relative weights to these three accident types may be used to evaluate and select improvements that best achieve this objective. However, the weighting scheme or evaluation approach used must reflect the goals and values of the jurisdiction.

2.4 Severity Weighting

A severity scale or a cost scale must be assigned to the different accident types because a fatal accident and a property damage only accident do not have equivalent social or economic value. The costs, pain and suffering from a fatal accident are far greater than for a property damage only accident. The values decrease in descending order for the accident types of:

1. Fatal accident,
2. Injury accident,
3. Property damage only accident.

A fatal accident is an accident resulting in one or more deaths, but may also involve injuries and property damage. An injury accident is an accident resulting in one or more non-fatal injuries, and may have property damage. Property damage only accidents are those involving damage to property, and are expressed in terms of dollars.

2.4.1 Procedure

The weighting scheme for accident severity takes account of the seriousness of the accident in terms of injury, pain, suffering, property damage, and accident costs. Some of the methods of weighting by accident severity are:

1. Ratio of fatal accidents to total accidents,
2. Average number of fatalities per accident,
3. Average number of fatal and non-fatal injuries per accident,
4. Numeral method of arbitrary, numerical weights,
5. Cost method, and

6. The ratio of fatal and non-fatal injury accidents to the total number of accidents.

In this study the severity weighting is the proportion of fatal and non-fatal injury accidents to the total accidents and is referred to as the severity index. Fatal accidents alone could be used to obtain the severity index. However, combining fatal and injury accidents makes it possible to analyze and evaluate safety programs more effectively. This severity weighting recognizes that fatal accidents are rare events and the proportion of deaths is small. Also, the likelihood of a fatality is influenced by numerous other factors such as the number of people in the car, their seating location, the use of seat belts and numerous other factors. Large volumes of accident data are needed to make the fatality indices statistically reliable. It is difficult to obtain such data for all types of obstacles. The advantages of using the ratio of the total number of fatal and non-fatal injury accidents to the total number of accidents are (14):

1. Less accident data are required.
2. The ratio is simple and easily calculable compared to methods using average number of fatalities per accident or average number of fatalities and non-fatal injuries per accident.
3. The ratio is expressed in decimals ranging from 0.00 to 1.00, and the values are rationally ranked according to the severity of the obstacle.

2.4.2 Severity Index

The severity index of an obstacle is a relative scale that indicates the degree of accident consequence associated with impacting various obstacles at various vehicle speeds. It is the probability of an accident causing a fatality or non-fatal injury if the object is struck. For example, a severity index of 0.50 means that 50 percent of the time, a collision with the obstacle involves either death or injury.

The Severity Index (S.I.) is mathematically the ratio of the number of fatal and non-fatal injury accidents to the total number of accidents:

$$S.I. = \frac{\text{Fatal accidents and non-fatal injury accidents}}{\text{Total number of accidents}}$$

Table 2.1 indicates the severity indices assigned to various obstacles (14,31). The severity indices for different obstacles vary between 0.2-0.8, depending on their rigidity, mass, strength, composition, etc. These indices are developed based on high speed conditions, corresponding to approximately 55 mph operations (14).

The severity indices for different obstacles is based on historical accident records (14). The precision of these indices depends on the availability and accuracy of accident records.

2.4.3 Numeral Method

Another method of weighting by severity is by assigning numerical weights to each degree of severity. These weights are arbitrary and have no satisfactory statistical basis. However, they do assign higher weights to fatal and injury accidents, thereby recognizing the severity of these types of accidents. Some agencies have used weights such as 1 for property damage, 3 for injury and 12 for fatality, or 1 for property damage, 6 for injury and 25 for fatality (53,15).

Table 2.1 Severity Indices of Hazards

Obstacle	Severity Index
Railroad Crossings	
Crossbucks	0.80
Wigwags	0.51
Flashing Lights	0.43
Automatic Gates	0.25
Intersections	
	(not available)
Geometrics	
Fill Slopes	
Greater than 2:1	0.70
3:1	0.53
4:1	0.43
5:1	0.33
Less than 6:1	0.22
Cut Slopes	
½:1 - 1:1	0.70
1½:1	0.53
2:1	0.43
3:1	0.33
4:1 or flatter	0.22
Ditch (1 - 2 ft.)	.37
Ditch (3 + ft.)	.60
Roadside Obstacles	
Trees	
13 inch diameter or greater	0.70
11-12 inch diameter	0.53
8-10 inch diameter	0.43
5-7 inch diameter	0.33
2-4 inch diameter	0.22

Table 2.1 Severity Indices of Hazards (cont.)

Obstacle	Severity Index
<u>Roadside Obstacles (cont.)</u>	
Single, Double, or Triple Steel Post Sign	
9 inch or greater post size	0.70
6-8 inch post	0.53
3-5 inch post	0.43
Breakaway Sign Posts (all sizes and types)	0.22
Single, Double, or Triple Wood Post Sign	
14 inch diamter or greater	0.70
10-13 inch diameter	0.53
7-9 inch diameter	0.43
8 x 8 inch (dimensional)	0.33
6 inch diameter	0.33
6 x 6 inch (dimensional)	0.33
4 x 4 inch (dimensional)	0.22
Animals	0.08
Miscellaneous (debris, construction barriers)	0.28
Fence	0.35
Fire hydrants	0.35
Culverts	0.57
Field Approach	0.65
Rocks	0.44
Small trees, brush	0.36
Fence	0.21
Mailbox	0.13

Sources: 5, 14, 15, 20, 32, 35, 40

2.4.4 Cost Method

The weighting scheme by cost assigns monetary values to the type of accidents, that is, fatal accidents, non-fatal injury accidents, and property damage only accidents. These costs are estimates of losses incurred by individuals and society.

It is quite difficult to assess accurately the costs of accidents. Vehicle damage and property damage can be calculated in monetary terms, but assigning a quantitative value to pain and suffering caused by injuries and deaths is difficult.

However, monetary values must be assigned if economic evaluation and decision-making techniques are to be used. Even if it were decided to forego economic evaluation of accidents, decisions would still be based on implicitly assigned weights, or values. The selection of the projects to be implemented, based on the judgement of the decision-maker, would arbitrarily assign values, and would reflect his set of values for accidents and safety.

Some of the methods that have been used to weight accident costs are:

1. Average property damage cost per accident,
2. Average direct cost per accident, including property damage, hospitalization, insurance premiums, funeral expenses, etc.,
3. Average total cost per accident, includes loss of future earnings, and values for human suffering in addition to direct costs,
4. Average total cost for each type of accident; that is, fatal accident, non-fatal injury accident and property damage only accident.

In this study the average total costs for fatal, injury and property damage only accidents are used. The costs indicate the severity of the accident. The highest costs are assigned to fatal accidents, injury accidents are second and property damage costs have the least costs associated with them. Fatal accidents account for a very small percentage of the total involvements, but they account for a high portion of total accident costs. Property damage accidents are very frequent, but the cost per involvement is little.

Estimates of accident costs are published by many agencies, such as the National Highway Traffic Safety Administration, the National Safety Council and many State Departments of Transportation. Any set of economic values may be used for economic analysis, as long as they are used consistently.

Estimates of National Highway Traffic Safety Administration NHTSA for 1975 (1) (48)

Average Fatal accident, including property damage	=	$307,210
Average Injury accident, including property damage	=	$ 14,600
Average Property Damage accident per vehicle	=	$ 650

The NHTSA estimates are based on "societal costs". These losses are not necessarily economic losses to society, but an approximate measure of losses in societal welfare. The value in dollars does not represent the value of a human life. It is an approximate measure of the loss in the welfare to society as a consequence of the accident. The estimate covers items such as wages lost, medical expenses, legal fees, insurance payments, home and family care, and property damage. A small percentage of the costs are assigned to pain and suffering.

Estimates of the National Safety Council NSC for 1976 (47)

Fatal accident	= $125,000
Non-fatal disabling injury	= $ 4,700
Property damage only including minor injuries	= $ 670

The NSC estimates include wage losses, medical expenses, insurance administrative costs, and property damage.

It is up to local decision makers to decide which cost elements should be included or which estimates to use. The most reliable data on accident costs are those that are collected locally. Information from the Motor Vehicle Department, local insurance companies, fleet operators and public health service are more suitable than nationwide statistics such as the NHTSA and NSC estimates (32).

2.5 Speed and Obstacle Influence on Accident Severity

A relationship to estimate the effects of speed on accident severity and the effects of obstacle characteristics on accident severity is developed in this section.

2.5.1 Speed Vs. Accident Severity

Studies have found that the severity of an accident varies directly with the speed of the vehicle, when all other factors are kept constant (25, 58, 37, 7, 49, 4). Speed is not the sole cause of accidents, but it contributes substantially to their numbers and severity.

As speed increases the severity of the accident also increases.

This is to be expected because impact energy varies as the square of the vehicle speed. Also, stopping distance increases approximately as the square of the initial speed, because braking lengths increase and drivers require a longer distance to react at higher speeds (52).

The accident severity at moderate and high speeds is considerably greater than that at lower speeds. Figures 2.2, 2.3, and 2.4 show the effect of speed on accident severity. As shown by these figures, an increase in speed correlates with an increase in the number of persons killed or injured, and in the amount of property damage.

Figure 2.5 shows the relationship between speed and the ratio of people injured to people killed in accidents.

Various studies support the hypothesis that the severity of accidents measured by fatalities, injuries, and property damage increases exponentially with travel speed (4,25,58,37,7,49).

2.5.2 Obstacle Characteristics Vs. Severity

The character of the object struck by a vehicle in a single vehicle accident is expected to affect the accident severity. The degree of accident severity associated with objects depends on the obstacle characteristics such as its location size, shape, rigidity mass, and strength. When all factors contributing to roadside hazards are the same, an object that is closer to the roadway is more hazardous than one that is farther away (20). Approximately 35 percent of the accidents involving roadside objects the objects are within a distance of 30 feet from the pavement edge (59). The size of the obstacle affects the accident potential as there is greater probability of hitting large objects than smaller ones simply because they occupy a greater area or

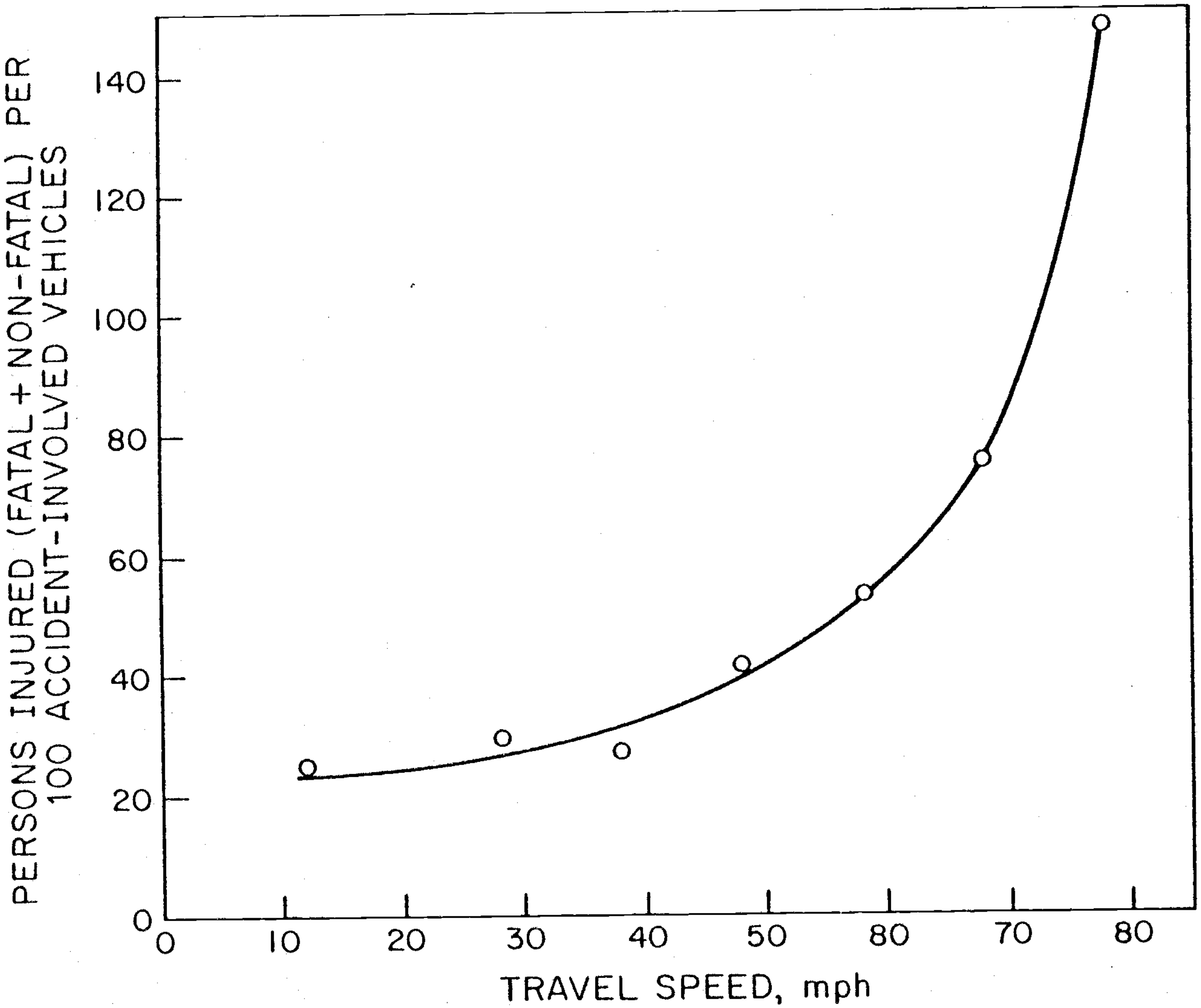

Figure 2.2 Speed vs. Injuries (Fatal and Non-Fatal) per 100 Involvements

Source: 49

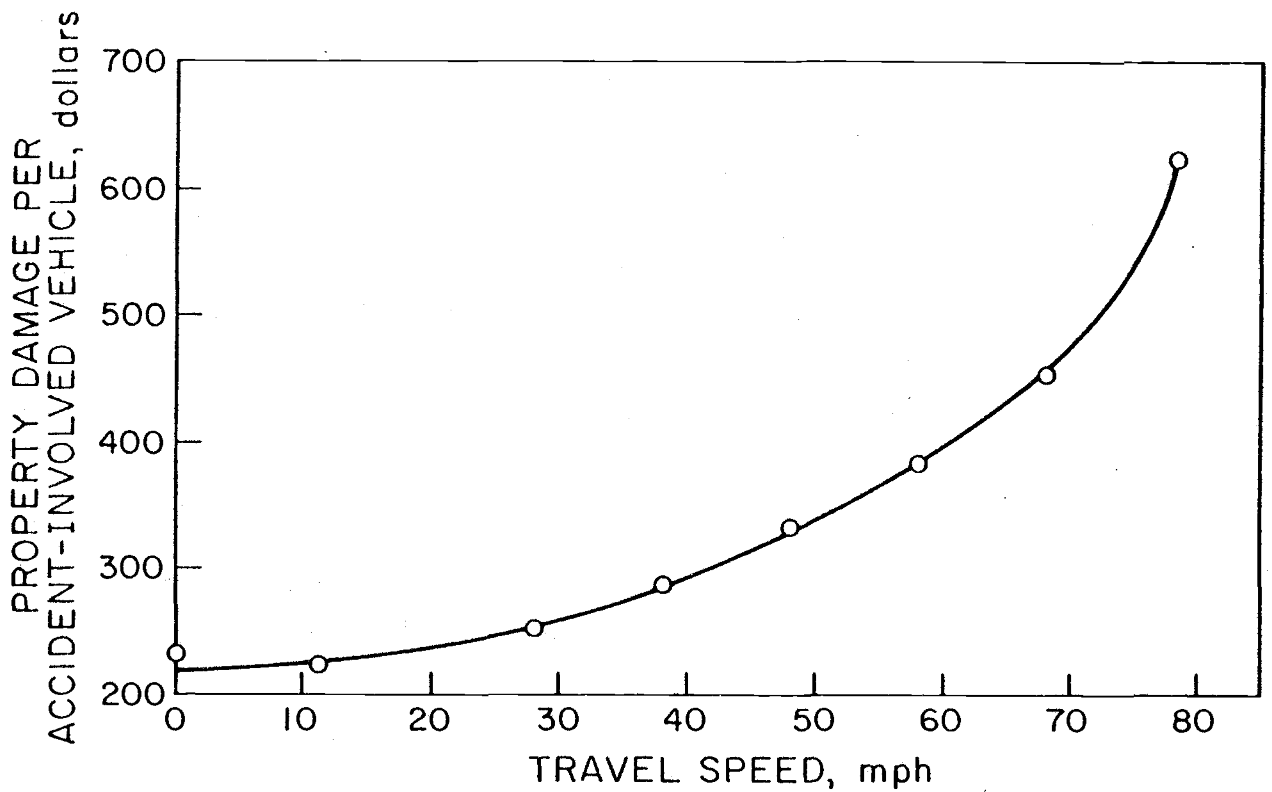

Figure 2.3 Speed Vs. Property Damage Per Accident Involved Vehicle

Source: 49

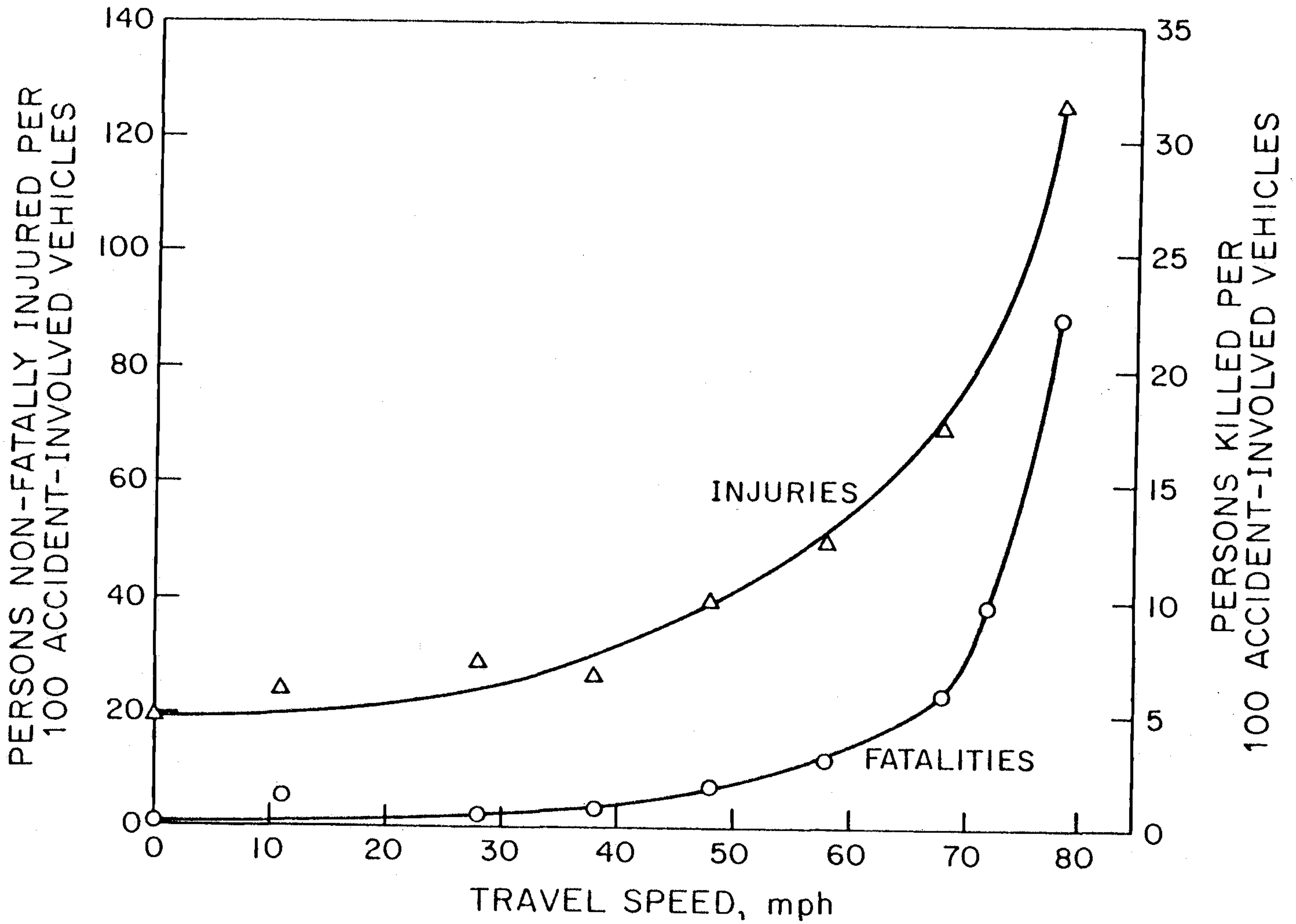

Figure 2.4 Speed Vs. Injuries and Fatalities Per 100 Involvements

Source: 49

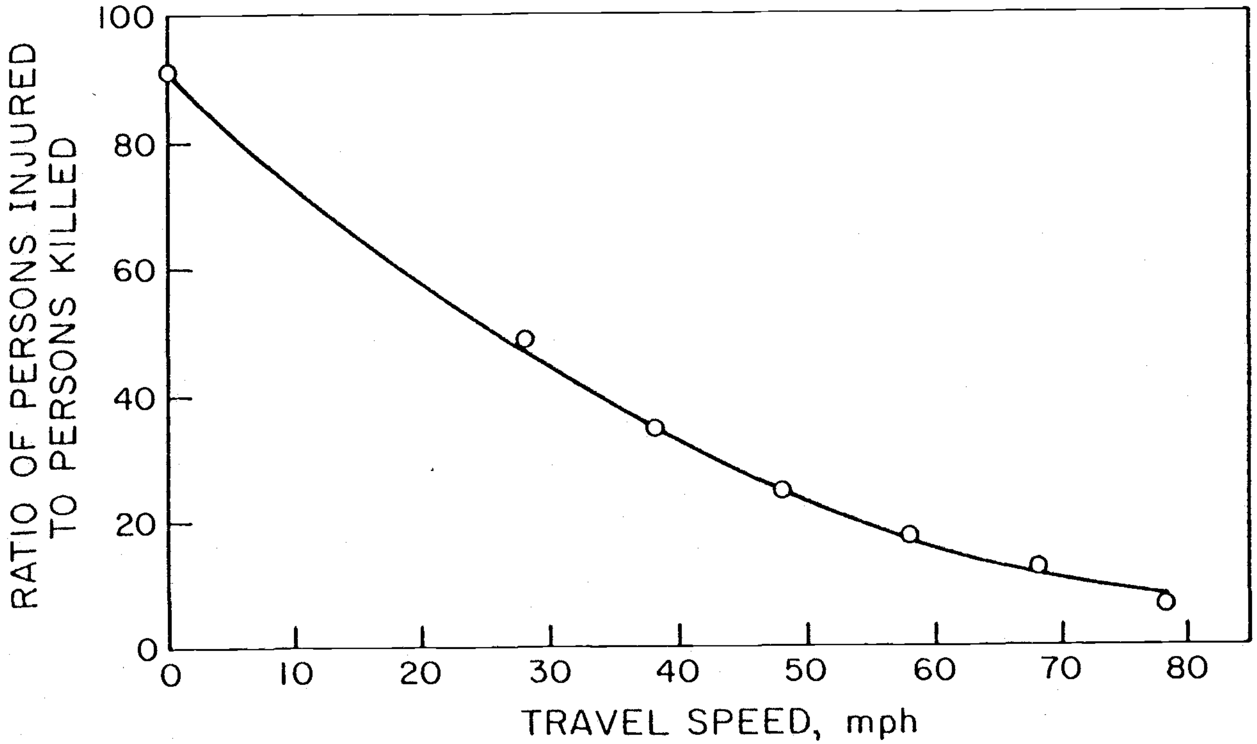

Figure 2.5 Speed Vs. Ratio of Persons Injured to Persons Killed

Source: 60

length along the roadside (14).

The mass, rigidity and shape of the object have a greater effect on the severity of the accident, than does size. The location or placement of an obstacle can indirectly affect the severity if the vehicle speed is higher because the vehicle has traveled less distance from the road or the obstacle is on a steep slope (40). Non-yielding or rigid objects produce higher resultant severity than yielding or less rigid objects at equivalent impact speeds. Table 2.1 indicates the accident severity in terms of injuries and fatalities associated with various obstacles on collision. By far, the greatest hazard presented is by bridge/overpass entrances. Trees and culverts also have high fatality and injury rates. Guardrails, fences, and small sign posts produce less severe accidents when struck (40).

2.5.3 Combined Effects of Speed and Obstacle Characteristics on Accident Severity

The resultant severity of accidents with roadside obstacles depends primarily on two factors--vehicle speed and obstacle characteristics. The accident severity depends on the combined effect of vehicle speed, obstacle rigidity, object mass and the shape of the obstacle. The severity index of obstacles as defined earlier takes into account the obstacle characteristics. However, the severity of impact with a given obstacle decreases as the speed decreases. Consequently, the severity index for a given obstacle would be different at different speeds.

The severity index, as previously defined, measures the likelihood, or probability, that a fatality or injury would occur upon impact. Thus, the probability of a fatality or injury from an accident can be estimated by combining the relationships for severity vs. speed with the

Table 2.2

Accident Severity of Obstacles

Object	Fatalities	Non-fatal Injuries	Property Damage Only	Total	% Killed	% Injured
Bridge/Overpass Entrance	14	52	22	88	15.9	59.1
Tree	48	405	214	667	7.2	60.7
Culvert	14	130	87	231	6.1	56.3
Embankment	18	216	172	406	4.4	53.2
Wooden Utility Pole	14	292	292	598	2.3	48.8
Brush	5	93	157	255	2.0	36.5
Guardrail	5	85	194	284	1.8	29.9
Fence	1	78	246	325	0.3	24.0
Small Sign Post	1	16	59	76	1.3	21.0

Source: 40

relationships for severity vs. obstacle characteristics. The fatality rates and injury rates at different speeds for the year 1977 are used to find the probability of fatal or injury accidents (7). The fatality rates and injury rates for various obstacles at specific speeds are used to find the probability of fatal and injury accidents (23). A relationship for the combined effect is developed by combining data on the severity indices of various obstacles at 55 mph with the relation of severity vs. speed. This relationship, shown in Figure 2.6, gives the probability of fatal and injury accidents vs. speed, for obstacles with various levels of severity index.

The values of severity index in Table 2.1 for the different obstacles are standardized at a speed of 55 mph, that is, the values of the severity index are obtained for 55 mph speed conditions. The individual curves on Figure 2.6 are the probability of fatality or injury for a obstacle with that severity index, S.I., at 55 mph. For example, a bridge abutment has a severity index of 0.7 at 55 mph, so the probability of a fatality or injury at any other speed would be found from the S.I. = 0.7 curve. As seen in Figure 2.6, at a speed of 55 mph, the probability of a fatal or non-fatal injury accident in a collision is equal to the severity index, S.I., of that obstacle. At any given speed, an obstacle with a higher severity index has a greater probability of a fatal or injury accident than an obstacle with a smaller severity index. For example, for collisions at 55 mph the likelihood of a fatal or injury accident is higher for a bridge pier or bridge abutment, with S.I. = 0.7, than for a guardrail, with S.I. = 0.33.

Figure 2.6 also shows that if an obstacle with a certain severity index is impacted at various speeds, the accident severity varies with

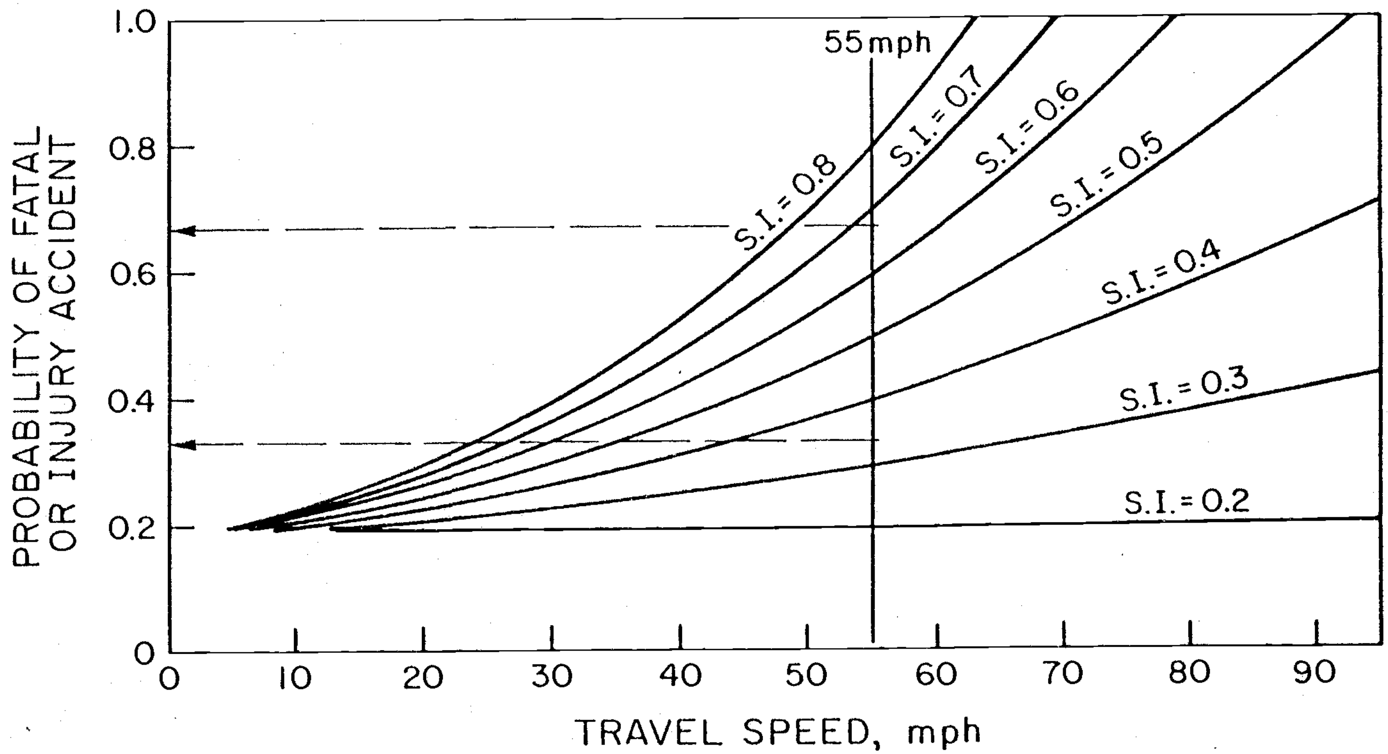

Figure 2.6 Speed Vs. Probability of Fatal of Injury Accident

Source: 7, 23, 37

the speed. For example, for a pier face with a severity of 0.70 the probability of a fatal or injury accident at 55 mph is 0.70, but as the speed increases to 70 mph, the probability of a fatal or injury accident increases to nearly 1.0.

The relationship shown in Figure 2.6 is disaggregated into relationships of speed versus the probability of a fatal injury, given in Figure 2.7, and speed vs. the probability of a non-fatal injury, given in Figure 2.8. In other words at 55 mph, the probability of a fatal accident, from Figure 2.7, plus the probability of an injury accident, from Figure 2.8, is equal to the probability of fatal or injury accident, from Figure 2.6. For example, for an obstacle with a S.I. of 0.50 at 55 mph;

Probability of fatal accident (Figure 2.7)	= 0.039
Probability of injury accident (Figure 2.8)	= 0.461
Probability of fatal + injury accident (Figure 2.6) = Sum	= 0.500

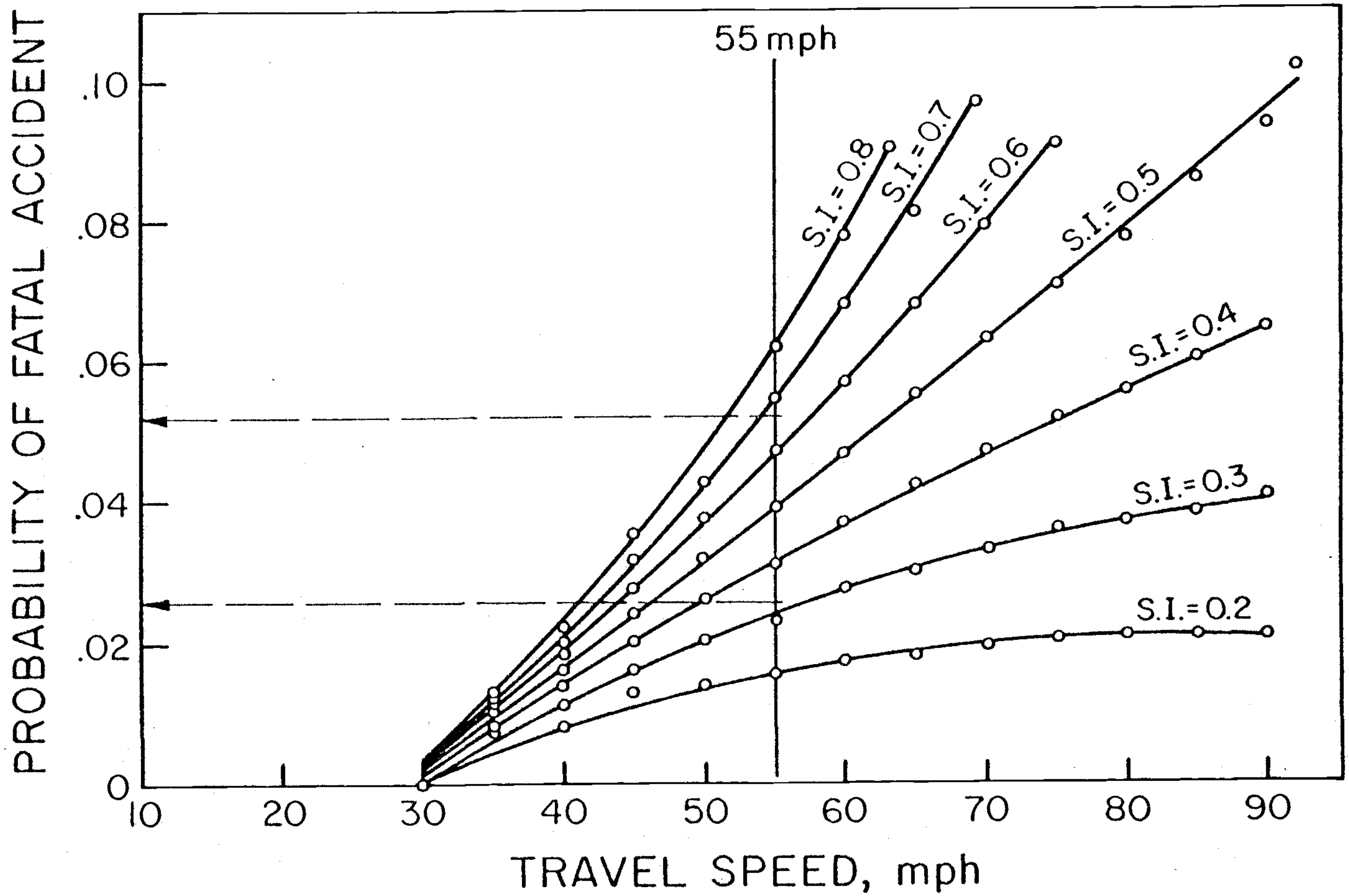

Figure 2.7 Speed Vs. Probability of Fatal Accident

Source: 7, 23, 37

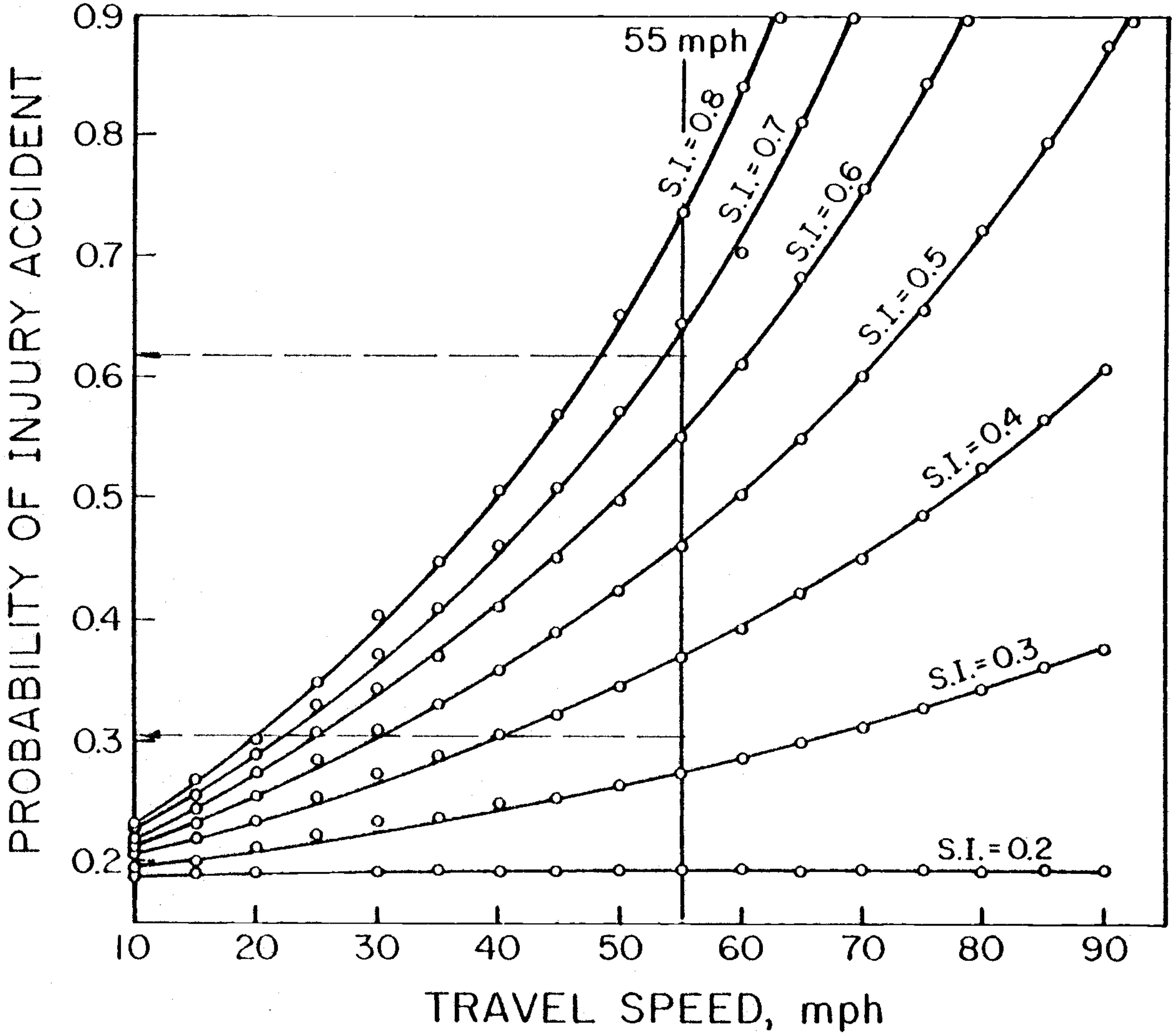

Figure 2.8 Speed Vs. Probability of Injury Accident

Source: 7, 23, 37

CHAPTER III. EVALUATION FRAMEWORK

The evaluation framework defines the outline of the methodology used to appraise the safety and economics of remedial measures. The possible safety improvements and their costs are compared to the improvement benefits, that are derived from accident reduction for each improvement.

3.1 Costs and Benefits

The purpose of benefit cost analysis is to compare costs to benefits. It is a means of rating potential safety countermeasures. The analysis determines the relationship between the cost of any measure adopted and the benefits accruing from the measure adopted. The increasing cost of safety improvements and lack of safety funds has made it necessary to conduct a thorough analysis of the consequences of decisions regarding highway safety improvements. The priorities for safety improvements can then be set according to their merits and feasibility. The comparison of benefits and costs provides a reasonable criteria to evaluate and select safety improvements, but benefits and costs should not be the only criteria.

3.1.1 Safety Benefits

The benefits of safety improvements are the reductions in the number and the cost of accidents, and in their severity.

Fatal and injury accidents cause the greatest pain, suffering, and cost. Although fatal and non-fatal injury accidents constitute a small percentage of the total accidents, they account for a large portion of the total accident costs. Property damage accidents are more frequent, but they do not account for a very large portion of the total accident costs. A primary goal of safety improvements must be the reduction of fatal and non-fatal injury accidents. However, the economics of total accident costs relative to the costs of improvements must also be taken into account.

Improvement benefits may either be calculated as equivalent uniform annual benefits or as present worth of benefits.

3.1.2 Improvement Costs

Improvement costs are the costs associated with improving hazardous locations to reduce the number and severity of accidents. Various suitable improvements, as discussed in the section on safety countermeasures, must be identified and their costs determined for evaluation.

The three primary elements of improvement costs are:

- Initial capital costs,
- Maintenance costs,
- Salvage or terminal value.

The initial capital costs are the costs of design, analysis and construction. They include costs of structures, barriers, signs, signals, pavement overlays, pavement modification, modification in geometrics and other safety appurtenances. Initial capital investment includes the materials, equipment and installation. The estimate of the initial cost of each improvement is best obtained from historical costs at similar locations. In the absence of historical costs, the estimate of initial costs can be based on the total estimated cost of each component or piece of hardware plus the cost of installation (32).

Maintenance costs are the yearly expenses of maintenance and operations. They can be estimated best using current maintenance and operating expenditures. Maintenance costs may remain constant or increase each year over the service life of the improvement.

Terminal or salvage value is the amount recoverable at the end of the improvements service life by its removal and sale (18). Most improvements have a zero salvage value, a very low salvage value, or a negative value, hence it does not affect the cost estimates substantially.

The service life of an accident reduction countermeasure is that period of time from the date of installation to the date of retirement. It is the period of time that an improvement can be expected to affect accident rates.

Generally, the potential for advancement in highway safety technology and possible price reductions are favorable to the selection of improvements with shorter service lives. The likelihood of price increases and extra costs incurred by replacement are favorable to the selection of alternatives with longer service lives.

In economic analysis a comparison of alternatives with different service lives is often made (18). To evaluate the alternatives on a comparable basis, it is assumed that the costs of replacement of a countermeasure are the same as the costs of the original.

The total cost of an improvement is then:

Total Cost = Initial Cost + Maintenance Cost - Terminal Value

All costs including improvement costs must be analyzed on a consistent cost basis, such as present worth of costs or equivalent uniform annual costs. Alternative improvement programs can then be evaluated and compared based on the total costs, as a consistent basis.

3.2 Calculation of Accident Reduction

In the analysis of any improvement program, the number of accidents that would be affected by the improvement program must be determined. For example, if a transition section of guardrail is being considered to protect a bridge end, then the affectable accidents are those where the untreated bridge end was struck (6). If two or more improvements are applied at the same location, then the combined reduction in the accidents is given by:

$$P_t = 1 - (1-P_1)(1-P_2)(1-P_3)$$

where:

P_t is the total reduction in accidents,

P_1 is the fractional reduction due to improvement No. 1,

P_2 is the fractional reduction due to improvement No. 2,

P_3 is the fractional reduction due to improvement No. 3.

The equation can also be of the form:

$$P_t = P_1 + (1-P_1)(P_2) + (1-P_1)(1-P_2)(P_3)$$

The above procedure is used so that the accident reduction due to an improvement is not exaggerated or considered twice.

The probable accident reduction factors for different safety improvements are shown in Appendix B.

3.3 Estimation of the Number of Fatal, Non-fatal Injury, and Property Damage Only Accident

Using the figures and tables introduced in an earlier section, the number of fatal, non-fatal injury, and property damage only accidents can be estimated. The accident potential in terms of expected number of accidents/year is determined from earlier studies (31,35). The procedure is:

1. Determine the severity index for the obstacle at 55 mph from Table 2.1.
2. Determine the probabilities of:
   a. Fatal accidents at the appropriate speed from Figure 2.7.
   b. Injury accidents at the appropriate speed from Figure 2.8.
   c. PDO accidents by subtracting the sum of the probabilities of fatal and injury accidents from Table 2.1.
3. Estimate the number of fatal and injury accidents:
   a. Number of fatal accidents = Accident potential x Probability of fatal accident
   b. Number of injury accidents = Accident potential x Probability of injury accident
   c. Number of PDO accidents = Accident potential x Probability of PDO accident

3.4 Accident Costs

The cost of the three types of accidents, fatal, non-fatal injury and property damage accidents, are defined in an earlier chapter. The cost estimates of the National Highway Traffic Safety Administration, NHTSA, for the three types of accidents are used to determine the costs of accidents in this study. The NHTSA cost estimates are:

Fatal accident = \$307,210

Non-fatal injury accident = \$ 14,600

Property damage only accident = \$ 650

If five injury accidents occur at a hazardous location in one year, then the annual accident costs are 5 x \$14,600 = \$73,000. If the hazardous location is improved, then the accident costs at the location are reduced due to the reduced severity and reduced number of accidents.

3.5 Identification of Potential Safety Improvements

Safety effects and budget limitations are the primary elements in the identification of countermeasures. A detailed list of the possible remedies for hazardous locations is given later. No countermeasure can eliminate accidents completely. At a hazardous location one or a combination of countermeasures can be undertaken to improve safety. The appropriate countermeasures at a location depend not only on the type of accidents but also the particular conditions at that location.

3.6 Accident Countermeasures

There is typically more than one possible improvement or combination of improvements to improve a safety problem. To select the "best" improvement for a safety problem, it must initially be identified as a potential improvement or recognized as a good solution after analysis and evaluation of other possible improvements. It is necessary to select and implement improvements which yield the greatest economic and safety return.

The purpose of safety improvements is to reduce the losses from accidental death, injury and property damage. The changes in these losses that can properly be attributed to a safety measure are the benefits to be estimated in evaluating the improvement (18).

The decision to implement a safety measure is not dependent solely on whether the benefits of a remedy justify its cost. In many countermeasures one must consider whether the benefit produced is in fact positive. The remedies considered can neither be rejected from all consideration not accepted as being worthwhile in all cases. They fall into the middle range where the benefits justify the costs in some situations and not in others.

An improvement may not show reductions in all types of accidents, For example, signalization at an intersection is very likely to increase the incidence of rear-end accidents, however the head on collisions may be reduced, while the number of certain types of accidents might increase. Further, guardrail installation often increases property damage damage accidents, but reduces the accident severity.

It is important to understand the mechanism by which roadway factors affect the highway safety, before implementing remedial action. Some factors include the treatment of curves, downgrades, vertical curves, embankment heights, etc. In almost all instances, consideration of drivers, their habits and their response rather than stipulations of what he or she should do, is an essential requirement in designing for safety.

Findings of some research is contrary to the view that improved conditions are in all respects safer (6). Snow covered roads and roadways with very sharp curvature may experience lower injury rates. A possible explanation is that these conditions are usually associated with low travel speeds. The driver adapts to the road conditions after taking the element of risk into account. Also conversely, the better the roadway, the fewer the precautions taken by the driver.

The various countermeasures that are appropriate to improve a particular hazardous location may be well-defined and obvious. For example, at a hazardous railroad crossing, warning signs, signals or gates may be used to reduce accidents. Other types of countermeasures are less obvious and may be easily overlooked, such as, improved sight distance or elimination of a railroad crossing. A comprehensive analysis and an indepth study of hazardous locations is necessary to ensure that the less obvious, and perhaps the "best solution," is not overlooked.

No improvement can eliminate accidents completely. They can reduce the number of accidents, their severity or both. Some countermeasures may increase their frequency but decrease their overall severity. The reduction in accidents and the mitigation of their severity are estimated for a number of possible countermeasures in Appendix B-1. These values are representative of the reduction in accidents that may be expected from a particular countermeasure. They should not be viewed as predictions. The accident reductions given can be used to estimate the incremental safety benefits derived from any improvement over the expected accident potential or an existing accident record.

Safety improvement programs generally consist of a four element procedure (13).

1. Remove roadside obstacles.
2. Relocate those obstacles that cannot be removed. This includes moving to a protected location and moving laterally.
3. Reduce the impact severity of those obstacles that cannot be removed. This includes improvements such as breakaway devices, turning down guardrail ends, and flattening roadside slopes.

4. Protect the driver from those obstacles that cannot be improved otherwise, using impact attenuation or redirection devices.

Possible countermeasures for different hazardous location are given in Table 3.1.

Table 3.1 Countermeasures

Accident Pattern	Probable Cause	Possible Improvements
Right-angle collisions at unsignalized intersections	Restricted sight distance	Remove sight obstructions Restrict parking near corners Install yield signs Install stop signs Install warning signs Install signals Channelize intersection Move near side bus stop to far side Install flashing beacons Install rumble strips Install or improve street lighting
	Large total inter-section volume	Install signals Reroute through traffic Overpass
	High approach speed	Reduce speed limit on approaches Install rumble strips Overpass
Right-angle collisions at signalized intersection	Poor visibility of signals	Install warning signs Install overhead signals Improve location of signal heads Install additional signal heads Remove obstructions Install rumble strips Reduce speed limits on approaches
	Inadequate signal timing	Retime signals Adjust amber intervals Provide red clearance intervals Install actuated signals Provide progression through a set of sig-nalized intersections

Table 3.1 Countermeasures (cont.)

Accident Pattern	Probable Cause	Possible Improvements
Rear end collisions at unsignalized intersections	Pedestrian Crossing	Install or improve signing and marking of pedestrian crosswalks Mark or relocate crosswalk
	Driver unaware of intersection	Install or improve warning signs Install rumble strips or simulate with pavement markings Remove obstructions
	Slippery surface	Overlay pavement Provide adequate drainage Groove pavement Provide warning signs Reduce speed limit on approaches
	Large number of turning vehicles	Create right or left-turn lanes Prohibit turns Increase curb radii
Rear end collisions at signalized intersections	Poor visibility of signals	Install/improve warning signs Install overhead signals Relocate signals Install additional signal heads Remove obstructions Reduce speed limit on approaches
	Inadequate signal timing	Adjust amber intervals Provide progression through a section of signalized intersections
	Pedestrian Crossings	Install or improve signing or marking of pedestrian crosswalks Provide pedestrian walk phase

Table 3.1 Countermeasures (cont.)

Accident Pattern	Probable Cause	Possible Adjustments
Rear end collisions at signalized inter-sections (cont.)	Slippery Surface	Overlay pavement Provide adequate drainage Groove pavement Provide warning signs Reduce speed limit
	Unwarranted signals	Remove signals
Rear end collisions of signalized inter-sections	Large turning volumes	Create left turn or right turn lanes Prohibit turns Prohibit right turn on red Provide exclusive pedestrian phase
Pedestrian accidents at intersection	Restricted sight distance	Remove sight obstructions Install or improve pedestrian crossing signs Reroute pedestrian paths
	Inadequate protec-tion for pedestrians	Add pedestrian refuge islands
	Inadequate signals	Install pedestrian signals
	School crossing area	Use school crossing guards
Pedestrian accidents	Driver has inadequate warning of mid block crossing	Prohibit parking Install warning signs Install pedestrian barriers
	Pedestrians walking on roadway	Install sidewalks Pave shoulders
	Long distance to nearest crosswalk	Install pedestrian actuated signals and warning signs

Table 3.1 Countermeasures (cont.)

Accident Pattern	Probable Cause	Possible Improvements
Left turn collisions at intersections	Large volume of left turns	Provide seperate left turn lane Provide left turn signal phases Prohibit left turns Reroute left turn traffic Channelize intersection Install stop signs Create one-way streets Provide turning guide lines if there is a dual left turn lane
	Restricted sight distance	Remove obstructions to improve visibility Install warning signs Install left-turn lanes Provide left turn signal phase Reduce speed limit on approaches Install flashing beacons
Right turn collisions at intersections	Short turning radii	Increase curb radii
Sideswipe collisions between vehicles travelling in opposite directions or head-on collisions	Roadway design inadequate for traffic conditions	Install or improve pavement marking Channelize intersections Create one-way streets Remove constrictions such as parked vehicles Install median divider Widen lanes
Collisions between vehicles travelling in same direction such as sideswipe turning or lane changing	Roadway design inadequate for traffic conditions	Widen lanes Channelize intersections Provide turning lanes Install advance route of street signs Install or improve pavement lane lines Remove parking Reduce speed limit

Table 3.1 Countermeasures (cont.)

Accident Pattern	Probable Cause	Possible Countermeasures
Collision with parked cars or cars being parked	Large parking turnovers	Prohibit parking Change from angle to parallel parking Reroute through traffic Create one-way streets Create off street parking Reduce speed limit
	Roadway design inadequate for present conditions	Widen lanes Change from angle to parallel parking Prohibit parking Reroute through traffic
Collision at driveways	Left turning vehicles	Install median divider Install two-way left-turn lanes Install protected left-turn lanes
	Improperly located driveway	Regulate minimum spacing of driveways Regulate minimum corner clearance Move driveway to side street Install curbing to define driveway location Consolidate adjacent driveways Prohibit backing maneuvers into the highway
	Right-turning vehicles	Provide right turn lanes Restrict parking near driveways Increase the width of the driveway Widen through lanes Increase curb radii
	Large volume of driveway traffic	Signalize driveway Provide acceleration and deceleration lanes Channelize driveway

Table 3.1 Countermeasures (cont.)

Accident Pattern	Probable Cause	Possible Countermeasures
Collision at driveways (cont.)	Restricted sight distance	Remove sight obstruction Restrict parking near driveway Install or improve street lighting Reduce speed limit
	Large volume of through traffic	Move driveway to side street Construct a local service road Reroute through traffic Provide sufficient spacing between adjacent driveways to avoid traffic interference
Night accidents	Poor visibility	Install or improve street lighting Install or improve delineation markings Install or improve warning signs
Wet pavement accidents	Slippery pavement	Overlay existing pavement Provide adequate drainage Groove existing pavement Reduce speed limit Provide caution signs
Collisions at railroad crossings	Restricted sight distance	Remove sight obstructions Reduce grades Install train actuated signals Install stop signs Install gates Install advance warning signs Install rumble strips Install pavement markings Install flashing light signals

Table 3.1 Countermeasures (cont.)

Accident Pattern	Probable Cause	Possible Countermeasures
Fixed object collisions	Objects near travelled way	Remove obstacles near roadway Install barrier curbing Install breakaway feature to light poles, signposts, etc. Protect objects with guardrail Install impact attenuations
Fixed object collisions or vehicles running off roadway	Slippery pavement	Overlay existing pavement Provide adequate drainage Groove existing pavement Reduce speed limit Provide warning signs
	Roadway design inadequate for traffic conditions	Widen lanes Relocate islands Close curb lane Reduce speed limits Flatten a sharp curve that is located at the end of long tangents or gentle curves Provide adequate sight distance to see the pavement where horizontal curves are on crest vertical curves Eliminate flat spots that result from curve superelevation to a horizontal curve introduced on a vertical curve
Fixed object collisions or vehicles running off roadway	Poor delineation	Improve or install pavement markings Install roadside delineations Install advance warning signs (e.g. curves)

Sources: 29, 32, 45

CHAPTER IV. EVALUATION CRITERIA

Evaluation criteria define the various measures of effectiveness and the relative value weightings that are to be used to determine the "best" safety improvements. The costs and benefits of countermeasures are compared on a common basis, either on an equal annual basis or present worth.

4.1 Improvement Benefits

The benefits of safety improvements include both safety benefits and non-safety benefits. Safety benefits include the savings of lives, injuries and property damage, and the costs associated with them. Non-safety benefits may include savings in travel time, increases in capacity, improved energy efficiency and reduced environmental impacts. The overall benefit-cost analysis done to evaluate the feasibility of safety improvements should take account of both the safety and non-safety benefits.

4.1.1 Non-Safety Benefits

Non-safety benefits or secondary benefits, in addition to safety benefits, may be derived from countermeasures. It is difficult to put a a dollar value on some secondary benefits while others can be readily valued. If the secondary benefits are quantifiable and can be assigned a dollar value, they should be included in the analysis. If they cannot, mention must be made of those non-quantifiable benefits.

Secondary benefits of safety improvements include:

1. Reduced traffic congestion, delay and operating cost.

2. Increased capacity.

3. More uniform traffic speeds and smoother operation.

4. Improved roadway and roadside geometrics.

5. Reduced crime and vandalism due to better lighted roadways.

6. Reduced air pollution.

Procedures to estimate these benefits are treated in other references (11,37,56).

Non-safety economic costs and benefits should be taken into account directly if there is a significant change in either the non-safety costs or benefits because of the safety improvements.

4.1.2 Safety Benefits

The direct measure of safety benefits is the reduction in the number and the severity of accidents. For decision making it is beneficial to assign values to the types of accidents and thereby measure safety benefits in economic terms. If the societal costs associated with one fatal accident is $307,210, then the societal benefits of one reduced fatal accident is the same. The benefit from an improvement that reduces injury accidents by one is $14,600. The benefit received by eliminating one property damage accident is $650. These values have been suggested by the National Highway Traffic Safety Administration (NHTSA).

The accident potential in terms of the expected number of accidents for different sections of highway and hazardous obstacles have been discussed in an earlier chapter. The expected accident reductions for various improvements are shown in Appendix B. By multiplying the expected number of accidents by the accident reduction factors, the reduction in accidents is obtained.

Accident Reduction = Expected Number of Accidents X Accident Reduction Factors

The savings in various accidents due to a countermeasure can then be converted to dollar benefits. The benefits are estimated by multiplying the reduction in accidents by the dollar value assigned to that accident.

Accident Reduction Benefits = Accident Reduction X Cost of Accident

If accident records are available, the benefits can be evaluated statistically. By observing the number of accidents before and after the introduction of a safety improvement over a given period of time, it is possible to estimate the reduction in the numbers and the severity of accidents.

The low volume conditions found in local jurisdictions and the accident records available usually do not give statistically valid measures of the safety before or after improvement.

4.1.3 Example 1: Calculation of Annual Benefits of Safety Improvements

Problem: A 500 foot long, 40 foot high fill with 2:1 slopes on a 4^{o} curve and 5% grade is thought to need guardrails for safety improvement. This is on a 24 foot secondary road with 4 foot shoulders and a sight distance of 1500 feet. The ADT is 2000 vehicles per day. Determine the accident savings by installing guardrails at the shoulder edge.

Solution: A comparison between the existing condition (without guardrail) and modified condition (with guardrail) is made below.

1. Find the total accident potential in terms of expected number of accidents for geometrics.

   From Figure 4.1,

   Accident rate = 2.0 accident/MVM

   From Figure 4.2,

   Accident potential = 0.15 accident/years

2. Find the expected number of accidents for roadside hazards.

   From Figure 4.3,

   Number of encroachments = 4/year/mile

   From Figure 4.4,

   Accident potential = 0.15 accidents/years

3. Severity without guardrail.

   a. Select the severity index for the fill and find the propability of fatal, injury and property damage accidents.

      From Figure A-1, for a 40 foot high fill with 2:1 slopes,

      Severity index = 0.67

      From Figure 2.7,

      Probability of a fatal accident = 0.052

      From Figure 2.8,

      Probability of an injury accident = 0.618

      then probability of a PDO accident = 1 - 0.052 - 0.618

      = 0.33

   b. Find the number of fatal, injury and PDO accidents by multiplying the accident potential with the accident probabilities.

      Number of fatal accidents = 0.15 x 0.052

      = 0.0078 acc/yr

      Number of injury accidents = 0.15 x 0.618

      = 0.0927 acc/yr

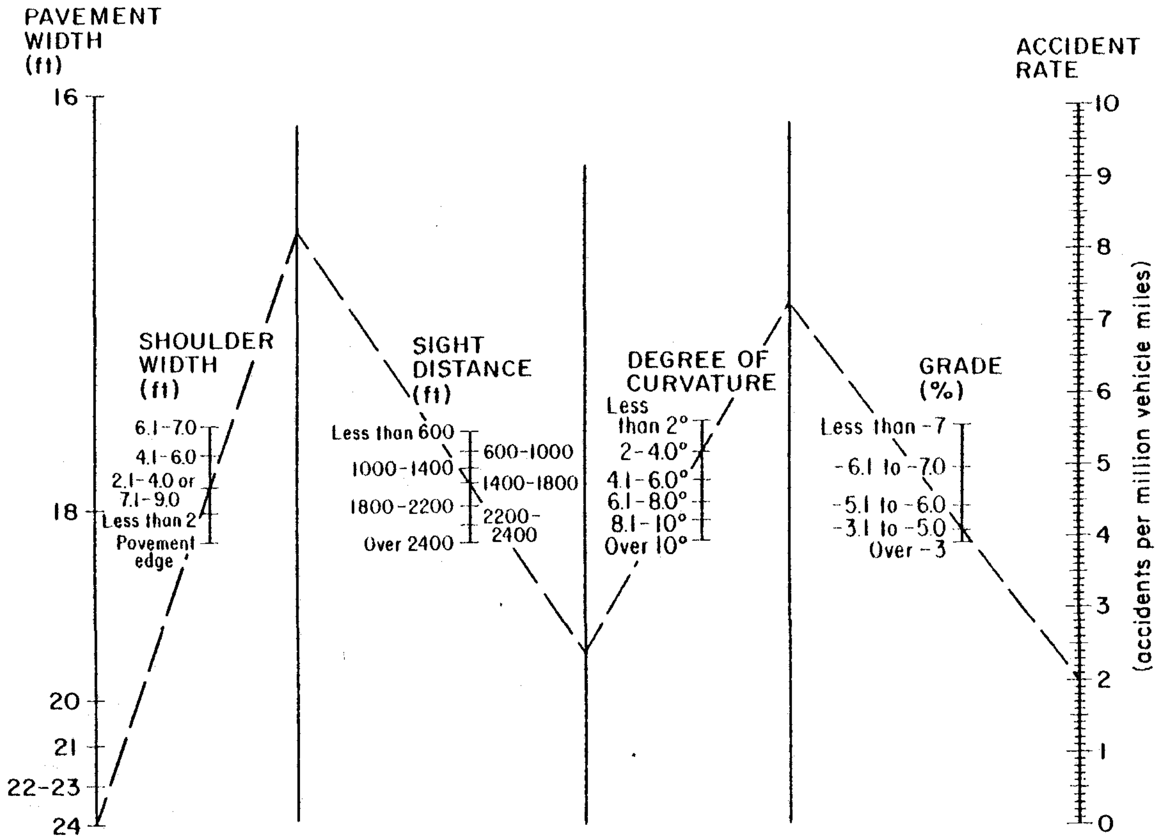

Figure 4.1 Accident Rate Vs. Geometrics

Source: 35

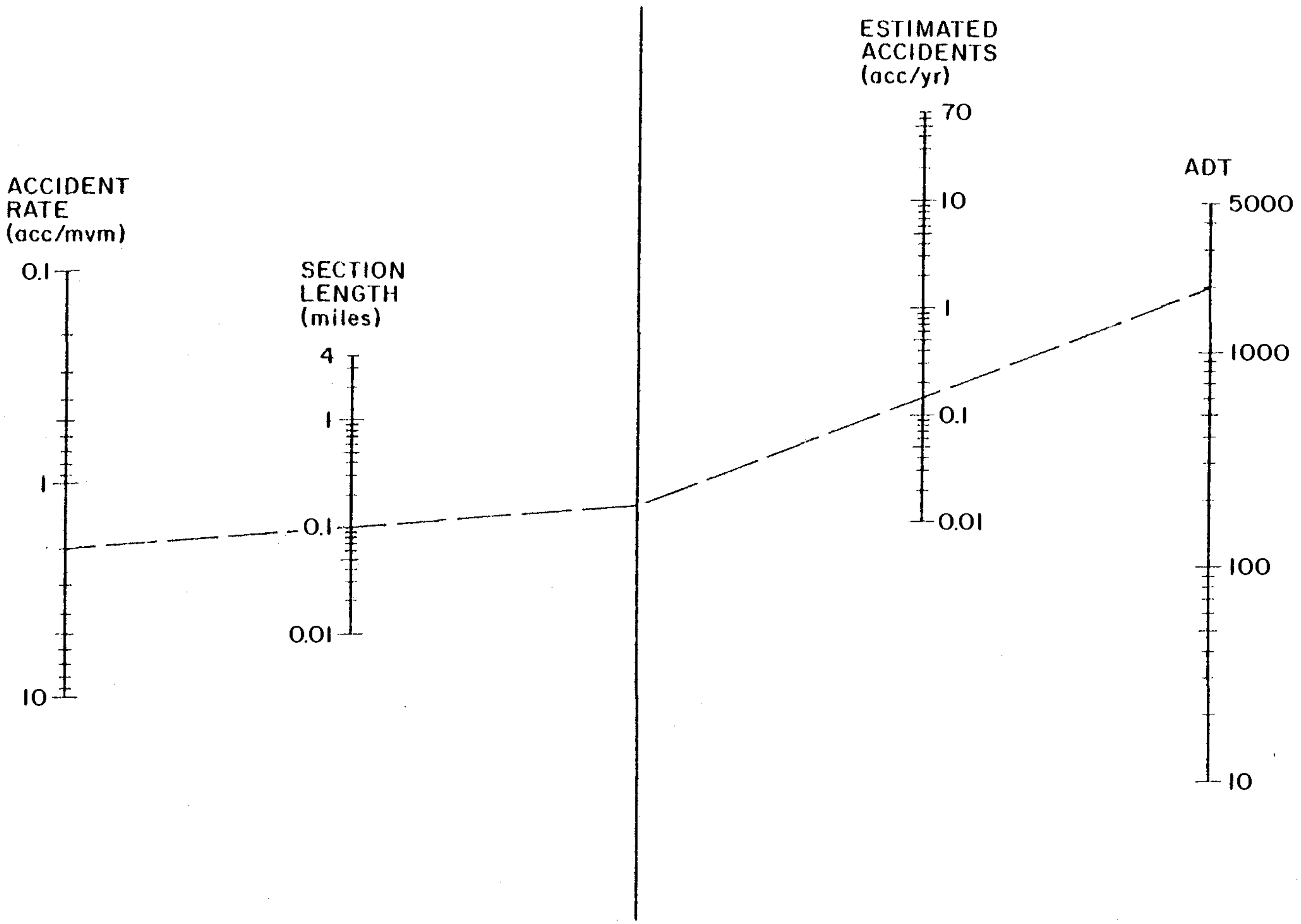

Figure 4.2 Accident Potential in Expected Number of Accidents per Year for Geometrics

Source: 35

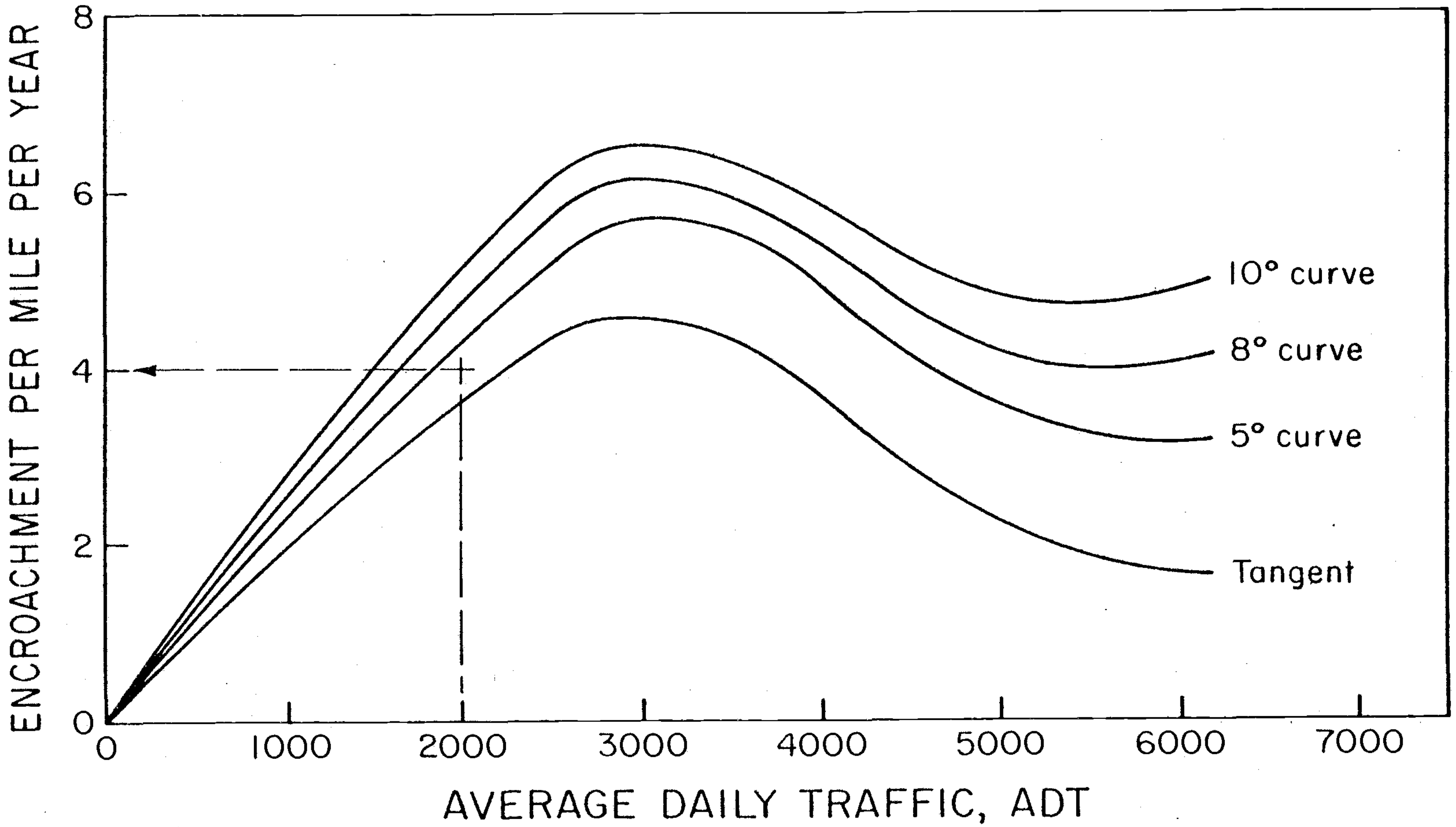

Figure 4.3 Estimation of Encroachments Per Year

Source: 35

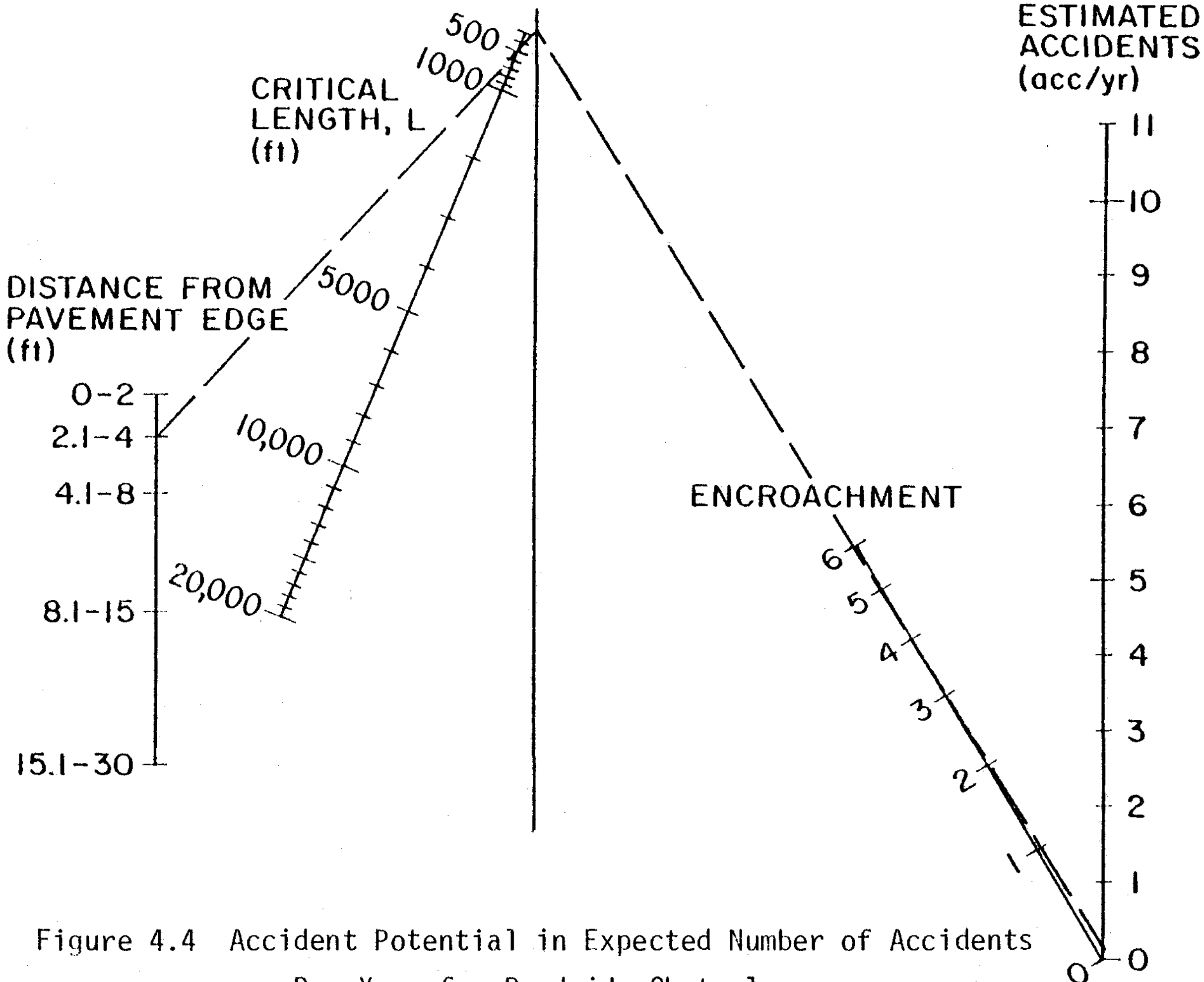

Figure 4.4 Accident Potential in Expected Number of Accidents Per Year for Roadside Obstacles

Source: 35

Number of PDO accidents = 0.15 x 0.33

= 0.0495 acc/yr

c. Multiply the numbers of each type of accident by the cost of that type to find total costs of accidents.

Fatal accident costs	= 0.0078 x 307,210	=	$2,396
Injury accident costs	= 0.0927 x 14,600	=	1,353
PDO costs	= 0.0495 x 650	=	32
Total cost of acc/yr without guardrail		=	$3,781

4. Severity with guardrail.

a. Select the severity index for the guardrail, and find the probability of fatal, injury and PDO accidents.

From Table 2.1,

Severity index = 0.33

From Figure 2.7,

Probability of fatal accident = 0.026

From Figure 2.8,

Probability of injury accident = 0.304

then probability of PDO accident = 1 - .026 - .304

= 0.67

b. Find the number of fatal injury and PDO accidents by multiplying the accident potential with the accident probabilities.

Number of fatal accidents = 0.15 x 0.026 = .0039 acc/yr

Number of injury accidents = 0.15 x 0.304 = 0.0456 acc/yr

Number of PDO accidents = 0.15 x 0.67 = 0.1005 acc/yr

c. Multiply the number of each type of accident by the cost of that type to find total costs of accidents.

Fatal accident costs	=	0.0039	x	307,210	=	$1,198
Injury accident costs	=	0.0456	x	14,600	=	666
PDO accident costs	=	0.1005	x	650	=	65
						$1,929

5. The annual benefit in using the guardrail is the difference between the accident costs in the absence of and the accident costs in the presence of the guardrail; \$3781 - \$1929 = \$1852.

4.2 Present Worth of Benefits

Costs and benefits can be compared by converting both to present worth. Future benefits which accrue from the reduction in fatalities, injuries and property damage can be estimated in terms of present worth of benefits. When alternatives are compared, the analysis for each improvement must be for the same time interval. If service lives differ, it is assumed that the improvements with shorter lives can be reapplied to give a continuation of the benefits, as before.

The equation used to find the present worth of benefits is:

$$PWOB = SPW(B),$$

where SPW = series present worth factor (Appendix C,D),

B = yearly benefit, in dollars.

The above relationship applies when the annual benefits are constant over the service life of the improvement.

Present worth of benefits is also expressed as:

$$PWOB = B/CRF$$

where B = yearly benefit in dollars,

CRF = capital recovery factor (Appendix C,D).

When the benefits vary from year to year, the formula for calculating present worth of benefits is:

$$PWOB = \Sigma\ PWF(B)$$

where PWF = present worth factor (Appendix C,D),

B = unequal yearly benefit, in dollars

4.2.1 Example 2: Calculation of Present Worth of Benefits

Problem: Find the present worth of benefits when the annual benefit of an improvement is $2,000, and it has a service life of 8 years. Assume an interest rate of 15%.

Given: B = $2,000

Life = 8 years

i = 15%

Solution: PWOB = SPW(B)

SPW for 8 years at 15% = 4.487 from Appendix D

PWOB = 4.487 (2,000) $8,974

4.3 Equivalent Uniform Annual Benefit

Benefits can be converted into equivalent uniform annual benefits to compare alternative improvement plans and to spread the benefits over the service life of the improvement. If volumes remain constant, then the equivalent uniform annual benefits remain constant and are the same as the annual benefits. For example, if property damage accidents are reduced by five each year, the annual benefits or the equivalent uniform annual benefits are: 5 x 650 = $3250. However, if the volume increases, the equivalent uniform annual benefit also increases, as seen in the next section.

4.4 Effects of Volume Increase on Improvement Benefits

Equal volumes of traffic throughout the service life of an improvement give constant benefits each year. However, it is very likely that traffic volumes increase each year over the improvement's service life. In general, increase in traffic volume leads to a proportionate increase in the number of traffic accidents. An annual growth rate for untreated accidents should be estimated based on the approximate increase in yearly traffic volume.* Therefore, as volumes increase, the beneficial effects of a safety improvement on the number of accidents is also enhanced. In other words, if volumes increase, the number of accidents and the accident reduction due to a countermeasure also increase.

The relationship between accidents saved and volume increase is given as:

$$\text{Accidents saved per year} = N \times P \times \frac{ADT_{after}}{ADT_{before}}$$

where N = the estimated number of annual accidents in the before period (base year);

P = the percent reduction in accidents, expressed as a decimal;

ADT_{before} = the average daily traffic before the safety improvement is implemented (base year);

ADT_{after} = the average daily traffic after the improvement is implemented.

The effect of volume increase on the present worth of benefits is now considered.

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*The growth rate in traffic volume is assumed to be constant over the service life of a safety improvement.

4.4.1 Effect of Volume Increase on Present Worth of Benefits

Increasing volumes increase the present worth of benefits of safety improvements. The formula for calculating present worth of benefits when the annual benefits are variable is:

$$PWOB = \Sigma\ PWF(B_i)$$

where PWF = the present worth factor (Appendix C,D),

(B_i) = the unequal yearly benefit, in dollars, for year i.

4.4.2 Example 3: Calculation of PWOB with Increasing Volumes

Problem: A safety improvement is being considered for a hazardous location where 5 PDO accidents occur in one year. The safety improvement reduces accidents by 50%. The annual increase in traffic is 5% and the ADT_{before} is 1000 vpd. The service life of the improvement is 6 years. Find the PWOB if the interest rate is assumed = 10%.

Given:

N	= 5 PDO accidents
P	= 0.50
ADT_{before}	= 1000 vpd
Service life	= 6 years
i	= 10%

Solution: The solution to this problem is given in Table 4.1.

4.4.3 Effects of Increasing Volumes on Equivalent Uniform Annual Benefit

Increasing volumes increase the equivalent uniform annual benefits of safety improvements.

EUAB for variable annual benefits is calculated by the formula:

$$EUAB = CRF\ \Sigma\ (PWF)\ (B_i)$$

Table 4.1 Solution to Example 3

Calculation of Present Worth of Benefits with Increasing Volumes

Service year	ADT present	ADT future	N	P	Accidents saved *	Cost per Accident $	Benefit $	PWF **	Present Worth of Benefits $
0	1000	——	5.00	0	——	650	----	1	——
1	1000	1050	5.00	.50	2.62	650	1703	.9091	1548
2	1000	1102	5.00	.50	2.76	650	1794	.8264	1483
3	1000	1157	5.00	.50	2.89	650	1879	.7513	1412
4	1000	1216	5.00	.50	3.00	650	1950	.6820	1330
5	1000	1276	5.00	.50	3.19	650	2074	.6209	1288
6	1000	1340	5.00	.50	3.35	650	2178	.5645	1229

PWOB = $8290 Σ PWF (B) = $8290

*Accidents Saved = $N \times P \dfrac{ADT_{after}}{ADT_{before}}$

**PWF values obtained from Appendix D.

where CRF = capital recovery factor (Appendix C,D),

PWF = present worth factor (Appendix C,D),

B_i = unequal yearly benefit for year i.

4.4.4 Example 4: Calculation of EUAB with Increasing Volumes

Problem: A safety improvement is considered for a hazardous location having 10 PDO accidents in one year. The improvement is expected to reduce accidents by 50%. The highway has an ADT of 200 vpd,and volume increase is estimated at 5% each year. Find the EUAB if the service life on the improvement is 5 years. Assume an interest rate of 15%.

Given: N = 10 accidents

P = 0.50

ADT_{before} = 200 vpd

Service life = 5 years

i = 15%

Solution: The solution to this problem is given in Table 4.2.

4.5 Interest Rate

Money has a time value. Investments are made to obtain returns in future which are greater than the initial investment. Capital invested somewhere eliminates the opportunity to invest elsewhere. Foregone alternative investment opportunities require the imputation of an interest charge on the capital invested.

The comparison of cash flows of the various consequences occurring at different points in time, make it necessary to convert monetary values to a common reference point in time by use of an appropriate compound interest factor (8). It is essential to state benefits and costs in

Table 4.2 Solution to Example 4

Calculation of Equivalent Uniform Annual Benefits with Increasing Volumes

Service year	ADT present	ADT future	N	P	Accidents saved *	Cost per Accident $	Benefit $	PWF **	Present Worth of Benefits $
0	2000	2000	10	0.50	———	650	———	———	0
1	2000	2100	10	0.50	5.25	650	3413	.8694	2967
2	2000	2205	10	0.50	5.51	650	2582	.7561	2708
3	2000	2315	10	0.50	5.79	650	3763	.6575	2474
4	2000	2431	10	0.50	6.08	650	3952	.5718	2258
5	2000	2553	10	0.50	6.38	650	4147	.4972	2062

Σ PWF (B) = \$12,469

EUAB = CRF Σ PWF (B)

= .2983 (12,469)

= \$3720

$$\text{*Accidents saved} = N \times P \ \frac{ADT_{after}}{ADT_{before}}$$

** PWF obtained from Appendix D.

comparable terms for economic evaluation of safety projects.

There is considerable debate over what interest rates are suitable for evaluating public projects. Different authorities suggest discount rates varying from 4 to 16%. Hirshleifer, et al, recommended an interest rate of 10% in 1960 (24). Grant suggested an interest rate of 7% in 1959 (18). Winfrey suggested rates between 6 and 15% in 1971 (56,57). Phelps advocates a minimum interest rate of 16% (41).

A recent study reported that highway agencies used rates between 5 and 10% though there are even some who use zero percent. No fixed criteria are available for selecting an interest rate. However, it is strongly recommended that a rationally determined interest rate be used in evaluating safety improvements.

In the water resource field there is a considerable amount of literature on the appropriate rates of interest for different types of projects (10, 24).

A high interest rate is proposed for highways (57). Highway design is a dynamic process. Designs are continually changing and previous designs tend to become obsolete. Certain features which are now considered essential were not even thought of a few years ago. This gives rise to uncertainty. Higher rates have an advantage over lower rates by lessening the effects on the analysis of future costs and benefits that are most affected by uncertainty. The higher the interest rate the less are the present values of future cash flows.

Interest rates are necessary because (32):

1. Government funds used on highway safety cannot be used elsewhere.
2. The taxpayer is foregoing the opportunity to invest. They should be compensated with a reasonable rate of return.

3. Taxpayers finance highway safety projects. It would be unfair to them to spend money on projects with less return than is available from private investments.

The rates of interest according to various authorities should be based on:

1. The price that citizens and the government are currently paying on borrowed money.
2. The agency borrowing cost.
3. The rate of return that could have been earned in the private sector of the economy when the decision is made to commit resources to the public sector.
4. The existing approximate rate of return in government investments.
5. Risks and uncertainties associated with proposed investments.

The lowest rate should be the current marginal borrowing rate of the public agency making the investment. This is generally reflected in state and municipal bonds, and is presently 8% (9).

The highest rate of interest should be roughly equal to the marginal rate of return in the marginal long term investment in the private sector. This rate generally tends to coincide to the going net rate of interest on private savings invested in real estate (3). Currently, this private rate of return is 10 to 15%.

Interest rate is also referred to as the "social rate of discount" (36). This rate should be somewhere between the public and private costs.

Variations in risks of project and repayment of loan occur between projects. The interest rate selected should consider the risk and uncertainty involved, the rates being higher if the risk and uncertainty are greater. Risk and uncertainty include such factors as (57):

1. Reliability of traffic forecasts,
2. Reliability of construction and maintenance cost estimates,
3. Rigidity of specifications and quality control.

Inflation should not be considered in selecting the interest rate because of the inherent uncertainty of future economic conditions, the commitment of the federal government to price stabilization and finally the inflating benefits in the economic analysis themselves contribute to inflation (32). Also, costs and benefits both inflate, however often at different rates, though their relative magnitudes cannot be predicted.

What specific interest rate should be used? It is up to the decision maker to select a reasonable interest rate. One solution is to use various rates of interest which have theoretically sound bases. This can help determine to what extent the analysis is sensitive to the interest rate. If the conclusions vary with different interest rates, it indicates the influence of the interest rate on the decision.

It is recommended that the rate of interest used should be the taxpayers minimum attractive rate of return. This value at present is around 15% annually.

4.6 Improvement Costs

The costs of safety improvements may be estimated either on the basis of annual costs or present worth. These costs include the initial capital investment, the yearly maintenance costs and the salvage value. The salvage value is positive if the resale value of the item exceeds its cost of removal. The salvage value is negative if the cost of removal exceeds the resale value.

4.7 Present Worth of Costs (PWOC)

The present worth of costs reduces all estimated future cash flows to one single equivalent sum at zero time, that is, the present (56). The improvement capital, maintenance and salvage value for various alternatives can be placed on a common basis for comparison using the present worth of costs. The advantage of using the present worth of costs is that variable future disbursements are converted to one convenient present value for all safety improvements.

The yearly maintenance costs may be constant or vary each year. The formula for computing PWOC when yearly maintenance costs are constant is:

$$PWOC = CI - PWF(T) + CYC/CRF$$

or,

$$PWOC = CI - PWF(T) + SPW(CYC)$$

where,

CI = Initial capital investment,

PWF = Present worth factor (Appendix C,D),

T = Terminal value, either positive or negative,

CYC = Constant yearly maintenance,

CRF = Capital recovery factor (Appendix C,D),

SPW = Series present worth factor (Appendix C,D).

If the yearly maintenance costs vary from year to year over the service life of the improvement, then the yearly maintenance cost for each year must be multiplied by the present worth factor for that particular year of the improvements's service life and these products summed:

$$PWOC = CI - PWF(T) + \Sigma(PWF \times VYC)$$

where VYC = Variable yearly maintenance costs.

All the other variables are defined above.

4.7.1 Example 5: Calculation of PWOC of Safety Improvements with Constant Yearly Maintenance Costs

Problem: Find the PWOC for a safety improvement having a service life of 10 years, initial cost = \$25,000, yearly maintenance cost = \$750, and salvage value = \$1,500. Assume an interest rate of 10%.

Given: CI = \$25,000

CYC = \$ 750

Salvage Value = \$ 1,500

Service Life = 10 years

i = 10%

Solution:

1. Divide the equal annual cost by the capital recovery factor for 10 years at i = 10%; CRF = .1628 from Appendix D.

$$CYC/CRF = \frac{750}{.1628} = \$4,607$$

2. Add the value obtained in step 1 to the initial capital cost.

$$4,607 + 25,000 = \$29,607$$

3. Multiply the present worth factor for 10 years at i = 10% by the terminal value; PWF = .3855 from Appendix D.

$$PWF(T) = .3855(1,500) = \$578$$

4. Subtract the value obtained in step 3 from the value obtained in step 2 to find the present worth of costs.

$$PWOC = 29,607 - 578 = \$29,029$$

The PWOC can also be obtained as follows:

1. Multiply the series present worth factor for 10 years at i = 10% by the constant yearly maintenance cost; SPW = 6.144 from Appendix D.

$$SPW(CYC) = 6.144(750) = \$4608$$

2. To obtain the PWOC, the remaining steps 2, 3, and 4 are repeated as before.

4.7.2 Example 6: Calculation of PWOC of Safety Improvements with Unequal Yearly Maintenance Costs

Problem: Find the PWOC for a safety improvement with a service life of 6 years, initial cost = \$15,000, salvage value = \$1,000 and variable yearly maintenance costs as shown below. Assume an interest rate of 15%.

Given:

Service Life	Yearly Maintenance Cost
1	300
2	400
3	500
4	600
5	700
6	800

CI = \$15,000

T = \$ 1,000

i = 15%

Solution:

1. Multiply the PWF for each year by the maintenance cost for that year and sum the results to obtain the present worth of maintenance costs.

Service Year	PWF*	Yearly Maintenance Cost VYC ($)	Present Worth of Maintenance Cost ($)
1	.8696	300	261
2	.7561	400	302
3	.6575	500	329
4	.5718	600	343
5	.4972	700	348
6	.4323	800	346
		Σ PWF(VYC)	= $1,929

*PWF values obtained from Appendix D.

2. Add the initial cost to the present worth of maintenance costs.

$$15,000 + 1,929 = \$16,929$$

3. Multiply the PWF for 6 years at i = 15% by the terminal value of the improvement to obtain the present worth of terminal costs; PWF = .4323 from Appendix D.

$$PWF(T) = 0.4323(1,000) = \$432$$

4. Subtract the amount obtained in step 2 from the amount obtained in step 3 to determine the present worth of costs.

$$16,929 - 432 = \$16,497$$

4.8 Equivalent Uniform Annual Cost EUAC

The EUAC is obtained by reducing all estimated future net cash flows to one single uniform annual sum that is equivalent to all disbursements over the analysis period (56). The improvement capital, maintenance, and terminal costs for various alternatives can be placed on a common basis for comparison using the equivalent uniform annual costs. The objective is to simplify and spread the elements of costs over the life of the improvements.

Disbursements may vary from year to year. Generally, maintenance costs increase with age, wages and property taxes increase, assessed evaluations change. However, it is cumbersome to estimate the variable costs for each year. It is better to calculate average annual costs and treat them as uniform. The slight difference in the yearly totals does not justify the effort in estimating annual costs separately.

The yearly maintenance costs of an improvement may be either constant or variable.

The formula used to calculate the equivalent uniform annual cost of an improvement with constant yearly maintenance costs is:

$$EUAC = CRF(CI) - PWF(T) + CYC$$

where all the variables have been previously defined.

If the yearly maintenance costs vary from year to year, their present worth must be estimated and converted to equal annual maintenance costs over the period of the improvement. The formula to calculate EUAC is then:

$$EUAC = CRF \ (CI) - PWF(T) + \Sigma \ (PWF \times VYC)$$

where all the variables have been previously defined.

4.8.1 Example 7: Calculation of EUAC for Improvement with Equal Annual Maintenance Cost

Problem: Find the EUAC for a safety improvement with a service life of 6 years if the initial cost of investment is \$10,000 and the yearly maintenance cost is \$500. The terminal value is \$1,000. Assume an interest rate of 12%.

Given: CI = \$10,000

CYC = \$ 500

T = \$ 1,000

Service life = 6 years

i = 12%

Solution:

1. Multiply the PWF for 6 years at i = 12% by the terminal value; PWF = .5066 from Appendix D.

   PWF(T) = .5066(1,000) = \$507

2. Subtract the result of step 1 from the initial capital investment.

   10,000 - 507 = \$9,493

3. Multiply the CRF for 6 years at i = 12% by the value obtained in step 2; CRF = .2432 from Appendix D.

   .2432 (9,493) = \$2,309

4. Add the result of step 3 to the constant annual maintenance cost to find the equivalent uniform annual cost.

   EUAC = 2,309 + 500 = \$2,809

4.8.2 Example 8: Calculation of EUAC of Improvement with Unequal Annual Maintenance Costs

Problem: Find the EUAC of a safety improvement having an 8 year lifetime if its initial cost is \$20,000 and the estimated terminal value is \$1,000. The variable yearly maintenance costs are as shown below. Assume an interest rate of 10%.

Given:

Service Year	Yearly Maintenance Cost
1	450
2	500
3	550
4	600
5	650
6	700
7	750
8	800

CI = \$20,000

T = \$ 1,000

Service Life = 8 years

i = 10%

Solution:

1. Multiply the maintenance cost for each year by that year's present worth factor and add the values obtained to determine the present worth of the maintenance costs.

Service Year	PWF*	Yearly Maintenance Cost VYC (\$)	Present Worth of Maintenance Cost (\$)
1	.9091	450	409
2	.8264	500	413
3	.7513	550	413
4	.6830	600	410
5	.6209	650	404
6	.5645	700	395
7	.5132	750	385
8	.4665	800	373
			Σ (PWF x VYC) = \$3,202

*PWF values obtained from Appendix D.

2. Add the initial capital cost to the result obtained in step 1.

   20,000 + 3,202 = \$23,202

3. Multiply the present worth factor for 8 years at i = 10% by the terminal value; PWF = .4665 from Appendix D.

   .4665(1,000) = \$466

4. Deduct the amount obtained in step 4 from the amount in step 3.

   23,202 - 466 = \$22,736

5. Multiply the capital recovery factor for 8 years at i = 10% by the result of step 5 to obtain the EUAC; CRF = .1874 from Appendix D.

   EUAC = .1874(22,736) = \$4,261

The EUAC can also be computed using the sinking fund factor, SFF (Appendix D), to spread the terminal value of the improvement over the service life. When maintenance costs are constant, the formula is:

$$EUAC = CRF(CI) - SFF(T) + CYC$$

SFF = Sinking fund factor (Appendix D)

where, all the variables have been previously defined. When the yearly maintenance costs are variable, the formula is:

$$EUAC = CRF(CI) - SFF(T) + CRF\ \Sigma\ (PWF \times VYC)$$

4.9 Equivalent Uniform Annual Cost with Staging

In a comprehensive safety improvement program, it may be desirable to implement the countermeasures in stages. Funds may not be available to finance the entire project at the present. Or, traffic volumes or conditions may not necessitate the complete improvement until later. The staged improvement costs can be converted to the total present worth by multiplying the capital cost by the appropriate present worth factor. The appropriate present worth factor is based on an acceptable interest rate and the time into the future when the improvement is made:

$$\text{PWOC of Capital} = PWF_1\ (CI_1) + PWF_2\ (CI_2) + \ldots\ldots\ PWF_n\ (CI_n)$$

The equivalent uniform annual cost can also be used to compare the economy of these alternatives. The equivalent uniform annual capital costs of the staged improvement would be found from:

$$\text{EUAC of Capital} = \text{CRF (PWOC of Capital)}$$

4.9.1 Example 9: Calculation of EUAC of Staged Improvements

Problem: It is proposed that improvements be carried out in three stages for a hazardous section of the roadway. The improvements are first to place a sign indicating low shoulders, second to raise the shoulder, and finally to widen the shoulder. The cost, service life, and year of each improvement is zero. The rate of interest is 10%. Find the Equivalent Uniform Annual Costs.

Given:

Improvement	Year of Implementation	Service Life	Capital Cost $	Maintenance Cost $
Place Sign	0	2 years	800	100
Raise Shoulder	2	3 years	5,000	500
Widen Shoulder	5	10 years	12,000	1,000

Solution:

$$EUAC = CRF\ (800) + CRF\ [(PWF)(5000)] + CRF\ [(PWF)(12000)] + 100$$
$$+ CRF\ [(SPW)(400)] + CRF\ [(SPW)(500)]$$
$$= 0.1315\ (800) + 0.1315\ [(.8264)(5000)] + 0.1315\ [(.6209)(12000)]$$
$$+ 100 + 0.1315\ [(7.103)(400)] + 0.1315\ [(6.144)(500)]$$
$$= 0.1315\ (800) + 0.1315\ (4132) + 0.1315\ (7451) + 100$$
$$+ 0.1315\ (2841) + 0.1315\ (3072)$$
$$= 105 + 543 + 980 + 100 + 374 + 404$$
$$= \$2,506$$

where, the following values have been obtained from Appendix D.

CRF for 15 years at 10% = 0.1315

PWF for 2 years at 10% = 0.8264

PWF for 5 years at 10% = 0.6209

SPW for 13 years at 10% = 7.103

SPW for 10 years at 10% = 6.144

Note: The conversion of the capital investments to their present value for this example is represented in Figure 4.5. The conversion of the yearly maintenance costs is given in Figure 4.6.

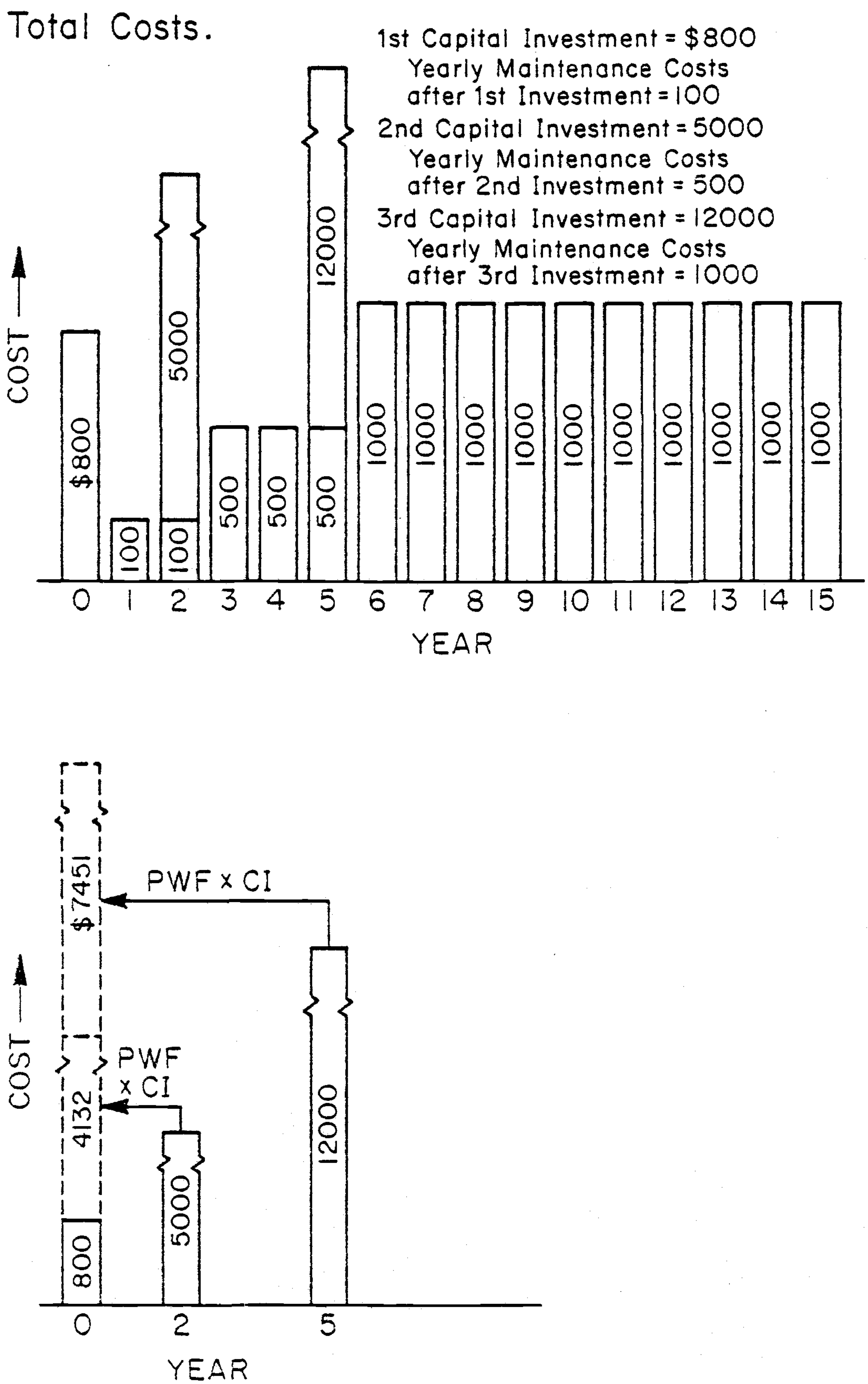

Figure 4.5 Conversion of Capital Investments to Present Worth

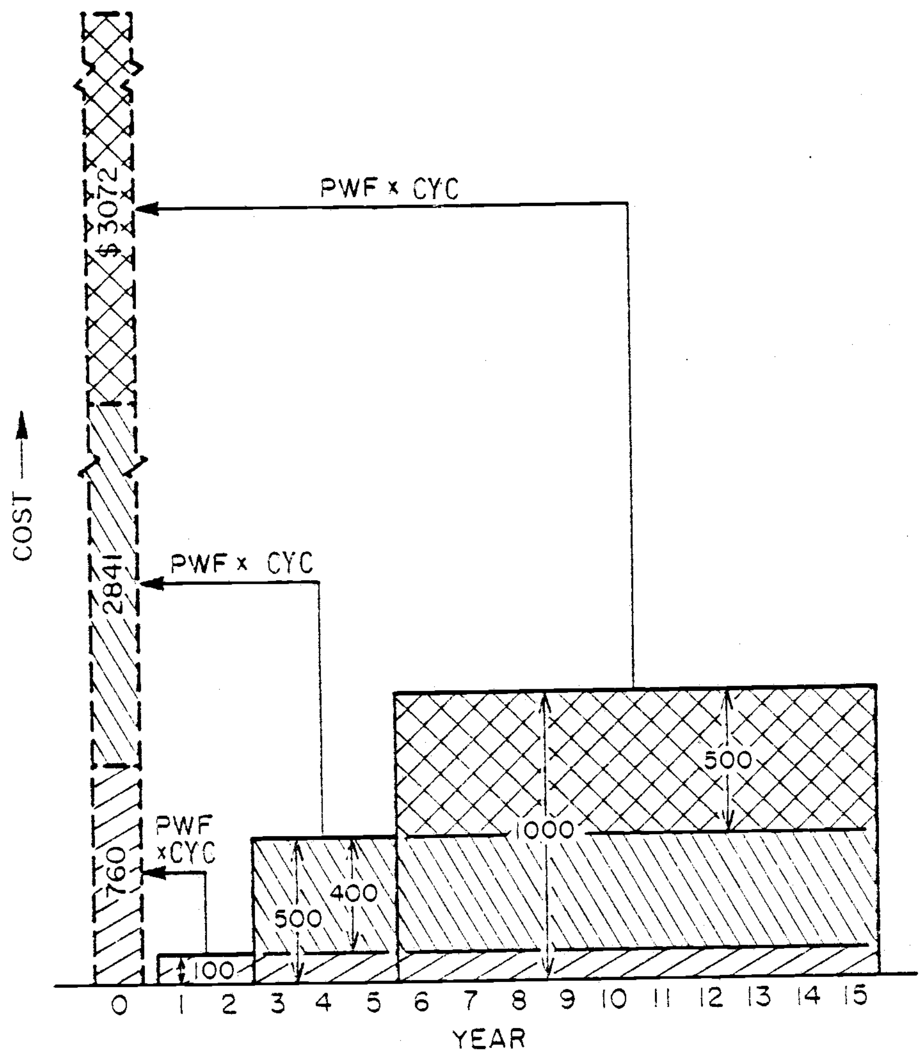

Figure 4.6 Conversion of Yearly Maintenance Costs to Present Worth

CHAPTER V. EVALUATION APPROACH

This chapter describes the details of the approach to evaluate safety improvements, prior to the decision making phase. Independent and mutually exclusive alternatives are defined and the various economic analysis methods for the evaluation of safety improvements are discussed. Examples of the economic analysis methods are presented.

The benefits and costs of safety improvements should be compared to determine the effectiveness of investing public monies in selected safety projects. Even though the funds are public, a suitable return on the investment should be derived. Because safety improvement funds are limited, the projects that achieve the greatest benefit from the expenditure of public funds must be selected.

Benefit cost analysis is an effective format for presenting and evaluating costs and benefits of highway safety improvements. It is restricted to those applications where both input resources and output consequences can be priced (56). However, benefit cost analysis trade-offs are not the only determinants for selecting highway safety improvements. Decision makers must use their own judgement to measure relative worths and make final choices. The selection of a safety project should not be made on the basis of economic efficiency alone. It should take account of the relative increase in safety in terms of reduced fatalities, injuries and property damage, and finally the budget limitations. Other consequences of the improvement should also be taken into account.

Safety improvement alternatives may either be independent or mutually exclusive. If it is independent, the improvement does not improve or diminish the safety at other improvement sites directly. A mutually exclusive alternative influences the safety conditions for other alternatives, and precludes the need for another improvement.

5.1 Independent Alternatives

Alternatives are independent if the selection of one does not preclude the simultaneous selection of any of the other alternatives (32). Independent alternatives do not affect safety at the same location or at other locations directly either to improve it or to diminish it. For example, suppose there are two hazardous locations, one with a dangerous railroad crossing and another location with steep side slopes. If after evaluation it is concluded that the first location needs the installation of automatic gates and the second location needs the placement of a guardrail, then the first countermeasure does not in any way affect the safety of the second countermeasure. Some of the methods used for the selection of independent alternatives are:

a. Benefit cost ratio

b. Payback period

c. Net discounted present value

d. Internal rate of return

e. Investment return analysis

The use of these approaches for economic evaluation of safety improvements is discussed in later sections.

5.2 Mutually Exclusive Alternatives

Alternatives are mutually exclusive if the selection of one alternative precludes the selection of any of the other alternatives at the same time (32). Mutually exclusive alternatives affect safety at the same location or at other locations directly either to improve it or diminish it. Examples of mutually exclusive alternatives for a hazardous railroad crossing could include the installation of either automatic gates or the construction of a grade separated crossing at that location. Both cannot be done simultaneously.

Two or more alternatives at the same or at separate locations become financially mutually exclusive when available funds are restrictive, that is the selection of one or more projects eliminates the selection of any or all others. Alternatives that may be independent from the safety standpoint would then be mutually exclusive from the financial standpoint. This aspect is discussed further in a later section of this report. Some of the methods used for the selection of mutually exclusive alternatives are (9):

a. Incremental benefit cost ratio
b. Net annual benefit
c. Net discounted present value
d. Incremental rate of return
e. Investment return analysis

5.3 Benefit Cost Ratio

This is a commonly used method, and its greatest advantage is its simplicity. The relative merit of an improvement is measured by its benefit - cost ratio. The benefit cost ratio is defined as:

$$\text{BCR or } \frac{B}{C} = \frac{\text{Present worth of benefits}}{\text{Present worth of costs}} = \frac{\text{PWOB}}{\text{PWOC}}$$

Also,

$$\frac{B}{C} = \frac{\text{Equivalent uniform annual benefits}}{\text{Equivalent uniform annual costs}} = \frac{\text{EUAB}}{\text{EUAC}}$$

Any project that has a benefit cost ratio greater than 1 is financially feasible. The rate of interest that is assumed to compute benefits and costs greatly influences the value of the benefit cost ratio.

In the incremental benefit cost ratio the relative merit of an improvement is measured by the ratio of its increased benefits over the next lower priced alternative to the increase in costs to provide the improvement over the next lower priced alternative (32). Incremental benefit/cost ratio is defined as:

$$\frac{IB}{IC} = \frac{EUAB_2 - EUAB_1}{EUAC_2 - EUAC_1}$$

also,

$$\frac{IB}{IC} = \frac{PWOB_2 - PWOB_1}{PWOC_2 - PWOC_1}$$

where,

$EUAB_1$ = the equivalent uniform annual benefit for the improvement with the lower annual cost,

$EUAB_2$ = the equivalent uniform annual benefits for the improvement with the higher annual cost,

$EUAC_1$ = the equivalent uniform annual costs for the improvement with the lower annual cost,

$EUAC_2$ = the equivalent uniform annual costs for the improvements with the higher annual cost,

$PWOB_1$ = the present worth of benefits for the improvement with the lower annual cost,

$PWOB_2$ = the present worth of benefits for the improvement with the higher annual cost,

$PWOC_1$ = the present worth of costs for the improvement with the lower annual cost,

$PWOC_2$ = the present worth of costs for the improvement with the higher annual cost.

If the alternative improvements have different service lives, an additional assumption must be made when using present worths of benefits and costs. That is, each improvement can be re-applied at the end of its service life.

When using equivalent uniform annual benefits and costs, the following assumption must be made. If an improvement with a service life is selected, the annual cost and benefit for its successor will be the same as its annual cost and benefit (32).

The use of benefit cost ratios for independent alternatives and incremental benefit cost ratios for mutually exclusive alternatives is demonstrated through an example later.

The greatest advantage of the benefit/cost ratio method is that it is straightforward and simple. However, as any of the other methods of economic analysis, the benefit/cost ratio method has its weaknesses and limitations. One common criticism is that the costs and benefits of a project can be manipulated. For example, a project has the following costs and benefits:

Present Worth of Benefits = 100,000

Present Worth of Construction Costs = 50,000

Present Worth of Maintenance Costs = 20,000

then the two possible benefit/cost ratios are:

$$\frac{B}{C} = \frac{100,000 - 20,000}{50,000} = 1.6$$

$$\frac{B}{C} = \frac{100,000}{50,000 + 20,000} = 1.43$$

It is apparent that the maintenance costs can be included either in the numerator if treated as reduced benefits or the denominator if treated as increased costs,and each method gives a different B/C ratio. Therefore, there is a need to be cautious and consistent in using the B/C ratio method. That is, if maintenance costs are included in the numerator for one project, they should be included in the numerator for all others.

5.3.1 Benefit Cost Ratio for Independent Alternatives

Benefit/cost ratio is an effective way to evaluate independent alternatives. A fixed interest rate should be used to evaluate and compare the alternatives. The most economic hazardous location treatment can be selected from the values of benefit/cost ratios. The stepwise procedure of selecting the best alternative is:

- Calculate the benefit/cost ratios
- List the improvements in order of decreasing benefit/cost ratios. All alternatives with B/C ratio greater than 1 are feasible.
- The most desirable alternative is the improvement with the largest benefit/cost ratio assuming feasibility within budget constraints.

5.3.2 Incremental Benefit/Cost Ratio for Mutually Exclusive Alternatives

The benefit cost ratio and the incremental benefit/cost ratio are used to evaluate mutually exclusive alternatives. The stepwise procedure of selecting the best alternative is:

- Calculate either the equivalent uniform annual cost and the equivalent uniform annual benefit, or the present worth of costs and the present worth of benefits of each of the alternatives.
- Calculate the benefit/cost ratios.
- List the improvements with B/C ratio greater than 1 in order of increasing equivalent uniform annual costs or present worth of costs.
- Calculate the incremental benefit cost ratio IB/IC for the second improvement compared to the first.
- If the IB/IC ratio is greater than 1, the second lowest cost improvement is more desirable than the lowest cost improvements. The process is repeated for each alternative. The most expensive improvement with an IB/IC ratio greater than 1 is the most desirable, assuming feasibility within budget constraints.

5.3.3 Example 10: Evaluation Using Benefit/Cost Ratios and Incremental Benefit/Cost Ratios

Problem: Four improvements are shown with costs, benefits, salvage values and service lives. The interest rate for all the alternatives is 10 percent. Find the benefit/cost ratios and incremental benefit/cost ratios.

Given:

	A	B	C	D
Capital Cost	45,000	20,000	30,000	70,000
Annual Maintenance Cost	1,500	1,000	1,500	3,000
Salvage Value	1,500	0	500	2,500
Service Life	9	6	8	12
Annual Benefits	15,000	8,000	12,000	20,000

Solution:

1. Find the equivalent uniform annual costs.

$EUAC = CRF\ (CI) - SFF\ (T) + CYC$

$EUAC_A = 0.1736\ (45{,}000) - 0.0736\ (1{,}500) + 1{,}500$

$= 7{,}812 - 110 + 1{,}500$

$= \$9{,}202$

$EUAC_B = 0.2296\ (20{,}000) - 0 + 1{,}000$

$= 4{,}592 + 1{,}000$

$= \$5{,}592$

$EUAC_C = 0.1874\ (30{,}000) - 0.0874\ (500) + 1{,}500$

$= 5{,}622 - 44 + 1{,}500$

$= \$7{,}078$

$EUAC_D = 0.1468\ (70{,}000) - 0.0468\ (2{,}500) + 3{,}000$

$= 10{,}276 - 117 + 3{,}000$

$= \$13{,}159$

CRF, SFF values obtained from Appendix D.

2. If the four alternatives are considered independent alternatives, then the benefit cost ratio may be used to determine improvement priorities and select the best alternatives. First calculate the benefit/cost ratio.

Improvement	EUAB	EUAC	B/C
A	15,000	9,202	1.63
B	8,000	5,592	1.43
C	12,000	7,078	1.70
D	20,000	13,159	1.52

All four alternatives have B/C ratios greater than 1 and are therefore economically feasible. The ranking in order of decreasing B/C ratios is C, A, D, B with the most desirable alternative being C.

3. If the four alternatives are considered mutually exclusive alternatives, the benefit cost ratio, and then the incremental benefit cost ratio is used to select the best improvement.

   a. Calculate the benefit cost ratios and list the improvements with B/C greater than 1 in order of increasing equivalent uniform annual costs.

Improvement	EUAB	EUAC	B/C
B	8,000	5,592	1.43
C	12,000	7,078	1.70
A	15,000	9,202	1.63
D	20,000	13,159	1.52

   b. Calculate the incremental benefit/cost ratio of C to B.

$$\frac{IB}{IC} = \frac{12{,}000 - 8{,}000}{7{,}078 - 5{,}592} = 2.69$$

   The increased benefit of C over B is 2.69 times the increased cost. Assuming that the cost increase can be afforded, C is preferable to B.

c. Calculate the incremental benefit/cost ratio of A to C.

$$\frac{IB}{IC} = \frac{15{,}000 - 12{,}000}{9{,}202 - 7{,}078} = 1.41$$

The increased benefit of A over C is 1.41 times the increased cost. Assuming that the capital cost increase is within funding limits, A is preferable to C.

d. Calculate the incremental benefit/cost ratio of D to A.

$$\frac{IB}{IC} = \frac{20{,}000 - 15{,}000}{13{,}159 - 9{,}202} = 1.26$$

The increased benefit of D over A is 1.26 times the increased cost. Assuming that the cost increase is permissible, D is preferable to A. Among the mutually exclusive alternatives, improvement D is the best according to the incremental benefit/cost ratios. This is the conventional method of evaluating mutually exclusive alternatives.

5.4 Rate of Return

Unlike other methods of economic analysis, the rate of return method does not require the selection of an interest rate prior to the analysis. In the rate of return method, the relative merit of an alternative is measured by the interest rate that sets its benefits equal to its cost.

The rate of return is the interest rate which gives:

$$\text{Present Worth of Benefits} - \text{Present Worth of Costs} = 0$$

$$PWOB - PWOC = 0$$

Equivalent uniform annual costs and benefits can also be used to calculate the rate of return. It is assumed that the costs and benefits remain constant each year and the safety improvement can be re-applied at the end of its service life.

Its advantage is that it yields an interest rate which is simple to understand. Another advantage is that it avoids the necessity of knowing a required or minimum interest rate before calculations are conducted, and the calculations produce a numerical rate that can be compared directly with other investment proposals. The main disadvantage of this method is the time and effort involved in finding the interest rate.

To select the best independent alternative, the rate of return for each alternative is compared to the minimum attractive rate of return which may be a predetermined value or a value adjusted by budget constraints. The best alternative is the improvement with the highest rate of return, and at least equal to or greater than the minimum attractive rate of return.

The internal rate of return is used to evaluate independent alternatives, and the incremental rate of return is used for mutually exclusive alternatives.

5.4.1 Internal Rate of Return for Independent Alternatives

Independent alternatives are evaluated based on the internal rate of return. The alternative with the highest rate of return, but greater than the minimum attractive rate of return, is the best if the budget is not restrictive. The stepwise procedure to select the best alterative using the internal rate of return based on present worths is:

- Convert the benefits and costs to present worth of benefits and costs.

- Equate the difference between PWOB and PWOC to zero to find the appropriate rate of return.
- Select the project with the highest rate of return, if it is greater than the minimum attractive rate of return.

5.4.2 Incremental Rate of Return for Mutually Exclusive Alternatives

Mutually exclusive alternatives are evaluated based on the incremental rate of return. The increment in benefits and costs of one alternative over another are equated to zero to obtain the incremental rate of return. The alternative with the highest incremental rate of return but greater than the minimum attractive rate of return is the best if the budget is not restrictive.

The stepwise procedure to select the best mutually exclusive alternative is:

- Select the alternative with the highest internal rate of return, and greater than the minimum attractive rate of return, as the base alternative.
- Find the incremental costs and benefits of other alternatives over the base alternative.
- Convert the incremental values to present worth of benefits and present worth of costs and equate the difference between PWOB and PWOC to zero to obtain the appropriate rate of return.
- Select a higher first cost alternative if the incremental rate of return is greater than the minimum attractive rate of return, and if the budget is not restrictive.

5.4.3 Example 11: Calculation of Internal Rate of Return and Incremental Rate of Return

Problem:

Two safety improvements A and B with costs and benefits are shown below. Find the rate of return and identify the better alternative.

Given:

Improvement	Initial Cost	Annual Benefit	Annual Cost	Salvage Value	Service lives
A	20,000	8,000	1,000	1,000	5
B	30,000	12,000	1,000	3,000	5

Solution:

The two improvements are treated first as independent and then as mutually exclusive alternatives to demonstrate both conditions.

1. For independent alternatives, the internal rate of return is used to evaluate the alternatives.

   Alternate A -

   Present Worth of Benefits - Present Worth of Costs = 0

   SPW (8,000 - 1,000) + PWF (1,000) - 20,000 = 0

   or, using i = 20%, SPW from Appendix D = 2.991

   PWF from Appendix D = .4019

   2.991 (7,000) + 0.4019 (1,000) - 20,000 = 0

   or, 20,937 + 402 - 20,000 = 0

   or, + 1,339 = 0

   Using i = 25%, SPW from Appendix D = 2.689

   PFW from Appendix D = .3277

   2.689 (7,000) + .3277 (1,000) - 20,000 = 0

   or, 18,823 + 328 - 20,000 = 0

   -849 = 0

   Interpolating,

$$i = 20 + \frac{1,339}{1,339 + 849} \ (5) = \underline{\underline{23.06\%}}$$

Alternate B -

Present Worth of Benefits - Present Worth of Benefits = 0

SPW (12,000 - 1,000) + PWF (3,000) - 30,000 = 0

Using i = 25%, SPW from Appendix D = 2.689

PWF from Appendix D = .3277

2.689 (11,000) + 0.3277 (3,000) - 30,000 = 0

or, 29,579 + 983 - 30,000 = 0

or, + 562 = 0

Using i = 30%, SPW from Appendix D = 2.436

PWF from Appendix D = .2693

2.436 (11,000) + 0.2693 (3,000) - 30,000 = 0

26,796 + 808 - 30,000 = 0

-2396 = 0

Interpolating,

$$i = 25\% + \frac{562}{562 + 2,396} \; (5) \; = \; \underline{\underline{25.95\%}}$$

Alternative B gives a higher rate of return and is better than A.

2. With mutually exclusive alternatives the incremental rate of return is used to evaluate the alternatives. First find the rate of return for alternative A.

Alternative A:

Present Worth of Benefits - Present Worth of Costs = 0

SPW (8,000 - 1,000) + PWF (1,000) - 20,000 = 0

Using i = 20%, SPW from Appendix D = 2.991

PWF from Appendix D = .4019

2.991 (7,000) + 0.4019 (1,000) - 20,000 = 0 or, 20,937 + 402 - 20,000 = 0

+ 1,339 = 0

Using, i = 25%, SPW from Appendix D = 2.689

PWF from Appendix D = .3277

2.689 (7,000) + .3277 (1,000) - 20,000 = 0

18,823 + 328 - 20,000 = 0

-849 = 0

Interpolating,

$$i = 20 + \frac{1,339}{1,339 + 849} \times (5) = 23.06\%$$

It is assumed that i = 23.06% makes alternative A economically acceptable.

Alternative B:

B over A are:

Initial Cost = 30,000 - 20,000 = $10,000

Annual Cost = 1,000 - 1,000 = 0

Salvage Value = 3,000 - 1,000 = $2,000

Annual Benefit = 12,000 - 8,000 = $4,000

Present Worth of Benefits - Present Worth of Costs = 0

SPW (4,000) + PWF (2,000) - 10,000 = 0

Using i = 30%, SPW from Appendix D 2.436

PWF from Appendix D = 0.2693

2.436 (4,000) + 0.2693 (2,000) - 10,000 = 0

9,744 + 539 - 10,000 = 0

+ 283 = 0

Using i = 35%, SPW from Appendix D = 2.220

PWF from Appendix D = 0.2230

$$2.220\ (4{,}000) + 0.223\ (2{,}000) - 10{,}000 = 0$$

$$8{,}880 + 446 - 10{,}000 = 0$$

$$-\ 674 = 0$$

Interpolating,

$$i = 30 + \frac{283}{283 + 674}\ (5) = 30 + 1.48$$

$$= 31.48\%$$

As the i obtained is greater than the minimum attractive rate of return, alternative B is preferable to A if funds permit the increased spending.

5.5 Net Annual Benefit, NAB

Net annual benefit is the difference between equivalent uniform annual benefits and equivalent uniform annual costs:

$$NAB = EUAB - EUAC$$

The merit of alternative improvements is judged by the relative increase in their net annual benefit.

The net annual benefit method assumes that if an improvement with a shorter service life is selected, then the annual cost and benefit for its successor will be the same as for the previous improvement.

The NAB method is a simple method to use, however, its use is restricted only to the economic appraisal of mutually exclusive alternatives. Another disadvantage is that its use starts with the assumption of an interest rate. The rate of interest used for the calculations should be selected very carefully. The stepwise procedure of selecting the best alternative is:

- Calculate the equivalent uniform annual benefit and the equivalent uniform annual cost for each alternative.

- Calculate the Net Annual Benefit of each alternative.
- List the improvement in order of decreasing net annual benefits. Alternatives with positive net annual benefits are economically feasible.
- The most desirable alternative is the improvement with the highest net annual benefit assuming feasibility within budget constraints.

The use of NAB method is demonstrated through the use of an example.

5.5.1 Example 12: Evaluation of Safety Improvements using the Net Annual Benefits Method

Problem:

The costs, benefits, salvage values and service lives of 4 safety improvements are shown below. The interest rate for all the alternatives is 10 percent. Find the net annual benefit for each and select the best alternative.

Given:

	A	B	C	D
Capital Cost	50,000	25,000	60,000	90,000
Annual Maintenance Cost	1,500	1,000	2,000	3,500
Salvage Value	1,000	0	1,500	2,500
Service Life	9	6	10	15
Annual Benefit	14,000	9,000	20,000	22,000

Solution:

1. Find the equivalent uniform annual costs.

$$EUAC = CRF\ (CI) - SFF\ (T) + CYC$$

$$EUAC_A = 0.1736\ (50{,}000) - 0.0736\ (1{,}000) + 1{,}500$$

$$= 8{,}680 - 74 + 1{,}500 = \$10{,}106$$

$EUAC_B$ = 0.22961 (25,000) - 0 + 1,000

= 5,740 + 1,000

= 6 740

$EUAC_C$ = 0.1628 (60,000) - 0.0628 (1,500) + 2,000

= 9,768 - 94 + 2,000

= $11,674

$EUAD_D$ = 0.1315 (90,000) - 0.0315 (2,500) + 3,500

= 11,835 - 79 + 3,500

= $15,256

The values of CRF and SFF are obtained from Appendix D.

2. Calculate the net annual benefits:

NAB = EUAB - EUAC

Improvement	EUAB $	EUAC $	NAB $
A	14,000	10,106	3,894
B	9,000	6,740	2,260
C	20,000	11,674	8,326
D	22,000	15,256	6,744

3. Among the four mutually exclusive alternatives, C is the best alternative because it has the highest net annual benefit.

5.6 Net Present Worth; NPV

The net present worth method is also known as the net present value method. Net present worth is the difference between the present worth of benefits and the present worth of costs.

NPV = PWOB - PWOC

The assumption behind the net present worth method is that the relative merit of an improvement is measured by its net present worth.

The advantage of the net present worth method is that it is used to evaluate independent alternatives as well as mutually exclusive alternatives. The disadvantage is that i is an assumed value. The stepwise procedure to evaluate by the NPV method is:

. Calculate the present worth of benefits

. Calculate the present worth of costs

. Calculate the net present worth by subtracting PWOC from PWOB.

The alternatives are ranked in order of decreasing net present value, the most desirable alternative having the highest net present value.

5.6.1 Example 13: Evaluation of Improvements Using Net Present Worth

Problem:

Four safety improvements have costs, benefits, and service lives as shown. Find the net present value of the four alternatives and select the best improvement. Assume i = 10%.

Given:

Improvement No.	Capital Cost	Annual Cost	Salvage Value	Service Life	Annual Benefits
1	20,000	1,000	0	5	8,000
2	30,000	1,500	500	10	9,000
3	45,000	1,500	1,500	10	15,000
4	70,000	3,000	2,500	10	18,000

i = 10%

Solution:

1. Calculate present worth of benefits:

PWOB = SPW (B)

Improvement	SPW*	B	PWOB
1	6.144	8,000	49,152
2	6.144	9,000	55,296
3	6.144	15,000	92,160
4	6.144	18,000	110,592

*SPW = 6.144 for 10 years at i = 10% (Appendix D).

2. Calculate the present worth of costs.

$$PWOC = CI - PWF\ (T) + SPW\ (CAC)$$

Improvement No. 1

$$PWOC = 20{,}000 - 0 + 1{,}000\ (SPW)^{10}_{10} + 20{,}000\ (PWF)^{10}_{5}$$

$$= 20{,}000 + 1{,}000\ (6.144) + 20{,}000\ (.6209)$$

$$= 20{,}000 + 6{,}144 + 12{,}418$$

$$= \$38{,}562$$

Improvement No. 2

$$PWOC = 30{,}000 - 500\ (PWF) + 1{,}500\ (SPW)$$

$$= 30{,}000 - 500\ (.3855) + 1{,}500\ (6.144)$$

$$= 30{,}000 - 193 + 9{,}216$$

$$= \$39{,}023$$

Improvement No. 3

$$PWOC = 45{,}000 - 1{,}500\ (PWF) + 1{,}500\ (SPW)$$

$$= 45{,}000 - 1{,}500\ (.3855) + 1{,}500\ (6.144)$$

$$= 45{,}000 - 578 + 9{,}216$$

$$= \$53{,}638$$

Improvement No. 4

$$PWOC = 70{,}000 - 2{,}500\ (PWF) + 3{,}000\ (SPW)$$

$$= 70{,}000 - 2{,}500\ (.3855) + 3{,}000\ (6.144)$$

$$= 70{,}000 - 964 + 18{,}432$$

$$= \$87{,}468$$

Note: Values of SPW and PWF obtained from Appendix D.

3. Calculate the net present worth.

NPV = PWOB - PWOC

Improvement No.	PWOB $	PWOC $	NPV $
1	49,152	38,562	10,590
2	55,296	39,023	16,273
3	92,160	53,638	38,522
4	110,592	87,468	23,124

4. The best alternative is Improvement No. 3 because it has the highest net present value, whether the alternatives are considered as independent or mutually exclusive.

5.7 Measures of Economic Effectiveness

The advantages and disadvantages of the various methods of economic analysis are discussed earlier. Any of these methods used alone as an indicator of a projects profitability is an insufficient and inefficient means of project evaluation.

Methods of economic analysis discussed may be classified into one of the following two categories:

1. Methods indicating a Level of Return
2. Methods indicating a Return Rate

Level of Return: The Net Present Value and the Net Annual Benefit methods indicate a level of return. These methods indicate only the cash flow involved and not the return rate or the economic effectiveness, in percentages or ratios. In these methods the preferred choice is that alternative whose benefits exceed its cost by the greatest amount.

Return Rate: The Benefit Cost Ratio, Incremental Benefit Cost Ratio, Rate of Return and Incremental Rate of Return indicates the economic or effectiveness by a ratio or a percentage. These methods are not dependent on the level of cash flow, explicity or directly. In these methods the preferred choice is that alternative where the return rate or the ratio of benefits to costs is the greatest.

The projects selected as optimal may differ when economic analysis methods from the two categories are employed. In the evaluation of any project at least one method from each category, that is, the Level of Return Category and the Return Rate Category, should be used to obtain maximum understanding of the economic viability of the set of alternatives. Such an approach allows the decision maker to identify an economically preferred choice among possible alternatives and to compare projects with widely varying costs or widely varying benefit levels.

CHAPTER VI. DECISION MAKING

This chapter discusses the decision making phase in the evaluation and selection of highway safety improvement projects. A comparison of two safety improvement projects is made comprehensively taking into account all the factors involved in evaluating safety improvement projects. A method is developed to compare all projects whether independent or mutually exclusive on a consistent basis by using the benefit/cost ratios and incremental benefit/cost ratio together. The effects of budget constraints on the selection of projects are considered. Also, the necessity of ranking projects in order of economic priority is discussed.

6.1 Example 14: Comparison of Two Projects

In this example two independent safety improvement projects are compared taking into account all the factors involved in the evaluation and selection of improvements.

Project No. 1

A 500-foot long, 40-foot high fill with 2:1 slopes on a 4° curve, and a 5% grade is thought to need guardrails for safety improvement. This is on a 24-foot wide secondary road with 4-foot shoulders and a sight distance of 1500 feet. The ADT is 2000 vehicles per day. Is guardrail use recommended?

Project No. 2

A 1000-foot long, 30-foot high fill with 3:1 slopes on a 5° curve and a 6% grade is thought to need guardrails for safety improvement. This is on a 20-foot wide secondary road with 4-foot shoulders and a sight distance of 1000 feet. The ADT is 3000 vehicles per day. Is guardrail use recommended?

Costs

The costs of placing a guardrail for each project are shown below:

	Project No. 1	Project No. 2
Initial Cost	$4,000	$8,000
Annual Maintenance Cost	$ 400	$ 800
Terminal Value	$ 200	$ 400

The service life of both improvements is 10 years.

Assume an interest rate of 10%.

Solution

Find if the use of guardrail is beneficial or not for either project. Compare the costs and benefits to determine which project of the two is better. The stepwise procedure is:

(1) Find the accident potential for geometrics.

	Project No. 1	Project No. 2
Accident Rate (Figure 4.1)	2.0 acc/mvm	3.5 acc/mvm
Accident Potential (Figure 4.2)	0.15 acc/yr	0.5 acc/yr

(2) Find the accident potential for roadside hazards.

	Project No. 1	Project No. 2
No. of Encroachments (Figure 4.3)	4.0	4.2
Accident Potential (Figure 4.4)	0.15 acc/yr	0.5 acc/yr

(3) Severity without Guardrail: Select the severity index for the fill and find the probability of fatal, injury and property damage only accidents.

	Project No. 1	Project No. 2
Severity Index (Table A-1)	0.67	0.60
Probability of Fatal Accidents (Fig. 2.7)	0.052	0.046
Probability of Injury Accidents (Fig. 2.8)	0.618	0.554
1 -(Sum of Probability of Fatal and Injury Accidents)	0.33	0.40

(4) Find the number of fatal injury and property damage only accidents per year.

	Project No. 1	Project No. 2
Fatal Accidents/yr	0.15 x 0.052 = 0.0078	0.5 x 0.046 = 0.023
Injury Accidents/yr	0.15 x 0.618 = 0.0927	0.5 x 0.554 = 0.277
Property Damage Only Accidents/yr	0.15 x 0.33 = 0.0495	0.5 x 0.400 = 0.200

(5) Severity with Guardrail: Select the severity index for the guardrail and find the probability of fatal, injury, and property damage only accidents.

	Project No. 1	Project No. 2
Severity Index (Table A-1)	0.33	0.33
Probability of Fatal Accidents (Fig. 2.7)	0.026	0.026
Probability of Injury Accidents (Fig. 2.8)	0.304	0.304
Probability of Property Damage Only Accidents	0.67	0.67

(6) Find the number of fatal, injury and property damage only accidents.

	Project No. 1	Project No. 2
Fatal Accidents/yr	0.15 x 0.026 = 0.0039	0.5 x 0.026 = 0.013
Injury Accidents/yr	0.15 x 0.304 = 0.0456	0.5 x 0.304 = 0.152
Property Damage Only Accidents/yr	0.15 x 0.67 = 0.1005	0.5 x 0.67 = 0.335

(7) Find the reduction in fatal, injury and property damage only accidents by subtracting the fatal, injury and property damage only accidents in the presence of the guardrail from the fatal, injury and property damage only accidents without the guardrail.

Fatality Reduction	0.0078 - 0.0039 = 0.0039	0.023 - 0.013 = 0.010
Injury Reduction	0.0927 - 0.0456 = 0.0471	0.277 - 0.152 = 0.125
Property Damage Reduction	0.0495 - 0.1005 = -0.0510	0.200 - 0.335 = -0.135

Negative values indicate an increase in accidents of that type.

(8) Find the annual benefit (EUAB) in using a guardrail.

Fatality Cost Saving	0.0039 x 307,210 = 1198	0.010 x 307,210 = 3072
Injury Cost Saving	0.0471 x 14,600 = 688	0.125 x 14,600 = 1,825
Property Damage Saving	-0.0510 x 650 = -33	-0.135 x 650 = -88
Total Annual Benefit, EUAB	$1,853	$4,809

(9) Calculate the equivalent uniform annual cost for each improvement.

	Project No. 1	Project No. 2
EUAC = CRF CI-PWF(T) + CYC	.1628 [4000 - .3855 (200)] + 400 = $1,039	.1628 [8000 - .3855 (400)] + 800 = $2,077

(10) Find the Benefit-Cost Ratios of placing a guardrail.

	Project No. 1	Project No. 2
B/C = EUAB/EUAC	1853/1039 = 1.78	4809/2077 = 2.32

(11) Rank the improvements in the order of decreasing B/C ratios. In the above example, Project No. 2 has a higher B/C ratio than Project No. 1. Also, both the projects are feasible because their benefit/cost ratios are greater than 1.

(12) The final selection should take account of both economic and safety consequences, as shown in Table 6.1. Economically, Project No. 2 is a better choice, and it also reduces a greater number of fatalities and injuries. Therefore, Project No. 2 is selected for implementation. Budget limitations are not considered here.

6.2 Budget Constraints

The cost of highway safety improvements is rising all the time. Larger and larger funds are required to implement safety improvements. It is very rare to have a situation where sufficient funds are available to implement all feasible safety improvements. Therefore, the attempt should be to obtain the greatest profits from the available funds.

If budget funds are unlimited, investment returns can be maximized.

Table 6.1 Improvement Evaluation Worksheet

STEP	PROJECT 1	PROJECT 2
Hazard Type	Inadequate Geometrics	Inadequate Geometrics
Accident Potential, accidents/yr	0.15	0.15
Hazard Severity Index	0.67	0.67
Improvement	Place Guardrail	Place Guardrail
Improvement Severity Index	0.33	0.33
Reduction in Fatalities	0.0078 - 0.0039 = 0.0039	0.023 - 0.013 = 0.010
Reduction in Injuries	0.0927 - 0.0456 = 0.0471	0.277 - 0.013 = 0.125
Reduction in PDO Accidents	0.0495 - 0.1005 = -0.1005	0.200 = 0.335 = -0.135
Capital Cost	$4,000	$8,000
Annual Maintenance Cost	$ 400	$ 800
Terminal Value	$ 200	$ 400
Equivalent Uniform Annual Cost, EUAC	$1,039	$2,077
Equivalent Uniform Annual Benefit, EUAB	$1,853	$4,809
Benefit-Cost Ratio, B/C	1.78	2.31
Improvement Ranking	2	1

The improvements with the greatest return on the dollar invested can be implemented. However, such an ideal condition often does not exist.

Accidents cannot be entirely eliminated, because of the difficulty of controlling the innumerable factors which cause them. The best that can be done is to make efforts to reduce accidents to the lowest possible level within available funds--which again is a dynamic process. Finances do not permit the elimination of all hazards along the highway.

The decision maker must select the improvements that best meet the objectives and values of the local population, the local jurisdiction and the funding program. The decision is significantly influenced by the availability of funds. The availability of funds can be divided into three levels; limited budget, moderate budget and large budget.

<u>Limited budget</u>: If the budget falls far short of the desirable amount, few safety improvements may be implemented and the selection may be restricted to low cost safety improvements only, even though they may not be the most effective. High cost safety measures will be eliminated. Such a situation would create the need to implement only the most immediate safety improvements or to stage the implementation of improvements.

<u>Moderate budget</u>: A moderate budget permits the selection of some large and some small projects. Not all desirable projects are selected, but the most important may be improved.

<u>Large budget</u>: A large budget permits the selection of all desirable projects. With a large budget the benefits from safety improvements can be maximized because the options are unlimited.

The improvement selected depends on the:

1. Economic evaluation,
2. Safety evaluation,
3. Funds required, including
   - (a) capital investment,
   - (b) maintenance and operation, and
   - (c) terminal value.

In addition to the economic evaluation, the results of the safety analysis, that is, the number of fatalities and injuries must be taken into account independently, to give sufficient consideration to the personal suffering that may occur.

6.3 Priority Ranking

Ranking is a method of comparing economic and social consequences, of safety improvements on the basis of their contribution to benefits and costs.

The priority ranking of potential improvements provides decision makers with a rational tool for comparing alternatives. But, when budget constraints are introduced, the use of the ranking alone does not guarantee the overall maximization of benefits. When funding constraints make various programs financially mutually exclusive, many budgetary combinations may have to be examined to maximize benefits.

Priorities are not always set by economic analysis. Economic analysis is not performed to make the decision, but to produce economic measures of effectiveness, such as the benefit cost ratio that assists the decision making process.

6.4 Simultaneous Comparison of Independent and Mutually Exclusive Alternatives Using Benefit Cost and Incremental Benefit Cost Ratios

Independent alternatives are evaluated on the basis of benefit/cost ratios. Mutually exclusive alternatives must be appraised using both the benefit/cost ratio and incremental benefit cost ratios together. In the following example a procedure to compare independent and mutually exclusive projects simultaneously is given.

Example 15:

Four Independent safety improvement projects A, B, C, D and four Mutually Exclusive safety projects E1, E2, E3, and E4 have costs, benefits, etc. shown below. Assume i = 10%.

Rank the projects and consider the budgeting constraints that influence the selection of the improvements.

Given:

Independent Projects	Initial Cost $	Annual Maintenance Cost $	Annual benefits $	Salvage Value $	Service Life (years)
A	20,000	1,000	8,000	0	5
B	30,000	1,500	9,000	500	10
C	45,000	1,500	15,000	1,500	10
D	70,000	3,000	18,000	2,500	10

Mutually Exclusive Projects	Initial Cost $	Annual Maintenance Cost $	Annual benefits $	Salvage Value $	Service Life (years)
E1	25,000	1,000	9,000	0	5
E2	50,000	1,500	17,000	1,000	10
E3	60,000	2,000	20,000	1,500	10
E4	90,000	3,500	30,000	2,500	10

Solution:

1. The equivalent uniform annual cost is calculated.

$EUAC = CRF\ (CI) - SFF\ (T) + CAC$

$EUAC_A = .2638\ (20{,}000) - 0 + 1000$

$= 5276 + 1000$

$= \underline{\underline{\$6276}}$

$EUAC_B = .1628\ (30{,}000) - .0628\ (500) + 1500$

$= 4884 - 31 + 1500$

$= \underline{\underline{\$6353}}$

$EUAC_C = .1628\ (45{,}000) - .0628\ (1500) + 1500$

$= 7326 - 94 + 1500$

$= \underline{\underline{\$8732}}$

$EUAC_B = .1628\ (70{,}000) - .0628\ (2500) + 3000$

$= 11{,}396 - 157 + 3000$

$= \underline{\underline{\$14{,}239}}$

$EUAC_{E1} = .2638\ (25{,}000) - 0 + 1000$

$= 6595 + 1000$

$= \underline{\underline{\$7595}}$

$$EUAC_{E2} = .1628\ (50{,}000) - .0628\ (1000) + 1500$$
$$= 8140 - 63 + 1500$$
$$= \underline{\underline{\$9577}}$$

$$EUAC_{E3} = .1628\ (60{,}000) - .0628\ (1500) + 2000$$
$$= 9768 - 94 + 2000$$
$$= \underline{\underline{\$11{,}674}}$$

$$EUAC_{E4} = .1628\ (90{,}000) - .0628\ (2500) + 3500$$
$$= 14{,}652 - 157 + 3500$$
$$= \underline{\underline{\$17{,}995}}$$

CRF, SFF values obtained from Appendix D.

2. The benefit/cost ratios for all the alternatives are calculated.

$$B/C = \frac{EUAB}{EUAC}$$

Alternative	EUAB	EUAC	B/C
A	8,000	6,276	1.27
B	9,000	6,353	1.42
C	15,000	8,732	1.72
D	18,000	14,239	1.26
E1	9,000	7,595	1.18
E2	17,000	9,577	1.78
E3	20,000	11,674	1.71
E4	30,000	17,995	1.67

3. The incremental benefit/cost ratios of the mutually exclusive alternatives are calculated.

Improvement	EUAC	EUAB	IB/IC
E1	9,000	7,595	———
E2	17,000	9,577	4.04*
E3	20,000	11,674	1.43**
E4	30,000	17,995	1.58***

$$^{*}\frac{EUAB_{E2} - EUAB_{E1}}{EUAC_{E2} - EUAC_{E1}} = \frac{17{,}000 - 9{,}000}{9{,}577 - 7{,}595} = 4.04$$

$$^{**}\frac{EUAB_{E3} - EUAB_{E2}}{EUAC_{E3} - EUAC_{E2}} = \frac{20{,}000 - 17{,}000}{11{,}674 - 9{,}577} = 1.43$$

$$^{***}\frac{EUAB_{E4} - EUAB_{E3}}{EUAC_{E4} - EUAC_{E3}} = \frac{30{,}000 - 20{,}000}{17{,}995 - 11{,}674} = 1.58$$

4. The annual benefits, annual cost, benefit cost ratios and incremental benefit cost ratios calculated in steps 1 through 3 are summarized in Table 6.2.

   a. Initially out of all eight projects the project with the highest benefit cost ratio is selected, that is Project E2.

   b. Incremental benefit/cost ratios for all higher cost mutually exclusive projects, E3 and E4, are recalculated based on E2. This is based on the assumption that the funds for E2 have already been allocated as a result of its selection in the first iteration.

$$\frac{EUAB_{E3} - EUAB_{E2}}{EUAC_{E3} - EUAC_{E2}} = \frac{20{,}000 - 17{,}000}{11{,}674 - 9{,}577} = 1.43$$

Table 6.2 Simultaneous Ranking of Independent and Mutually Exclusive Alternatives

Improvement Alternative	Initial Cost $	EUAB $	EUAC $	BCR_1	$IBCR_1$	BCR_2	$IBCR_2$	BCR_3	$IBCR_3$	BCR_4	$IBCR_4$	Ranking	
A	20,000	8,000	6,276	1.27	—	1.27	—	1.27		[1.27] (4)	—	Rank #4	Independent Projects
B	30,000	9,000	6,353	1.42	—	1.42	—	1.42		[1.42] (3)	—	Rank #3	
C	45,000	15,000	8,732	1.72	—	[1.72] (2)	—	Rank #1		Rank #1		Rank #1	
D	70,000	18,000	14,239	1.26	—	1.26	—	1.26	—	[1.26] (5)	—	Rank #5	
E1	25,000	9,000	7,595	1.18	neglect	—	—	—	—	—	—	—	Mutually Exclusive Projects
E2	50,000	17,000	9,577	[1.77] (1)	4.04	Rank #1		Replace by E4		Replaced		—	
E3	60,000	20,000	11,674	1.71	1.43	—	1.43	—	1.43	neglect		—	
E4	90,000	30,000	17,995	1.67	1.58	—	1.54*	—	[1.54] (3)	Rank #2		Rank #2	

$$^{*}\frac{EUAB_{E4} - EUAB_{E2}}{EUAC_{E4} - EUAC_{E2}} = \frac{30,000 - 17,000}{17,995 - 9,577} = 1.54$$

Note: BCR stands for Benefit Cost Ratio

IBCR stands for Incremental Cost Ratio

[ ] indicates the project selected at each iteration

( ) indicates the rank of newly selected projects

$$\frac{EUAB_{E4} - EUAB_{E2}}{EUAC_{E4} - EUAC_{E2}} = \frac{30{,}000 - 17{,}000}{17{,}995 - 9{,}577} = 1.54$$

c. For the second iteration, the project with the highest benefit/cost ratio or incremental benefit/cost ratio,that is project C, is selected.

d. The second project selected is not one of the mutually exclusive projects. It is independent. Therefore, the incremental benefit/cost ratio is not recalculated.

e. For the third iteration, the project with the highest benefit/cost ratio or incremental benefit/cost ratio is selected, that is project E4. Since this project E4 and project E2 are mutually exclusive, the previously selected project E2 is superceded. The project ranking for project C is raised from second to first and project E4 is ranked second.

f. The remaining three independent alternatives A, B and D are ranked according to their decreasing benefit/cost ratios.

5. Budgetary restraints have significant influence on the selection of projects. The total amount needed to finance the initial cost of all projects selected is:

   45,000 + 90,000 + 30,000 + 20,000 + 70,000 = $255,000

   If such funds are available, all the projects can be implemented as all five projects have B/C and IB/IC greater than 1.

6. When the budget is limited, all desirable projects may not be implemented. Those projects with the highest rankings, within budgeted constraints, are selected. Consider 2 cases.

<u>Case 1.</u> Budget = $100,000

The following projects are selected.

Alternative	Ranking	Initial Cost	
C	First	45,000	$\Sigma < 100,000$
E2	Second	50,000	

Project E2 is selected instead of E4 because project E4 requires $90,000 for first costs and a total budget of $135,000 is needed to implement both E4 and E5.

<u>Case 2</u>. Budget = $160,000

The following projects are selected.

Alternative	Ranking	Initial Cost	
C	First	45,000	
E4	Second	90,000	$\Sigma < 160,000$
A	Third	20,000	

Project A is selected instead of B. If project B were selected, it would force the total first costs over the budget limit. Project A is next in rank and can be afforded within the budget.

CHAPTER VII. CONCLUSIONS AND RECOMMENDATIONS

This study presents a procedure to evaluate and set priorities for highway safety improvements. The accident potential of the four hazard categories, their relative severities and the possible countermeasures to remedy the hazards are discussed. A decision-making framework to select the most suitable improvements within available funds is presented. This chapter draws conclusions from the study and recommends research for future work.

7.1 Conclusions

This study deals primarily with the effect of roadway geometrics, roadside obstacles, the roadway environment on safety, and discusses means to evaluate and appraise highway safety improvements through economic analysis.

The causes of accidents are so complex that they cannot readily be related to physical conditions. No attempt has been made to consider the influence of the driver and the vehicle on safety since they cannot be totally controlled by control devices or design improvements on the highway. Therefore, probable driver related and vehicle related improvements and their evaluation are not discussed.

7.2 Recommendations for Further Research

Safety hazard improvements have been applied extensively to limited access facilities, however, much improvement is still desired for low volume highways and streets.

The evaluation procedures and relationships developed are based on statistics and techniques presented in current literature. Many of these techniques were developed for limited access facilities and have been adapted here for low volume applications. Economic analysis and evaluation provide a good basis for the selection of safety improvement projects. The comparison of independent and mutually exclusive alternatives simultaneously for highway safety improvements is a relatively new concept and may be refined further.

Severity Index. The severity indices used in this study were developed for high speed and high volume facilities and have been adapted here for low volume conditions in local jurisdictions. The severity indices indicate the probability of fatal and injury accidents, as well as, defining the probability of property damage only accidents. In Figure 2.6 relating speed to the probability of fatal and injury accidents, an attempt is made to estimate the probability of accidents at lower speeds. It is recommended that the severity indices and their related accident probabilities be determined from research on accidents on low volume and low speed facilities.

Accident Reduction Factors. A list of estimated accident reduction factors for various types of improvements is included in the Appendix. Many of these factors are estimated for high volume facilities, and have been adapted for low volume roads. It is recommended that accident reduction factors for low volume and low speed roads be developed. It is advisable for local highway agencies to develop their own accident reduction factors for local traffic conditions.

Identification of Hazardous Locations. The safety evaluation procedures presented in this study, and earlier research, are developed for low volume roads where adequate accident records rarely exist (31). Therefore, according to the approach taken in this study, hazardous locations need not wait to have a significantly high accident rate to be discovered. The desire is to identify hazards and hazardous locations before accidents have occurred. An inventory of all potential hazards and their severity should be made instead of identifying hazards after accidents have occurred at the locations.

Combined Effects of Hazards at a Location. Two or more types of hazards may occur at a particular location. An example is a sharp horizontal curve on a 2:1 side slope and high embankment fill. Both the sharp curve and the steep fill are potential hazards. In such cases it is very difficult to assign a specific degree of accident severity or accident potential to each hazard. It is not known if the total effect of the two or more hazards is greater than or less than the sum of the effects taken independently.

More research is recommended to determine the combined effect of two or more hazards at a location so that the accident potential and accident severity associated with each hazard can be identified.

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APPENDIX A

Severity Indices of Hazards

Table A-1 Severity Indices of Hazards

Obstacle	Severity Index
Railroad Crossings	
Crossbucks	0.80
Wigwags	0.51
Flashing Lights	0.43
Automatic Gates	0.25
Intersections	
	(not available)
Geometrics	
Fill Slopes	
Greater than 2:1	0.70
3:1	0.53
4:1	0.43
5:1	0.33
Less than 6:1	0.22
Cut Slopes	
½:1 - 1.1	0.70
1½:1	0.53
2:1	0.43
3:1	0.33
4:1 or flatter	0.22
Ditch (1 - 2 ft.)	.37
Ditch (3 + ft.)	.60
Roadside Obstacles	
Trees	
13 inch diameter or greater	0.70
11-12 inch diameter	0.53
8-10 inch diameter	0.43
5-7 inch diameter	0.33
2-4 inch diameter	0.22

Table A-1 Severity Indices of Hazards (cont.)

Obstacle	Severity Index
Roadside Obstacles (cont.)	
Single, Double, or Triple Steel Post Sign	
9 inch or greater post size	0.70
6-8 inch post	0.53
3-5 inch post	0.43
Breakaway Sign Post (all sizes and types)	0.22
Single, Double, or Triple Wood Post Sign	
14 inch diameter or greater	0.70
10-13 inch diameter	0.53
7-9 inch diameter	0.43
8 x 8 inch (dimensional)	0.33
6 inch diameter	0.33
6 x 6 inch (dimensional)	0.33
4 x 4 inch (dimensional)	0.22
Animals	0.08
Miscellaneous (debris, construction barriers)	0.28
Fence	0.35
Fire hydrants	0.35
Culverts	0.57
Field Approach	0.65
Rocks	0.44
Small trees, brush	0.36
Fence	0.21
Mailbox	0.13

Sources: 5, 14, 15, 20, 32, 35, 40

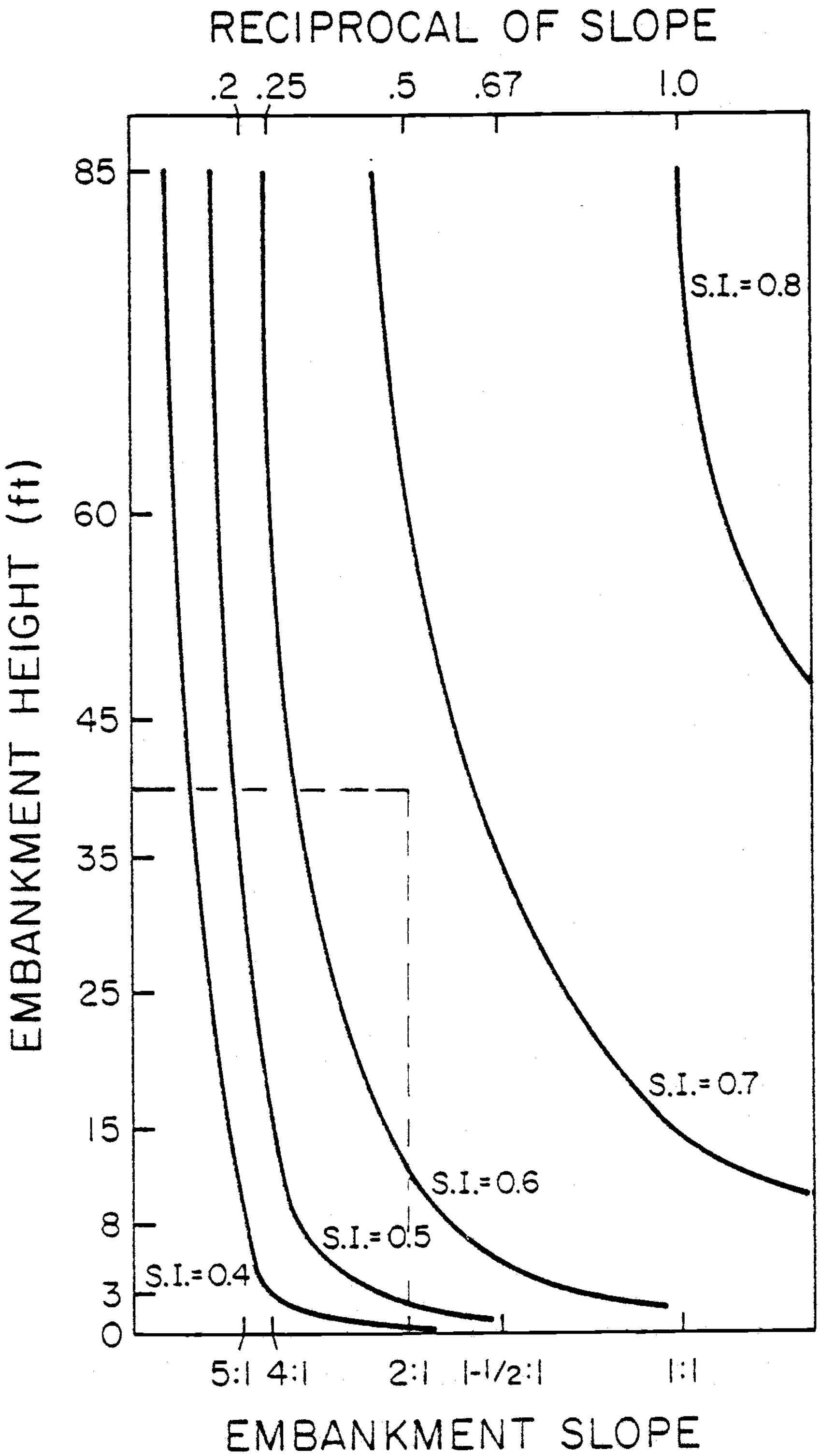

Figure A-1 Combined Severity Index for Embankment Slope and Embankment Height

Source: 15

APPENDIX 3

ACCIDENT REDUCTION FACTORS

Differentiates Between
Fatal and Injury Accidents

[1]Washington
[2]Missouri
[3]California
[4]ITE (Jorgenson)
[5]DOT-FH 11-9129 (Jorgenson)
March 1977
[6]NCHRP 197

ROADSIDE

IMPROVEMENT	FAT. & INJ. REDUCTION, %	PDO REDUCTION, %	TOTAL REDUCTION
Guardrail at embankments	39(F)[5], 15(I),[5] 20[1]	20[1]	13[5], 30[3]
Improve guardrail to design standards			5[3]
Guardrail at bridge ends, etc.	50[1]	35[1]	50[3]
Flatten side slopes	20[1]	20[1]	46[3]
Install breakaway signs	50[1]	0[1]	35[3], 25[3]
Energy absorption devices	44(I)[5], 100(F)[5], 50[1]	20[1]	80[3]
Relocate fixed objects			35-99[3]
Relocate fixed objects (fixed object accidents)			60[2]
Safety treat concrete headwall			50[3]
Install Protection @ twin bridge median opening			50[3]

GEOMETRICS

Widen roadway	38(I)[5], 37(F)[5], 30, 30[4]	40[1]	25[5], 38[4], 23[3]
Widen shoulder	20(I)[5], 49(F)[5], 7[4], 5[1]	0[1]	29[5], 5[3], -2[4]
Flatten side slopes	20[1]	20[1]	46[3]
Improve horizontal and/or vertical alignment			40[3], 50[2]
Modernize to design standards	-6[4]		10[4], 15[3]

GEOMETRICS (Cont.)

IMPROVEMENT	FAT. & INJ. REDUCTION, %	PDO REDUCTION, %	TOTAL REDUCTION
Reconstruct curve	39[4], 50[1]	96[4]	30[1], 88[4], 42[5]
Reconstruct curve for superelevation			65[5], 50[2]
Reconstruct road	35[1]		35[1], 25[2]
Construct pedestrian walkway			60[5]
Widen existing bridge	60[1]		44[5], 60[1]
Replace narrow bridge			62[5]
Widen small structures			40[5]
Modernize bridge rail to design standards			5[5]
Construct pedestrian crossover (Ped. accidents)			95[5]
Construct pedestrian crossover (All accidents)			5[5]
Shoulder stabilization	30+		38[4], 28[5]
Relocate driveways (Head on & rear end acc.)			20[2]
Relocate driveways (Rt. angle, sideswipe & turning acc.)			10[2]
Deslicking (Wet pavement accidents)			50[2]
Deslicking	27(I)[5], 15[2], 30(F)[5]		17[5], 20[2], 20[5]
Resurfacing	46[2], 21[4]	26[6]	21[5], 42[2], 12[4]
Resurfacing (Wet pavement accidents)			75[6], 42[5]
Groove to prevent hydroplaning	74(F)[5], 30(I)[5]		21[5], 48[5]
Groove to prevent hydroplaning (wet acc.)			42[5]
Add asphalt seal coat			21[5]
Add asphalt seal coat (wet accidents)			42[5]
Install ACP overlay			21[5]
Install rumble strips	25[1]		27[5], 25[2]
Add turning lane (2-way)	50[1]		35[2], 25[5], 50[1]
Livestock fencing (livestock acc.)			90[4], 90[5]
Modernize drainage to design standards			30[5]
Remove curb and/or riprap			20[5]
Improve sight distance	38(I)[5], 36(F)[5]		31[5]
Replace bridge or other major structure	60(I)[5], 47(F)[5]		44[5]
Add lanes	11(I)[5], 31(F)[5]		17[5]
Widen bridge or other major structure	74(I)[5], 35(F)[5]		65[5], 67[6]

GEOMETRICS (Cont.)

IMPROVEMENT	FAT. & INJ. REDUCTION, %	PDO REDUCTION, %	TOTAL REDUCTION
Install safety lighting	73(F)[5], 9(I)[5]		23[5], 9[5]
Install safety lighting (night acc.)			50[2]
Install safety lighting at bridge			50[5]
Install safety lighting at bridge (night acc.)			50[2]
Install safety lighting at underpass			10[5]
Install safety lighting at underpass (night acc.)			10[2]
Install safety lighting at terminal nosing	25[1]	25[1]	

PAVEMENT MARKINGS & DELINEATION

IMPROVEMENT	FAT. & INJ. REDUCTION, %	PDO REDUCTION, %	TOTAL REDUCTION
Install striping and/or delineation	20(I)[5], 46(F)[5]		13[5]
Install centerline striping			65[3]
Install centerline striping @ crests			64[9]
Install/improve edge marking	15[1], 17[4]	15[1]	2[2], 23[3], 14[4]
Install/improve edge marking (run-off road acc.)			25[2]
Reflectorized raised pavement markings	5[1]	5[1]	20[5]
Reflectorized traffic buttons			25[3], 5[2]
Install delineators			30[3]
Install delineators on curve	16[4]		2[4]
Install delineators on bridge or underpass	-8[4]		47[4]
Double yellow centerline	5[1]	5[1]	5[2]
No passing stripes			65[2]
Install painted or raised median	10[1]	10[1]	8[3]
Install guide posts on curve	25[1]	25[1]	
Signs/striping combination	26(I)[5], 27(F)[5]		24[5]
Install advance warning signs	14[2]		14[2], 33[5]
Install advance warning signs on curves	71[4]	23[4]	57[4], 75[2]
Install advance warning signs (rural)	30[1]	35[1]	
Install advance warning signs (urban)	15[1]	15[1]	
Install warning signs and delineation on curves	41[4]		22[4]
Install or upgrade signs	33(I)[5], 27(F)[5]		23[5]
Signing and/or marking	42(I)[5], 35(F)[5]		0[5]

INTERSECTIONS

IMPROVEMENT	FAT. & INJ. REDUCTION, %	PDO REDUCTION, %	TOTAL REDUCTION
Install/improve signs, direct., warn. (rural)	19[4]		37[4]
Install/improve signs, direct., warn. (urban)	29[4]		51[4]
Install/improve signs, directional, warning	59[2]		39[2]
Install/improve warning signs and delineators	27[2]		20[2]
Install/improve signs at T-junction (rural)	43[4]		61[4]
Install stop ahead signs (rural)	96[4], 80[1]	45[1]	47[4]
Install stop ahead signs			47[3]
Install yield signs	30[2]		59[2], 59[3]
Install yield sign (urban)	30[4], 30[1]	60[1]	59[4]
Install minor leg stop control	71[2]		48[3], 48[2]
Install minor leg stop control (rural)	89[4], 80[1]	65[1]	65[4]
Install minor leg stop control (urban)	71[4], 70[1]	50[1]	48[4]
Install all way stop signs	67[2]		70[2], 56[6]
Install all way stop signs (urban)	67[4], 65[1]	70[1]	68[4]
Install/improve stop signs			68[3]
Add left turn lane w/o signal	30[2]		19[2], 25[3]
Add left turn lane w/o signal (rural)	30[1]	20[1]	
Add left turn lane w/o signal (urban)	30[1], 30[4]	20[1]	19[4]
Add left turn lane w/o signal T-intersection (Urban)	30[1], 79[4]	30[1], 79[4]	
Add left turn lane w/o signal Y-intersection (rural)	5[1], 5[4]	35[1], -15[1]	33[1]
Add left turn lane with signal	1[2]		36[3], 27[2]
Add left turn lane with signal (rural)	58[4]		45[4]
Add left turn lane with signal (urban)	1[4]	7[4]	27[4]
Add left turn lane with signal and illumination	76[2]		46[2]
Curtail turning movement	39[2]		40[2], 40[3]
Install new traffic signal	32(I)[5], 49(F)[5], 50[1], 50[4]	30[1], 29[4]	29[3], 18[3]
Install new traffic signal (Right angle accidents)			30[2]
Install new traffic signal (Rear end accidents)			-1/1000 vpd[2]
Add left turn signal (no lane)	57[2]		22[3], 39[2]
Improve/modernize signals	30[1], 35[2], 35[4]	30[1]	47[6], 31[2], 25[3], 31[4]
Add pedestrian signal	56[2]		13[3], 13[2]

INTERSECTIONS (Cont.)

IMPROVEMENT	FAT. & INJ. REDUCTION, %	PDO REDUCTION, %	TOTAL REDUCTION
Add pedestrian signal (urban)	53[1], 56[4]	15[1]	15[4]
Add pedestrian phase (Pedestrian accidents)			60[2]
Install warning signals	73[2]		42-56[3]
Install warning signals (rural)	30[1], 29[4]	50[1]	56[4]
Flashing beacons (red-yellow)			50[2]
Flashing beacons (all red)			75[2]
Advance warning flashers			30[2]
Interconnect traffic signals	30[1]	30[1]	
12" lens (rear-end accidents)			10[2]
Optically programmed signals (head-on accidents)			20[2]
Optically programmed signals (rear-end, right angle & left turn accidents)			10[2]
Improve timing (rear end, right angle, turning & night accidents)			10[2]
Channelization (	29(I)[5], 65(F)[5]		25[5]
Actuated signals (Rear end, right angle, left turn accidents)			10[2]
Actuated signals (Sideswipe and right turn accidents)			20[2]
Remove signal (rear end accidents)			90[2]
Increase radii at intersection	25[1]	15[1]	
Reconstruct intersection			40[3]
Install new lighting	15[1]	20[1]	75[3]
Improve lighting			50[3]
Install new lighting (night acc.)			75[2]
Improve lighting (night acc.)			50[2]
Install signal (T-intersection)			-73[6]
Install signal (cross intersection)			-53[6]

RAILROAD CROSSING

IMPROVEMENT	FAT. & INJ. REDUCTION, %	PDO REDUCTION, %	TOTAL REDUCTION
Install lighting	15[1]	20[1]	
Install lighting (night acc.)			60[2]
Install railroad warning device			50[3]
Install flashing beacon			30[2]
Flashing lights replacing signs only	93(I)[5], 99(F)[5]		94[5]
Automatic gates replacing signs only	99(I)[5], 100(F)[5]		99[5]
Automatic gates replacing active device	75(I)[5], 96(F)[5]		81[5]

MISCELLANEOUS

IMPROVEMENT	FAT. & INJ. REDUCTION, %	PDO REDUCTION, %	TOTAL REDUCTION
Remove parking	3[2]		32[2], 32[5]
Change from two-way to one-way			25[2]

APPENDIX C

DEFINITIONS AND FORMULAS OF PWF, SFF, CRF, SPW

Present Worth Factor PWF, (single payment) - The PWF is the multiplier that is used to convert a known future sum to present value.

$$\frac{P}{F} = \frac{1}{(1 + i)^n}$$

Sinking Fund Factor, SFF - The SFF is the multiplier used to convert payments through a period to produce a desired amount at the end of a given period of time.

$$\frac{A}{F} = \frac{i}{(1 + i)^n - 1}$$

Capital Recovery Factor, CRF - The CRF gives the uniform annual payment which can be secured from a known present sum.

$$\frac{A}{P} = \frac{i\,(1 + i)^n}{(1 + i)^n - 1}$$

Series Present Worth Factor, SPW - The SPW is the factor used to convert to present worth a uniform series of annual payments.

$$\frac{P}{A} = \frac{(1 + i)^n - 1}{i(1 + i)^n}$$

where, i = interest rate per interest period

n = number of interest periods

P = present sum of money

F = sum of money at the end of n periods (future sum of money)

A = end-of-period payment or receipt

APPENDIX D

Compound Interest Factors

7% Compound Interest Factors

Service Life n	Present Worth Factor PWF	Sinking Fund Factor SFF	Capital Recovery Factor CRF	Series Present Worth Factor SPW	Service Life n
1	0.9346	1.0000	1.0700	0.935	1
2	0.8734	0.4841	0.5531	1.808	2
3	0.8163	0.3111	0.3811	2.624	3
4	0.7629	0.2252	0.2952	3.387	4
5	0.7130	0.1739	0.2439	4.100	5
6	0.6663	0.1398	0.2098	4.767	6
7	0.6227	0.1156	0.1856	5.389	7
8	0.5820	0.0975	0.1675	5.971	8
9	0.5439	0.0835	0.1535	6.515	9
10	0.5083	0.0724	0.1424	7.024	10
11	0.4751	0.0634	0.1334	7.499	11
12	0.4440	0.0559	0.1259	7.943	12
13	0.4150	0.0497	0.1197	8.358	13
14	0.3878	0.0443	0.1143	8.745	14
15	0.3624	0.9398	0.1098	9.108	15
16	0.3387	0.0357	0.1057	9.447	16
17	0.3166	0.0324	0.1024	9.763	17
18	0.2959	0.0294	0.0994	10.059	18
19	0.2765	0.0268	0.0968	10.335	19
20	0.2584	0.0244	0.0944	10.594	20
21	0.2415	0.0223	0.0923	10.836	21
22	0.2257	0.0204	0.0904	11.061	22
23	0.2109	0.0187	0.0887	11.272	23
24	0.1971	0.0172	0.0872	11.469	24
25	0.1842	0.0158	0.0858	11.654	25
26	0.o722	0.0146	0.0846	11.826	26
27	0.1609	0.0134	0.0834	11.987	27
28	0.1504	0.0124	0.0824	12.137	28
29	0.1406	0.0115	0.0815	12.278	29
30	0.1314	0.0106	0.0806	12.409	30
31	0.1228	0.0098	0.0798	12.532	31
32	0.1147	0.0091	0.0791	12.647	32
33	0.1072	0.0084	0.0784	12.754	33
34	0.1002	0.0078	0.0778	12.854	34
35	0.0937	0.0072	0.0772	12.948	35
40	0.0668	0.0050	0.0750	13.332	40
45	0.0476	0.0035	0.0735	13.606	45
50	0.0339	0.0025	0.0725	13.801	50
55	0.0242	0.0017	0.0717	13.940	55
60	0.0173	0.0012	0.0712	14.039	60
65	0.0123	0.0009	0.0709	14.110	65
70	0.0088	0.0006	0.0706	14.160	70
75	0.0063	0.0004	0.0704	14.196	75
80	0.0045	0.0003	0.0703	14.222	80
85	0.0032	0.0002	0.0702	14.240	85
90	0.0023	0.0002	0.0702	14.253	90
95	0.0016	0.0001	0.0701	14.263	95
100	0.0012	0.0001	0.0701	14.269	100

8% Compound Interest Factors

Service Life n	Present Worth Factor PWF	Sinking Fund Factor SFF	Capital Recovery Factor CRF	Series Present Worth Factor SPW	Service Life n
1	0.9259	1.0000	1.0800	0.926	1
2	0.8573	0.4808	0.5608	1.783	2
3	0.7938	0.3080	0.3880	2.577	3
4	0.7350	0.2219	0.3019	3.312	4
5	0.6806	0.1705	0.2505	3.993	5
6	0.6302	0.1363	0.2163	4.623	6
7	0.5835	0.1121	0.1921	5.206	7
8	0.5403	0.0940	0.1740	5.747	8
9	0.5002	0.0801	0.1601	6.247	9
10	0.4632	0.0690	0.1490	6.710	10
11	0.4289	0.0601	0.1401	7.139	11
12	0.3971	0.0527	0.1327	7.536	12
13	0.3677	0.0465	0.1265	7.904	13
14	0.3405	0.0413	0.1213	8.244	14
15	0.3152	0.0368	0.1168	8.559	15
16	0.2919	0.0330	0.1130	8.851	16
17	0.2703	0.0296	0.1096	9.122	17
18	0.2502	0.0267	0.1067	9.372	18
19	0.2317	0.0241	0.1041	9.604	19
20	0.2145	0.0219	0.1019	9.818	20
21	0.1987	0.0198	0.0998	10.017	21
22	0.1839	0.0180	0.0980	10.201	22
23	0.1703	0.0164	0.0964	10.371	23
24	0.1577	0.0150	0.0950	10.529	24
25	0.1460	0.0137	0.0937	10.675	25
26	0.1352	0.0125	0.0925	10.810	26
27	0.1252	0.0115	0.0915	10.935	27
28	0.1159	0.0105	0.0905	11.051	28
29	0.1073	0.0096	0.0896	11.158	29
30	0.0994	0.0088	0.0888	11.258	30
31	0.0920	0.0081	0.0881	11.350	31
32	0.0852	0.0075	0.0875	11.435	32
33	0.0789	0.0069	0.0869	11.514	33
34	0.0730	0.0063	0.0863	11.587	34
35	0.0676	0.0058	0.0858	11.655	35
40	0.0460	0.0039	0.0839	11.925	40
45	0.0313	0.0026	0.0826	12.108	45
50	0.0213	0.0017	0.0817	12.233	50
55	0.0145	0.0012	0.0812	12.319	55
60	0.0099	0.0008	0.0808	12.377	60
65	0.0067	0.0005	0.0805	12.416	65
70	0.0046	0.0004	0.0804	12.443	70
75	0.0031	0.0003	0.0803	12.461	75
80	0.0021	0.0002	0.0802	12.474	80
85	0.0014	0.0001	0.0801	12.482	85
90	0.0010	0.0001	0.0801	12.488	90
95	0.0007	0.0001	0.0801	12.492	95
100	0.0005	0.0000	0.0800	12.494	100

10% Compound Interest Factors

Service Life n	Present Worth Factor PWF	Sinking Fund Factor SFF	Capital Recovery Factor CRF	Series Present Worth Factor SPW	Service Life n
1	0.9091	1.0000	1.1000	0.909	1
2	0.8264	0.4762	0.5762	1.736	2
3	0.7513	0.3021	0.4021	2.487	3
4	0.6830	0.2155	0.3155	3.170	4
5	0.6209	0.1638	0.2638	3.791	5
6	0.5645	0.1296	0.2296	4.355	6
7	0.5132	0.1054	0.2054	4.868	7
8	0.4665	0.0874	0.1874	5.335	8
9	0.4241	0.0736	0.1736	5.759	9
10	0.3855	0.0628	0.1628	6.144	10
11	0.3505	0.0540	0.1540	6.495	11
12	0.3186	0.0468	0.1468	6.814	12
13	0.2897	0.0408	0.1408	7.103	13
14	0.2633	0.0358	0.1358	7.367	14
15	0.2394	0.0315	0.1315	7.606	15
16	0.2176	0.0278	0.1278	7.824	16
17	0.1978	0.0247	0.1247	8.022	17
18	0.1799	0.0219	0.1219	8.201	18
19	0.1635	0.0196	0.1196	8.365	19
20	0.1486	0.0175	0.1175	8.514	20
21	0.1351	0.0156	0.1156	8.649	21
22	0.1228	0.0140	0.1140	8.772	22
23	0.1117	0.0126	0.1126	8.883	23
24	0.1015	0.0113	0.1113	8.985	24
25	0.0923	0.0102	0.1102	9.077	25
26	0.0839	0.0092	0.1092	9.161	26
27	0.0763	0.0083	0.1083	9.237	27
28	0.0693	0.0075	0.1075	9.307	28
29	0.0630	0.0067	0.1067	9.370	29
30	0.0573	0.0061	0.1061	9.427	30
31	0.0521	0.0055	0.1055	9.479	31
32	0.0474	0.0050	0.1050	9.526	32
33	0.0431	0.0045	0.1045	9.569	33
34	0.0391	0.0041	0.1041	9.609	34
35	0.0356	0.0037	0.1037	9.644	35
40	0.0221	0.0023	0.1023	9.779	40
45	0.0137	0.0014	0.1014	9.863	45
50	0.0085	0.0009	0.1009	9.915	50
55	0.0053	0.0005	0.1005	9.947	55
60	0.0033	0.0003	0.1003	9.967	60
65	0.0020	0.0002	0.1002	9.980	65
70	0.0013	0.0001	0.1001	9.987	70
75	0.0008	0.0001	0.1001	9.992	75
80	0.0005	0.0001	0.1001	9.995	80
85	0.0003	0.0000	0.1000	9.997	85
90	0.0002	0.0000	0.1000	9.998	90
95	0.0001	0.0000	0.1000	9.999	95
100	0.0001	0.0000	0.1000	9.999	100

12% Compound Interest Factors

Service Life n	Present Worth Factor PWF	Sinking Fund Factor SFF	Capital Recovery Factor CRF	Series Present Worth Factor SPW	Service Life n
1	0.8929	1.0000	0.1200	0.893	1
2	0.7972	0.4717	0.5917	1.690	2
3	0.7118	0.2964	0.4164	2.402	3
4	0.6355	0.2092	0.3292	3.037	4
5	0.5674	0.1574	0.2774	3.605	5
6	0.5066	0.1232	0.2432	4.111	6
7	0.4523	0.0991	0.2191	4.564	7
8	0.4039	0.0813	0.2013	4.968	8
9	0.3606	0.0677	0.1877	5.328	9
10	0.3220	0.0570	0.1770	5.650	10
11	0.2875	0.0484	0.1684	5.938	11
12	0.2567	0.0414	0.1614	6.194	12
13	0.2292	0.0357	0.1557	6.424	13
14	0.2046	0.0309	0.1509	6.628	14
15	0.1827	0.0268	0.1468	6.811	15
16	0.1631	0.0234	0.1434	6.974	16
17	0.1456	0.0205	0.1405	7.120	17
18	0.1300	0.0179	0.1379	7.250	18
19	0.1161	0.0158	0.1358	7.366	19
20	0.1037	0.0139	0.1339	7.469	20
21	0.0926	0.0122	0.1322	7.562	21
22	0.0826	0.0108	0.1308	7.645	22
23	0.0738	0.0096	0.1296	7.718	23
24	0.0659	0.0085	0.1285	7.784	24
25	0.0588	0.0075	0.1275	7.843	25
26	0.0525	0.0067	0.1267	7.896	26
27	0.0469	0.0059	0.1259	7.943	27
28	0.0419	0.0052	0.1252	7.984	28
29	0.0374	0.0047	0.1247	8.022	29
30	0.0334	0.0041	0.1241	8.055	30
31	0.0298	0.0037	0.1237	8.085	31
32	0.0266	0.0033	0.1233	8.112	32
33	0.0238	0.0029	0.1229	8.135	33
34	0.0212	0.0026	0.1226	8.157	34
35	0.0189	0.0023	0.1223	8.176	35
40	0.0107	0.0113	0.1213	8.244	40
45	0.0061	0.0007	0.1207	8.283	45
50	0.0035	0.0004	0.1204	8.305	50
∞	-	-	0.1200	8.333	∞

15% Compound Interest Factors

Service Life n	Present Worth Factor PWF	Sinking Fund Factor SFF	Capital Recovery Factor CRF	Series Present Worth Factor SPW	Service Life n
1	0.8696	1.0000	1.1500	0.870	1
2	0.7561	0.4651	0.6151	1.626	2
3	0.6575	0.2880	0.4380	2.283	3
4	0.5718	0.2003	0.3503	2.855	4
5	0.4972	0.1483	0.2983	3.352	5
6	0.4323	0.1142	0.2642	3.784	6
7	0.3759	0.0904	0.2404	4.160	7
8	0.3269	0.0729	0.2229	4.487	8
9	0.2843	0.0596	0.2096	4.772	9
10	0.2472	0.0493	0.1993	5.019	10
11	0.2149	0.0411	0.1911	5.234	11
12	0.1869	0.0345	0.1845	5.421	12
13	0.1625	0.0291	0.1791	5.583	13
14	0.1413	0.0247	0.1747	5.724	14
15	0.1229	0.0210	0.1710	5.847	15
16	0.1069	0.0180	0.1680	5.954	16
17	0.0929	0.0154	0.1654	6.047	17
18	0.0808	0.0132	0.1632	6.128	18
19	0.0703	0.0113	0.1613	6.198	19
20	0.0611	0.0098	0.1598	6.259	20
21	0.0531	0.0084	0.1584	6.312	21
22	0.0462	0.0073	0.1573	6.359	22
23	0.0402	0.0063	0.1563	6.399	23
24	0.0349	0.0054	0.1554	6.434	24
25	0.0304	0.0047	0.1547	6.464	25
26	0.0264	0.0041	0.1541	6.491	26
27	0.0230	0.0035	0.1535	6.314	27
28	0.0200	0.0031	0.1531	6.534	28
29	0.0174	0.0027	0.1527	6.551	29
30	0.0151	0.0023	0.1523	6.566	30
31	0.0131	0.0020	0.1520	6.579	31
32	0.0114	0.0017	0.1517	6.591	32
33	0.0099	0.0015	0.1515	6.600	33
34	0.0086	0.0013	0.1513	6.609	34
35	0.0075	0.0011	0.1511	6.617	35
40	0.0037	0.0006	0.1506	6.642	40
45	0.0019	0.0003	0.1503	6.654	45
50	0.0009	0.0001	0.1501	6.661	50
∞	-	-	0.1500	6.667	∞

20% Compound Interest Factors

Service Life n	Present Worth Factor PWF	Sinking Fund Factor SFF	Capital Recovery Factor CRF	Series Present Worth Factor SPW	Service Life n
1	0.8333	1.0000	1.2000	0.833	1
2	0.6944	0.4546	0.6546	1.528	2
3	0.5787	0.2747	0.4747	2.106	3
4	0.4823	0.1863	0.3863	2.589	4
5	0.4019	0.1344	0.3444	2.991	5
6	0.3349	0.1007	0.3007	3.326	6
7	0.2791	0.0774	0.2774	3.605	7
8	0.2326	0.0606	0.2606	3.837	8
9	0.1938	0.0481	0.2481	4.031	9
10	0.1615	0.0385	0.2385	4.192	10
11	0.1346	0.0311	0.2311	4.327	11
12	0.1122	0.0253	0.2253	4.439	12
13	0.0935	0.0206	0.2206	4.533	13
14	0.0779	0.0169	0.2169	4.611	14
15	0.0649	0.0139	0.2139	4.675	15
16	0.0541	0.0114	0.2114	4.730	16
17	0.0451	0.0094	0.2094	4.775	17
18	0.0376	0.0078	0.2078	4.812	18
19	0.0313	0.0065	0.2065	4.844	19
20	0.0261	0.0054	0.2054	4.870	20
21	0.0217	0.0044	0.2044	4.891	21
22	0.0181	0.0037	0.2037	4.909	22
23	0.0151	0.0031	0.2031	4.925	23
24	0.0126	0.0026	0.2026	4.937	24
25	0.0105	0.0021	0.2021	4.948	25
26	0.0087	0.0018	0.2018	4.956	26
27	0.0073	0.0015	0.2015	4.964	27
28	0.0061	0.0012	0.2012	4.970	28
29	0.0051	0.0010	0.2010	2.975	29
30	0.0042	0.0009	0.2009	4.979	30
31	0.0035	0.0007	0.2007	4.982	31
32	0.0029	0.0006	0.2006	4.985	32
33	0.0024	0.0005	0.2005	4.988	33
34	0.0020	0.0004	0.2004	4.990	34
35	0.0017	0.0003	0.2003	4.992	35
40	0.0007	0.0001	0.2001	4.997	40
45	0.0003	0.0001	0.2001	4.999	45
50	0.0001	0.0000	0.2000	4.999	50
∞	-	-	0.2000	5.000	∞

25 Percent Compound Interest Factors

Service Life n	Present Worth Factor PWF	Sinking Fund Factor SFF	Capital Recovery Factor CRF	Series Present Worth Factor SPW	Service Life n
1	0.8000	1.0000	1.2500	1.0000	1
2	0.6400	0.4444	0.6944	1.4400	2
3	0.5120	0.2623	0.5123	1.9520	3
4	0.4096	0.1734	0.4234	2.3616	4
5	0.3277	0.1218	0.3718	2.6893	5
6	0.2621	0.0888	0.3388	2.9514	6
7	0.2097	0.0663	0.3163	3.1611	7
8	0.1678	0.0504	0.3004	3.3289	8
9	0.1342	0.0387	0.2887	3.4631	9
10	0.1074	0.0301	0.2801	3.5705	10
11	0.8590	0.0235	0.2735	3.6564	11
12	0.0687	0.0184	0.2684	3.7251	12
13	0.0550	0.0145	0.2645	3.7801	13
14	0.0440	0.0115	0.2615	3.8241	14
15	0.0352	0.0091	0.2591	3.8593	15
16	0.0281	0.0072	0.2572	3.8874	16
17	0.0225	0.0057	0.2557	3.9099	17
18	0.0180	0.0046	0.2546	3.9279	18
19	0.0144	0.0037	0.2537	3.9424	19
20	0.0115	0.0029	0.2529	3.9539	20
21	0.0092	0.0023	0.2523	3.9631	21
22	0.0074	0.0019	0.2519	3.9705	22
23	0.0059	0.0015	0.2515	3.9764	23
24	0.0047	0.0012	0.2512	3.9811	24
25	0.0038	0.0009	0.2509	3.9849	25
26	0.0030	0.0008	0.2508	3.9879	26
27	0.0024	0.0006	0.2506	3.9903	27
28	0.0019	0.0005	0.2505	3.9923	28
29	0.0015	0.0004	0.2504	3.9939	29
30	0.0012	0.0003	0.2503	3.9951	30
31	0.0010	0.0002	0.2502	3.9960	31
32	0.0008	0.0002	0.2502	3.9968	32
33	0.0006	0.0002	0.2502	3.9975	33
34	0.0005	0.0001	0.2501	3.9980	34
35	0.0004	0.0001	0.2501	3.9984	35

30 Percent Compound Interest Factors

Service Life n	Present Worth Factor PWF	Sinking Fund Factor SFF	Capital Recovery Factor CRF	Series Present Worth Factor SPW	Service Life n
1	0.7692	1.0000	1.3000	0.7692	1
2	0.5917	0.4348	0.7348	1.3609	2
3	0.4552	0.2506	0.5506	1.8161	3
4	0.3501	0.1616	0.4616	2.1662	4
5	0.2693	0.1106	0.4106	2.4356	5
6	0.2072	0.0784	0.3784	2.6427	6
7	0.1594	0.0569	0.3569	2.8021	7
8	0.1226	0.0419	0.3419	2.9247	8
9	0.0943	0.0312	0.3312	3.0190	9
10	0.0725	0.0235	0.3235	3.0915	10
11	0.0558	0.0177	0.3177	3.1473	11
12	0.0429	0.0135	0.3135	3.1903	12
13	0.0330	0.0102	0.3102	3.2233	13
14	0.0254	0.0078	0.3078	3.2487	14
15	0.0195	0.0060	0.3060	3.2682	15
16	0.0150	0.0046	0.3046	3.2832	16
17	0.0116	0.0035	0.3035	3.2948	17
18	0.0089	0.0027	0.3027	3.3037	18
19	0.0068	0.0021	0.3021	3.3105	19
20	0.0053	0.0016	0.3016	3.3158	20
21	0.0040	0.0012	0.3012	3.3198	21
22	0.0031	0.0009	0.3009	3.3230	22
23	0.0024	0.0007	0.3007	3.3254	23
24	0.0018	0.0006	0.3006	3.3272	24
25	0.0014	0.0004	0.3004	3.3286	25
26	0.0011	0.0003	0.3003	3.3297	26
27	0.0008	0.0003	0.3003	3.3305	27
28	0.0006	0.0002	0.3002	3.3312	28
29	0.0005	0.0002	0.3002	3.3317	29
30	0.0004	0.0001	0.3001	3.3321	30
31	0.0003	0.0001	0.3001	3.3324	31
32	0.0002	0.0001	0.0001	3.3326	32
33	0.0002	0.0001	0.0001	3.3328	33
34	0.0001	0.0000	0.3000	3.3329	34
35	0.0001	0.0000	0.3000	3.3330	35
∞	0.0000	0.0000	0.3000	3.3333	∞

APPENDIX E

Improvement Service Lives

Improvement	Service Life, Years
Illumination	15[1], 20[3], 10[2]
Delineation	
Paint	2[1], 2[2]
Reflectorized	5[1], 5[2], 4[3]
Signs	
Major	10[1], 10[2], 10[3]
Minor	5[1], 5[2], 4[3]
Signals	15[1], 10[2], 10[3]
Flashing Beacon	10[1]
Guard Rail	10[1], 10[3]
Pavement Grooving	5[1], 20[3]
Channelization	
Curbed	20[1]
Painted	10[1], 10[2], 10[3]
Pavement Widening	20[3]
Flashing Lights at Railroad Crossing	10[3]
Automatic Gates at Railroad Crossing	10[3]
Replace Bridge	30[3]
Widen Bridge	20[3]

Sources:
1: 27
2: 33
3: 44