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ROADSIDE SAFETY IMPROVEMENTS

by

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INTRODUCTION

Single vehicle accidents account for about 50 percent of fatal accidents and approximately 40 percent of all accidents on freeways. Certain elements of roadside design are heavy contributors to single vehicle accidents. Bridge abutments and piers, bridgerails, signposts, luminaire supports, utility poles, trees, drainage structures, steep side slopes and guardrails are the heaviest contributors. The influence of roadside design is, therefore, an important safety consideration.

Roadside safety improvements were largely ignored until the early 1960's. Fatality rates rose to over 50,000 people a year before Congress recognized a state of emergency. In 1966 Congress passed the Highway Safety Acts, at last recognizing the need for uniform national policy for roadside safety. Also in 1966, the Special Traffic Safety Committee of the American Association of State Highway Officials (AASHO) conducted a nationwide survey of highways, studying the effects of design and operational practices in relation to safety. The reports were published under the title "Highway Design and Operational Practices Related to Highway Safety," in February of 1967 after approval of the AASHO Executive Committee. Commonly known as the "Yellow Book", the AASHO report was composed of discussion, comments and recommendations of the committee about various aspects of design and practices

related to safety on roads and streets under local and state transportation department control. Yellow Book concepts were endorsed by the Federal Highway Administration and it became policy to incorporate provisions of the report in the plans for all projects of high-speed facilities (design speeds of 50 MPH or more). It was also recommended that information from the report be utilized on primary and secondary projects with lower design speeds. The Federal Highway Administration then asked state and local agencies to apply "Yellow Book" standards in a corrective program to Federal-aid-projects already completed.

Further impetus was given to the safety movement with the adoption of the Highway Safety Program Standards which were a direct result of the Highway Safety Act of 1966. HSPS 9, "Identification and Surveillance of Accident Locations," HSPS 12, "Highway Design, Construction, and Maintenance," and HSPS 13, "Traffic Engineering Services," all require establishment of programs based on the "Yellow Book" principles.

The Congress of the United States has taken a more active interest in roadside safety recently. A series of hearings by subcommittees of the House Committee on Public Works dealing with highway safety, design, and operations dealt with the question of responsibility. In "The Need For a Safer Driving Environment" (93rd Congress, 1st session, Committee Print 93-7), the committee states;

> "On this the committee is adamant. It is the responsibility of Government and specifically those

agencies that, by law, have been given that mandate. This responsibility begins with Congress and flows through the Department of Transportation, its Federal Highway Administration, the State highway departments and safety agencies, and the street and highway units of counties, townships, cities, and towns. There is no retreating from this mandate, either in letter or in spirit."

The Federal-Aid Highway Act of 1973 shows Congressional concern is still strong. The act contains several specific authorizations for safety programs. In addition to Federal-Aid Systems programs, there are for the first time, programs to use federal funds for non Federal-Aid system projects in the area of construction improvement of the driving environment.

It is obvious that federal funding of highway projects is a major factor in the reduction of roadside hazards. The 1972 Highway Needs Study of the Department of Transportation showed that over 600 billion dollars would be needed in the period up to 1990. Of this, $560 billion would be spent for highways and bridges, $19 billion for urban highways, and $32 billion for the completion of the Interstate System.

In 1973 before the Congressional Public Works Committee, AASHTO (formerly AASHO) recommended a 50 percent funding of the improvements recommended by the Needs Study. Since financial resources are not unlimited, all the projected needs could not realistically be met. It was felt that the

50 percent level would allow for the correction of many narrow bridges, substandard roadway sections, and roadside hazards, as well as other deficiencies.

PROGRESS

In the past only a minimal effort was made to improve the roadside for safety. It was felt by many highway designers that each roadway user must "drive at his own risk," accepting the consequences of allowing his vehicle to leave the roadway for any reason. As single vehicle accidents became more numerous, the driver leaving the roadway became a more important design consideration. Eventually the concept of roadside safety improvement evolved.

One of the first significant attempts at improved safety was the installation of guardrail. Miles of guardrail were installed where other improvements such as shoulder grading would have been safer or where no improvement was necessary to begin with. Rather than increasing safety, many lives were lost in guardrail accidents.

In 1966 the first objective criteria for guardrail installation were developed. The relative safety of guardrail was compared to various combinations of embankment variables in a mathematical model. Comparative severity indices were developed from sample embankment and guardrail accidents.

In 1966 a study by Hutchinson and Kennedy uncovered the basic nature of single vehicle accidents and roadside encroachments.(12) They studied the following relationships;

1. The frequency of roadside encroachments as a

function of traffic volume.

2. The distribution of encroachment angles.
3. The distribution of lateral displacements of encroaching vehicles.

It was this study that led to the adoption of a 30 foot clear zone concept because of the evidence that very few encroachments exceeded 30 feet from the edge of pavement.

New construction since 1967 has incorporated many of the "Yellow Book" principles. Various state improvement programs and the Highway Safety Improvement Program have helped to upgrade existing facilities. Safety improvements in urban areas have been aided as a result of the TOPICS (Traffic Operations Program to Increase Capacity and Safety) programs. General upgrading of signs, signals, and markings and increased uniformity is a result of the 1971 revision of "The Manual on Uniform Traffic Control Devices." Total progress since 1967 has been substantial even though less than optimal. Most significant, however, is the increased attention focused on highway design and operations by government.

Some state agencies have already funded programs to reduce roadside hazards on existing facilities. All have followed the same basic four step procedure.

1. Remove the obstacles.
2. Move obstacles which cannot be removed completely to a more protected location.
3. Reduce impact severity of obstacles which cannot

be moved. (Includes devices such break-away signs and the flattening of slopes.)

4. Protect the driver from obstacles which cannot otherwise be improved with some type of impact attenuation device.

COST EFFECTIVENESS ANALYSIS

The recent increase in interest in safety related roadside improvements has prompted a wide variety of improvement programs. Since the funds for roadside safety are generally limited, there is serious debate on the scope and effectiveness of various programs. Principally the question seems to be whether one or two major improvements is of more benefit than a larger number of minor improvement alternatives.

The principal use of a cost-effectiveness (C/E) analysis is the scheduling of improvements in order to obtain the greatest safety payoff from the funds expended. It is also possible to use the C/E model in design considerations. For example, would it be cost-effective to extend box culvert wing walls beyond the traveled way or protect the wing walls with guardrail?

Although the mathematical computation of cost-effectiveness can be complex, the basic concepts are easily understood. In a cost-effectiveness analysis, the cost of hazard improvement is compared to the degree of reduction of hazard from the original conditions. Though somewhat simplified, cost-effectiveness may be expressed in the following way;

$$C/E = \frac{\text{cost of improvement}}{\text{hazard reduction}}$$

where---

C/E = cost to reduce one injury (either fatal or non-fatal) accident.

cost = annualized cost of improvement alternative

hazard reduction = difference of hazard reduction before and after improvement

The cost of improvement is actually composed of three cost elements;

1. the uniform annual cost of improvement
2. the difference in uniform annual maintenance costs between the improved and pre-existing conditions
3. the difference in uniform annual cost of repair following each accident

Since the different cost elements are incurred over a variable period of time, it is necessary to convert the dollar values to a common base. The Texas cost-effectiveness model (4), for example, utilizes a 20 year service life and interest rate of 6 percent to compute annualized costs.

The hazard index is a function of three variables;

A = the probability of an object being struck given that a vehicle does encroach

B = the probability of encroachment for the particular traffic volume observed

C = the severity of the accident if a collision does occur

the hazard index would then have the following relationship;

Hazard Index (H.I.) = A x B x C

The probability of encroachment, B, is a function of the length of exposure and environmental variables such as geometric design. The variation of encroachment with traffic volume as reported by Hutchinson and Kennedy (12) can be

seen in figure 1.

The probability of a collision given that an encroachment occurs, A, is a function of four variables. The variables are the angle of encroachment, the vehicle's lateral displacement, the lateral displacement of the hazard, and the size of the hazard. The area described is often referred to as the "Hazard Envelope" and its general configuration can be seen in figure 2.

The computational form used by Glennon and Wilton (5) for determining the hazard index is shown below. The elements of the equation can be seen in figure 2.

$$H.I. = \frac{E_f S}{5280}\left[l\int_{s}^{\infty} f(y)\,dy + \int_{1}^{1+d\csc\theta}\int_{s+(x-1)\cos\theta\sin\theta}^{\infty} f(y)\,dy\,dx + \int_{1+d\csc\theta}^{1+d\csc\theta+w\cot\theta}\int_{s+d\cos\theta+(x-1-d\sec\theta)\tan\theta}^{\infty} f(y)\,dy\,dx\right]$$

where

E_f = encroachment frequency, number of encroachments per mile per year;

S = severity index, number of fatal and nonfatal injury accidents per total accidents;

l = longitudinal length of obstacle, in feet;

w = lateral width of obstacle, in feet;

s = lateral placement of obstacle, in feet;

d = width of vehicle, in feet;

θ = angle of encroachment, in degrees;

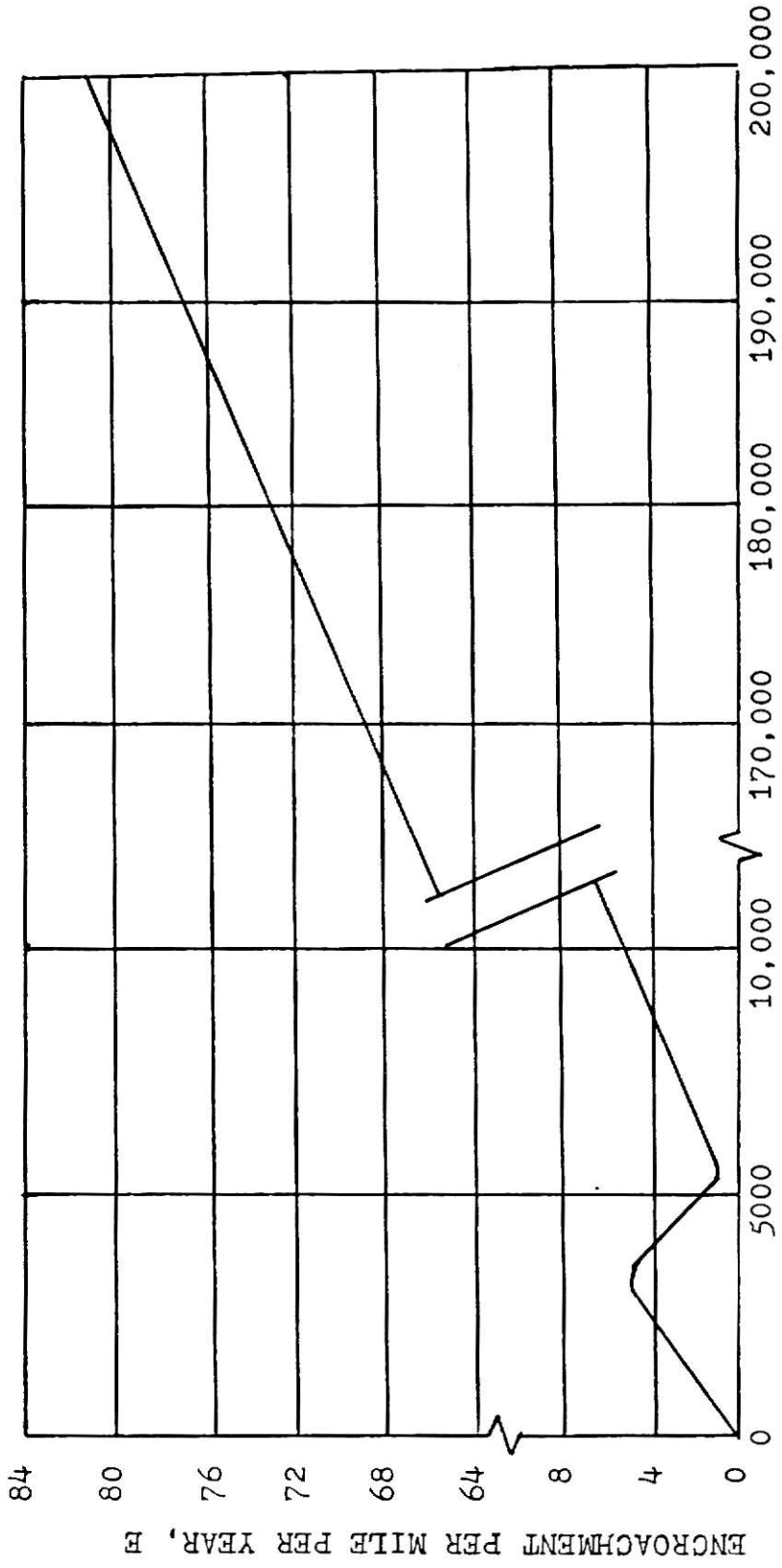

Figure 1 - Roadside Encroachment Frequency (12)

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

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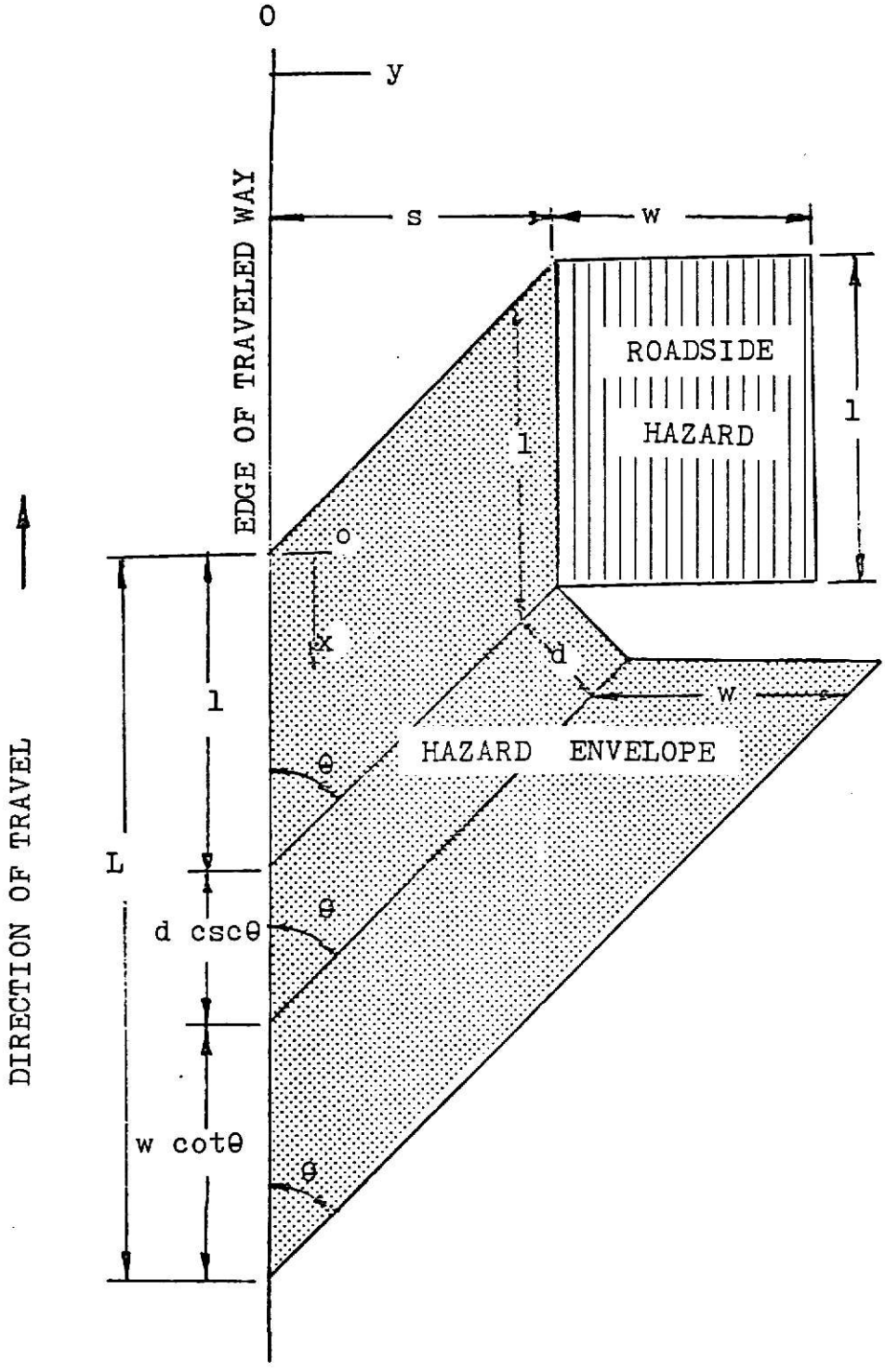


Figure 2 - Schematic Illustration of Roadside Obstacle and its Relationship to an Encroaching Vehicle (12)

x = longitudinal distance from the farthest downstream encroachment point to the encroachment point of reference, in feet;

$f(y)$ = percentile distribution of lateral displacements of encroaching vehicles.

In the above equation multiplying each element in the brackets by $E_f S / 5280$ yields the number of fatal and nonfatal injury accidents per year expected for each subdivision of the hazard envelope. The first integral within the brackets represents "hits" by the right front of the encroaching vehicles and is associated with the exposure length l, and the probability of a vehicle lateral displacement greater than s. The second expression in the brackets is associated with exposure length d csc θ, and represents hits with the entire front of the vehicle. The third integral within the brackets represents hits with the left front of the vehicle and is associated with exposure length w cot θ. The double integration of the second and third expressions is necessary because of the varying lateral displacements required for collision.

The size and shape of the hazard envelope varies greatly with the angle of encroachment and the nature of the hazard. For small angles of encroachment, the envelope is quite large, and for angles approaching 90 degrees, the envelope becomes smaller. In all cases the path of encroaching vehicles is assumed to be straight. Although the assumption is not always valid, the model is thought to be an accurate representation of the over-all situation.

The severity indices, are usually a function of the

goals of the particular improvement program and normally are average values for total fatalities, total injuries, or property damage. Higher numbers are assigned to the more serious accidents. Serious accidents resulting in one or more deaths would be assigned a value close to 10. Minor accidents would be assigned values close to 1.

The cost-effectiveness value is expressed in annualized dollars necessary to prevent one fatal or serious injury accident. As the cost of an improvement becomes larger the the desirability of the alternative decreases, and as the difference in hazard indices increases, the alternative becomes more desirable. Therefore, the smaller the C/E value, the more desirable is the alternative. Any limiting values applied to the C/E value are arbitrary values selected by the user of the model.

It is possible for the C/E ratio to have a negative value. In this case, two possibilities exist. In the first case, where the numerator of the C/E value is negative, the negative value means that the cost of improvement is less than making no improvement. In this situation the improvement ranks higher than any positive C/E values and, in general, the greater the magnitude of the negative value, the higher the priority.

In the second case, when the denominator is negative, the hazard index of the improvement is greater than the index of the original situation. This often occurs when guardrail is installed to protect a small culvert. Negative C/E values of this sort mean the improvement is not cost-effective.

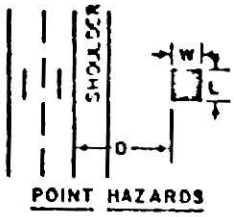
THE INVENTORY

Any cost-effectiveness model requires a detailed roadside hazard inventory. Both primary and secondary recovery areas are normally inventoried, thereby benefitting approximately 85 percent (9) of the drivers encroaching the roadway. This includes all hazards within the 30 foot lateral distance from the outer edge of the roadway. Break away sign supports and luminaires are normally excluded from the inventory as damage caused by striking them is usually negligible and it is not likely that they can be improved beyond their present state. Roadside obstacles used for operational control, such as median barriers, are not inventoried since their removal would cause a greater hazard to exist. Other "necessary" hazards such as retaining walls, are also excluded.

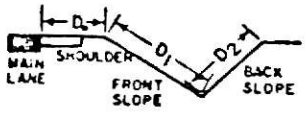
The most important aspect in the inventory process is the uniformity of hazard identification. Those hazards which are to be included in a program are usually assigned an input coding system such as the one used by Texas Transportation Institute (TTI) illustrated in figure 3 (9). The hazards are grouped under a general descriptive title and, where necessary, are broken down into sub-classifications, each with its own code. This procedure permits greater flexibility since it allows for additional categories and subdivisions as "new hazards" or "unusual hazards" are encountered in the inventory.

Since there are a large number of hazards along any

IDENTIFICATION CODE		DESCRIPTOR CODES
01	Utility Poles	(00)
02	Trees	(00)
03	Rigid Signpost	(01) single-pole-mounted (02) double-pole-mounted (03) triple-pole-mounted (04) cantilever support (05) overhead sign bridge
04	Rigid Base Luminaire Support	(00)
05.	Curbs	(01) mountable design (02) non-mountable design less than 10 inches high (03) barrier design greater than 10 inches high
06.	Guardrail or Median Barrier	(01) w-section with standard post spacing (6 ft-3 in.) (02) w-section with other than standard post spacing (03) approach guardrail to bridge--decreased post spacing (3 ft-1 in.) adjacent to bridge (04) approach guardrail to bridge--post spacing not decreased adjacent to bridge (05) post and cable (06) median fence (07) median barrier (CMB design or equivalent)
07.	Roadside Slope	(01) sod cut slope (02) sod fill slope (03) concrete-faced cut slope (04) concrete-faced fill slope (05) rubble rip-rap cut slope (06) rubble rip-rap fill slope
08.	Washout Ditch (Does not include ditch formed by intersection of front and back slopes)	(00)
09	Culverts	(01) headwall (or exposed end of pipe culvert) (02) gap between culverts on parallel roadways (03) sloped culvert with grate (04) sloped culvert without grate
10	Inlets	(01) raised drop inlet (tabletop) (02) depressed drop inlet (03) sloped inlet
11.	Roadway Under Bridge Structure	01 bridge piers (02) bridge abutments
12.	Roadway Over Bridge Structure	01 open gap between parallel bridges (02) closed gap between parallel bridges (03) rigid bridgerail--smooth and continuous construction (04) semi-rigid bridgerail--smooth and continuous construction (05) other bridgerail--penetration likely; severe snagging likely; severe pocketing and snagging likely; or, vaulting likely (06) elevated gore abutment
13.	Retaining Wall	(00)



POINT HAZARDS



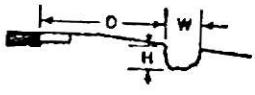


Figure 3 (9)

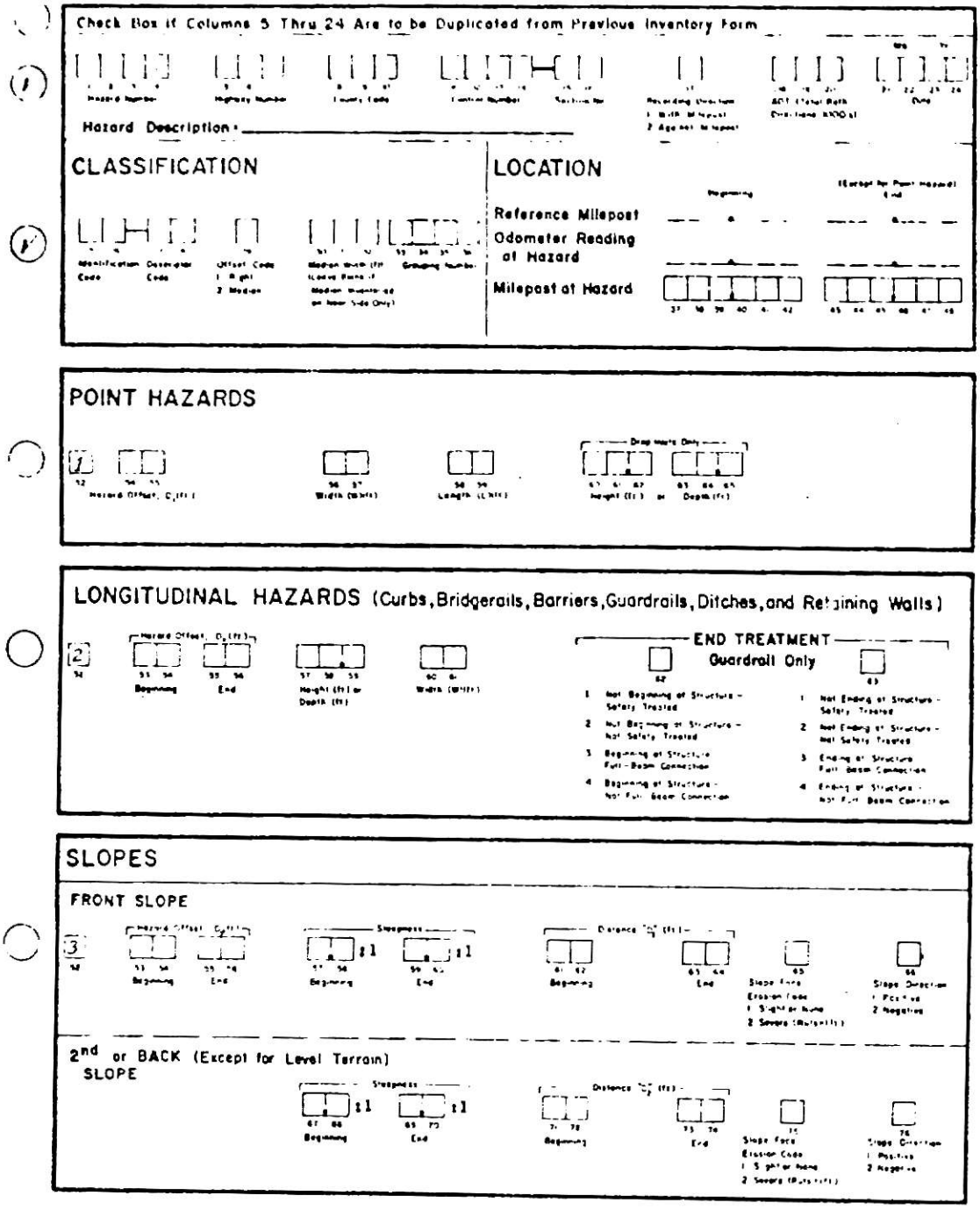
given section of roadway it is necessary to use a systematic coding procedure that can be easily analyzed by computer. The form used by T.T.I. (9) can be seen in figure 4. Box 1 contains specific hazard identification information including highway type, highway number, mile-post location and other general information needed for computer operation. Hazards are classified in three groups: point hazards, box 2; longitudinal hazards, box 3; and slopes, box 4. Box 1 must be completed on each form, and one only of boxes 2, 3, or 4. Each box is subscripted with the computer card column number in which the information will be key-punched. Box 1 also contains hazard classification and location information. Location information includes highway number, county, control number and section. All are standard highway department designations already in use. Recording direction, average daily traffic (ADT) and date are also required and easily obtained. The classification section of Box 1 contains the identification and description codes which are representative of the various possible hazards. Offset code, either right or median, median width, and grouping number are also included. Location information section of Box 1 consists of reference mile-post, odometer reading at hazard and mile-post at hazard.

Box 2 is completed for point hazards only. Required information includes hazard offset, in feet; width, also in feet; and length, again measured in feet. If the point hazard is a drop inlet, height and depth must also be recorded.

Box 3 is completed for longitudinal hazards such as

ROADSIDE HAZARD INVENTORY

Inventory Conducted by _____ Page _____ of _____



Recommendations: _____

Roadside Hazard Inventory Form

Figure 4 (9)

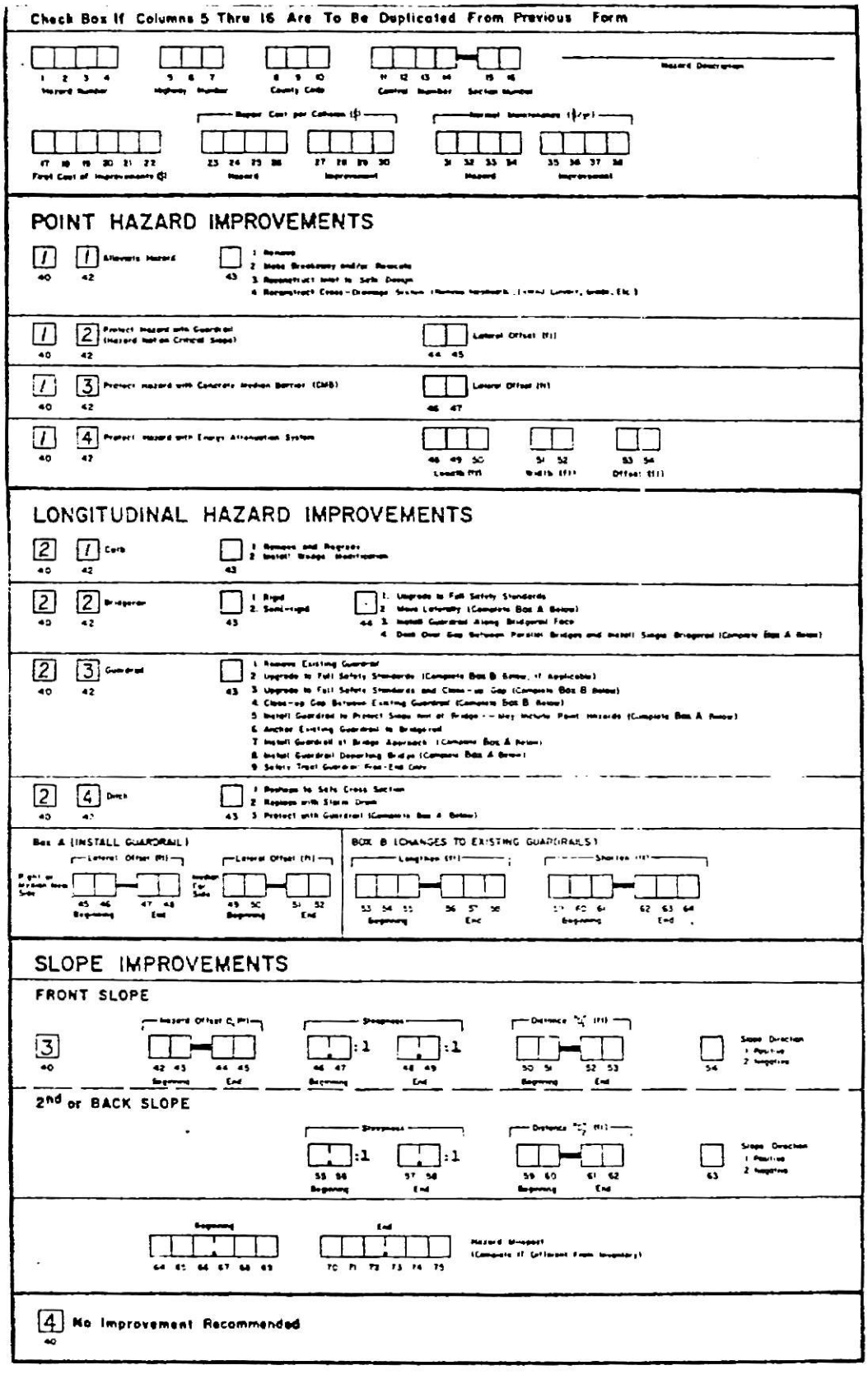
curbs, bridgerails, guardrails, ditches and retaining walls. Necessary information includes hazard offset at both ends of the hazard. For hazards parallel to the roadway, the offsets would be equal. The height or depth of hazard, whichever is appropriate, and the width must also be recorded. If the hazard is guardrail, a section for end-treatment must also be filled in.

Box 4 is the inventory form for slope hazards. Necessary information includes the offset from the edge of roadway both at the beginning and end of the hazard. The slope or steepness must be estimated and expressed as a ratio to 1. The steepness is recorded at both the beginning and end of the hazard. The length of the slope from the hinge to the toe is required at the ends of the hazard. An erosion code is also included (code 1 indicates no or slight erosion, code 2 indicates severe ruts) and can be determined by sight as well as the slope direction (positive or negative). If there is a backslope, the same information must be recorded for it.

In addition to the roadside hazard inventory form, it is also necessary to complete a hazard improvement form for each hazard. The format of the form is similar to the hazard inventory form, and consists of five information boxes. Figure 5 shows the form used by the TTI programs (9).

Box 1 contains cost information related to hazard improvement. Im all cases the costs are those which will be borne by the highway department and do not include vehicle damage or personal injury costs resulting from accidents. Coded information in box 1 consists of the same hazard

ROADSIDE HAZARD IMPROVEMENTS



Roadside Hazard Improvement Form

Figure 5 (9)

number, highway number, county code and control and section numbers as the hazard inventory form. Also coded are: first cost of improvement, the initial lump sum for incorporating the improvement; repair cost per collision, an estimated dollar value; and normal maintenance costs.

Box 2 is completed for point hazards only. Four alternatives are possible for improvements; alleviate the hazard, protect it with guardrail, protect it with a concrete median barrier, protect it with energy attentuation device. For the second and third cases it is necessary to know the lateral offset. For the last case it is necessary to know the length and width of improvement as well as the offset.

Box 3 is computed for longitudinal hazards only. Separate improvement choices are listed for curb, bridgerail, guardrail, and ditch hazards. Each possible improvement is number coded and listed on the improvement form. If it is necessary to install or alter guardrail, the lateral offsets and lengths must be recorded in boxes A and B.

Box 4 is coded only for slope improvements. Information is recorded for both the front slope and back slope. It is necessary to record roughly the same information as for the hazard inventory; offset, steepness and distance. In the case of improvements, these distances can be estimated.

Box 5 is completed if no improvement is recommended.

CONDUCTING THE INVENTORY

Recommendations for hazard improvements can greatly affect the results of the cost-effectiveness analysis. It is therefore necessary that the inventory team include those having extensive experience in geometric design, maintenance, traffic operations, and construction costs. Texas Transportation Institute tests (9) have found that a four person team consisting of a driver, a data recorder and two decision makers is the most effecient combinations. With the four man team, it is the driver's responsibility to identify each hazard, stop the vehicle alongside it and read the odometer. The recorder, who should be familiar with the data form and and the various codes, fills out the necessary forms. At the same time, the two decision makers evaluate the improvement situation and select the improvement to be used.

PHOTOLOGGING

Another method for conducting a hazard inventory is photologging. Photologging is the process of taking uniformly spaced photographs of the roadway and surrounding area. When done properly, the photographs clearly show the condition of the roadway surface and shoulders, slopes, side ditches and drainage channels as well as signs, guardrails and any adjacent apurtenances. Any hazard to be included in an inventory can be identified in properly spaced photographs. The only other necessity is that dimensions and distances also be obtainable from the photographic record.

A paper, entitled "Photologging to Obtain Dimensions" (8) by William Pryor, sets forth the procedure for obtaining desired dimensions from the photographic record. The basic principle behind the process is if A and B are two dimensions in a photographic plane perpendicular to the camera axis, then their relationship to the dimensions of their images is given by;

$$\frac{A}{B} = \frac{a}{b}$$

Therefore if any one dimension in the perpendicular plane is known, the other dimension can be computed if the size of the image is measured. Computations made in this fashion are independent of camera focal length, magnitude of photograph enlargement and units of measurements on the photograph.

There are several methods of establishing a known dimension. The easiest is simply to use pavement width,

median width or some dimension which is usually known. It is also possible to use the height of the camera above plane pavement. When photologging a highway with no vertical curvature, the "image" of camera height is the distance from the photograph vanishing point to any plane of interest. Comparing the image height to that of the camera at the time the log was made yields the ratio of other dimensions in the same plane. It is also possible to use the camera height above a pavement with vertical curvature or above any other surface using the method suggested by Pryor (8).

It has been suggested that it might be possible to project the photographs onto a grid in order to directly estimate dimensions. This would eliminate the more time consuming method of mathematical computations.

It is obvious that since dimensions and distances are obtainable using photologging, the process is a viable one for conducting a hazard inventory. The process also has certain advantages that other inventory procedures do not have.

First, photologging provides a permanent visual record of the roadway and its elements. This record can therefore be referred to at any time. Moreover, the person reviewing the photograph sees exactly what the inventory personnel saw, not merely a written record.

Secondly, the photologging process can be used for other purposes without modification. The same photograph can be used to determine sufficiency ratings and for evaluating design alternatives.

Thirdly, the photologging process for hazard inventory allows greater flexibility of personnel. The actual photologging can be done by a smaller crew of specialized people as weather permits, with hazard inventory being done in the office as engineering personnel are available. This provides for best use of personnel and allows inventory to be conducted when free time becomes available.

SUMMARY

It is apparent that public opinion strongly favors roadside safety improvements and that Congress, reflecting that opinion, is willing to take the steps necessary to accomplish that end. It is also apparent that the Cost-effectiveness analysis is a workable method for establishing improvement priorities and determining the best use of limited funds. The main question remaining then is how best to conduct a hazard inventory. Considering the available alternatives, photologging emerges as the most promising option.

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Department of Civil Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1975

ABSTRACT

With current Congressional emphasis on roadside safety, various highway departments have instituted programs to improve the roadside environment. Engineers and administrators who must make policy decisions involving improvement programs are subject to various constraints. Limited funds is generally the principal constraint. If funds were not limited, it would be possible to free the roadside of most hazards and protect the driver from those hazards that are not moveable. With the ever increasing costs of construction and spiraling inflation rates, it is unrealistic to plan for unlimited funds. Therefore, it is necessary to obtain maximum benefit from the funds available.

The cost-effectiveness analysis provides for the comparison of improvement alternatives on a common basis. Using the approach, a decision maker may choose the best of two alternatives or establish a priority list among numerous alternatives.

Several computer models have been created to evaluate the effectiveness of roadside improvements. The elements considered in the model include encroachment frequencies, lateral displacement of encroaching vehicles, the placement of the roadside obstacle, the size of the roadside obstacle, and the accident severity characteristic of the obstacle.

The cost-effectiveness model requires a detailed hazard inventory and a hazard improvement plan. The inventory requires basic information such as highway number, route

number, milepost, and control section number. Detailed information such as the type of hazard and its dimensions and location are also required. Distances need not be exact and may be estimated by crew personnel without leaving the survey vehicle.

Photologging is a promising new technique which may have practical application in the hazard inventory. It is possible to obtain dimensions and distances from the photographic record which are accurate enough for the cost-effectiveness model. Such measurements may be calculated from geometrics or measured directly from the photograph using a projector and grid system. Use of photologging could provide greater flexibility of personnel while providing a permanent photographic record for future reference.