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16. Abstract

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IMPROVED SAFETY INDICES FOR PRIORITIZING BRIDGE PROJECTS

by

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Research Report 439-2

Strategies for Bridge Replacement
Research Project 3-5-86-439

conducted for

Texas State Department of Highways
and Public Transportation

in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

by the

Center for Transportation Research
Bureau of Engineering Research
The University of Texas at Austin

January 1987

PREFACE

This report summarizes work to date on Research Project 3-5-86-439, "Strategies for Bridge Replacement." Significant progress has been made toward an improved bridge project prioritization procedure with the development of the safety indices presented in this report. Relevant background material is included in the text and the appendices. This report may be considered partial fulfillment of the complete research necessary to develop a practical and consistent bridge replacement strategy.

The authors are grateful to Ralph Banks of the Texas State Department of Highways and Public Transportation for his assistance to date. Many other SDHPT employees have been helpful, including Paul Ysaguirre, Cindy Knox, and Brenda Kalapach. The authors would like to acknowledge the assistance of the staff at the Center for Transportation Research during the course of the research. Tony Tascione, Lyn Gabbert, and Rachel Hinshaw were particularly helpful in the preparation of this report.

LIST OF REPORTS

Report No. 439-1, "Improvements in On-System Bridge Project Prioritization," by Chris Boyce, W. R. Hudson, and Ned H. Burns, presents a computerized procedure for prioritizing bridge replacements and rehabilitations. Background information and directions for further research are included.

Report No. 439-2, "Improved Safety Indices for Prioritizing Bridge Projects," by Chris Boyce, W. R. Hudson, and Ned H. Burns, presents two indices useful in bridge project prioritization procedures. A Structural Safety Index and a Geometric Safety Index are documented. Background information on the nature of bridge project prioritization procedures is presented, as is a chronological history of federal legislation concerning federal funding of bridge projects. A discussion of current prioritization procedures, including the federal Sufficiency Rating, is included.

ABSTRACT

This report introduces the Structural Safety Index and the Geometric Safety Index. Both of these indices represent improvements that could be made to to the current procedure used by the State Department of Highways and Public Transportation to select and/or prioritize bridge projects·for rehabilitation and replacement. It is also shown in this report where these indices fit into the developed Computerized Bridge Project Selection Program. Background information is provided on the condition of bridges in Texas and nationwide. Current selection and prioritization methods are reviewed and the federal Sufficiency Rating is critiqued. The Structural Safety Index is implemented using information contained in the guidelines for determining condition ratings. The Geometric Safety Index is implemented using Texas accident data for 1985. Examples are used to illustrate calculation of the indices. Methods for using the indices are presented and illustrated with an example. Directions for future research are included.

SUMMARY

This report presents methods for evaluating the structural and geometric levels of safety for highway bridges. These methods are seen as steps toward a rational bridge prioritization procedure. The research was sponsored by the Texas State Department of Highways and Public Transportation as Research Project 3-5-86-439.

Budget restrictions force decision makers to prioritize bridge replacement and rehabilitation projects. Decisions are often made based on limited inspection data and without first-hand knowledge of each bridge in question. Improvements to Texas' current bridge project prioritization process are presented in this report. The discussion is as general as possible to make it possible for other states to use the methods developed.

Replacing and rehabilitating bridges generally increases the safety provided to bridge users. Increases in safety are measured using two indices developed in this report. One index, the Structural Safety Index (SSI), quantifies the level of deterioration of bridges. The other index, the Geometric Safety Index (GSI), quantifies the geometric character of bridges. These indices are cast in similar forms and may be combined. The indices and their combination may be used as part of a bridge project prioritization program. Other indicators of the level of service of a proposed project, and a structure's essentiality must also be in the prioritization procedure.

This report briefly examines the problem of prioritizing bridge projects for rehabilitation and replacement. Background information is provided on the nature of the problem and on selected bridge project prioritization schemes. Appendices to the report contain additional background information previously unavailable within one volume.

A rational, understandable, and implementable method is urgently needed for prioritizing bridge projects for replacement and rehabilitation. Though optimization programs may require better data than those currently available, existing data can be used to produce prioritization procedures significantly better than current methods. Many bridges in the United States are for various reasons nearing the ends of their useful lives. Immediately implementable improvements are presented in this report.

Bridge safety is examined from structural and geometric points of view. An index for structural safety and another for geometric safety are presented, and these are put into common units so they may be readily manipulated. The indices may be used to predict post-

project safety levels, allowing decision makers to compare proposed bridge projects in terms of relative safety gains.

Methods for using the Structural Safety Index and Geometric Safety Index are outlined and explained. These indices may be used as safety indicators in any bridge project prioritization procedure. The indices may be especially valuable when used in a computerized bridge project prioritization program such as TEBS1 (Texas Eligible Bridge Sorter version 1).

The report does not offer a complete bridge project prioritization procedure. Such a procedure requires, as mentioned above, consideration of the essentiality of a bridge and the level of service it provides to its users. Essentiality and level of service are not explicitly addressed herein. The Structural Safety Index and Geometric Safety Index should be used as components in more comprehensive bridge project prioritization procedures.

IMPLEMENTATION STATEMENT

We recommend that the safety indices presented in this report be used along with, or in place of current the indicators of structural and geometric safety of bridges. The safety indices have the potential to significantly improve TEBS1 (Texas Eligible Bridge Sorter Version 1).

We also recommend that the federal Sufficiency Rating not be used as the only element of Texas' prioritization procedure.

The BRINSAP data file contains many coded data items. Improperly coded data, if it exists, hinders computer program development and implementation efforts. We recommend that the BRINSAP database be reviewed for improperly coded data, in order to ensure the intended results of these computerized processes.

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CHAPTER 1. BACKGROUND INFORMATION

INTRODUCTION

Bridges are vital links in the American system of highways and roads. Loss of a single bridge can negatively affect convenience, trade, public safety, and national defense. This country currently has over half a million bridges, according to the Department of Transportation's National Bridge Inventory (NBI). Data for the inventory are collected by each state and maintained by the Federal Highway Administration (FHWA). Nearly 40 percent of America's bridges are deficient enough that the Federal Highway Administration (FHWA) provides funds to help states rehabilitate and replace them. Though nearly $12 billion in federal bridge project funds have been authorized since 1972 (Ref 1, p 15), many bridges remain deficient. (A summary of bridge deficiencies may be found in Appendix A.) Federal Highway Administration reports estimate that $50.8 billion are required to correct all existing deficient bridges (Ref 1, p 10).

Budget constraints prohibit the immediate funding of improvements to all deficient bridges. However, Federal Highway Administration studies show that many deficient bridges are not actually unsafe, and that there may be no need to fund rehabilitation or replacement projects for all deficient bridges (Ref 2, p 5). Many structurally deficient bridges can, with proper load posting and weight limit enforcing, continue to serve most traffic, and many bridges with geometric deficiencies can be upgraded using relatively inexpensive corrections such as applying roadway stripping, placing advisory signs, and installing crash cushions and barriers to minimize severity of accidents (Ref 1, p 7). The fact that many deficient bridges are not necessarily unsafe emphasizes the need for properly directing available funds to the most critical bridges. Incorrectly prioritizing a set of unsafe bridges may be bad, but funding improvements for a safe bridge before an unsafe bridge could be catastrophic.

Texas has more bridges than any other state. With that honor comes a large-scale bridge project prioritization problem. Over 16,000 bridges in Texas are deficient (Ref 1, pp 57, 58). In the 1985-86 fiscal year, the combination of local, state, and federal funds was enough to treat only 577 bridges in Texas, or about 3.5 percent of Texas' total number of deficient bridges (Ref 1, pp 48-50).

DEFINITIONS

It is important to be acquainted with the terminology used in this report and the associated literature. Most of the following definitions are from the FWHA or the American Association of State Highway and Transportation Officials (AASHTO).

(1) Bridge A bridge is defined within the April 1, 1986, United States Code of Federal Regulations (Ref 3, p 237) in accordance with the AASHTO Highway Definitions Manual (Ref 4, p 2):

> "...a "bridge" is defined as a structure including supports erected over a depression or an obstruction, such as water, highway, or railway, and having a track or passageway for carrying traffic or other moving loads, and having an opening measured along the center of the roadway of more than 20 feet between undercopings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes; it may also include multiple pipes, where the clear distance between openings is less than half of the smaller contiguous opening."

Bridges, for the purposes of this report, do more than cross natural obstacles such as rivers and canyons. Freeway overpasses, for example, are also bridges.

(2) Deficient According to the FHWA, a bridge is termed deficient if it is structurally deficient or functionally obsolete. Many structurally deficient bridges are also functionally obsolete, but they are counted only as structurally deficient because the FHWA believes it to be the more critical condition (Ref 1, p 7).

(3) Structurally Deficient A bridge is termed structurally deficient if, by a visual inspection, either the roadway, superstructure, or substructure condition rating is four or less. A condition rating of four on any element is described as "...Marginal condition. Potential exists for major rehabilitation..." (Ref 5, Plate III–1). The FHWA further explains that structurally deficient bridges are "...those which have been: (1) restricted to light vehicles only, (2) closed, or (3) require immediate rehabilitation to remain open..." (Ref 1, p 6).

Condition ratings measure the degree of deterioration of several bridge elements. Bridges typically have six main components: roadway, superstructure, substructure, channel and channel protection devices, retaining walls, and approaches. Each of these is inspected visually and given a one-digit rating for condition. No consideration is given to the bridge's design when assigning condition ratings; a poorly designed bridge with no deterioration will receive high condition ratings when properly scored. Condition ratings range from zero- "Critical condition. Bridge is closed & is beyond repair..."- to nine- "New condition..." (Ref 5, Plate III-1). Condition ratings are described in detail in Chapter 4.

A bridge may also be termed structurally deficient if, by visual inspection or review of its plans, either its structural condition or waterway adequacy is given an appraisal rating of two or less. An appraisal rating of two is described as "Basically intolerable condition(s) requiring high priority to replace the structure..." (Ref 5, Plate III-3). Appraisal ratings differ from condition ratings in that appraisal ratings measure the degree to which a bridge's design and configuration meet current standards for the route the bridge is on. Deterioration is not an issue where appraisal ratings are concerned. Appraisal ratings range from zero- "Immediate replacement of the structure necessary to put back in service..."- to nine- "Condition(s) superior to present desirable criteria..." (Ref 5, Plate III-3).

Confusion over the "structural condition" appraisal rating is typical. This data item compares the bridge's current load-bearing capacity to standard design loads specified in AASHTO's "Standard Specifications for Highway Bridges... (Ref 6, pp 17-20)" and is therefore an appraisal rating. Deterioration is considered only indirectly, and hence the rating given to structural condition is not a condition rating. The structural condition appraisal rating "...should be no higher than the lowest of the superstructure and substructure condition ratings. The rating should also be no higher than the roadway condition rating plus 1..." (Ref 5, p 3-2). These limitations imply that condition ratings and appraisal ratings are comparable; however, the reader should not assume that scores on the condition rating scale have the same meaning as scores on the appraisal rating scale. Scales for the ratings may be of different lengths. A unit increase in appraisal rating may be much more important than a unit increase in condition rating.

(4) Functionally Obsolete A bridge is termed "functionally obsolete" if it is not structurally deficient and meets one of the following three criteria:

(a) It receives an appraisal rating of three or less for its roadway geometry and the roadway width does not meet the minimum width standards shown in Table 1.1;

(b) It receives an appraisal rating of three or less for under clearances or for approach roadway alignment;

(c) It receives an appraisal rating of three for structural condition or waterway adequacy.

The Federal Highway Administration further defines functionally obsolete bridges as those "...on which the deck geometry, load carrying capacity (comparison of the original design load to the current State legal load), clearance, or approach roadway alignment no longer meet the usual criteria for the system of which it is an integral part..." (Ref 1, p 6).

TABLE 1.1. MINIMUM ACCEPTABLE ROADWAY WIDTHS

Average Daily Traffic (ADT)	Minimum Acceptable Roadway Width (feet)
0 < ADT ≤ 250	20
250 < ADT ≤ 750	22
750 < ADT ≤ 2,700	24
2,700 < ADT ≤ 5,000	30
5,000 < ADT ≤ 9,000	44
9,000 < ADT ≤ 35,000	56

All bridges with ADT greater than 35,000 are reviewed individually by FHWA. The roadway width is measured curb to curb.

Source: Ref 5, p 3-9

(5) Sufficiency Rating The FHWA's Sufficiency Rating is intended to indicate a bridge's sufficiency to remain in service in its present condition. Sufficiency ratings range from zero (completely deficient) to one hundred (completely sufficient).

These are the basic definitions. Dozens of others exist; they will be introduced as needed.

STATE OF THE NATION'S BRIDGES

Over $12 billion in federal funds have been distributed to states for replacement and rehabilitation of deficient bridges since 1970, more than half since fiscal year 1982. About 91 percent of the nation's deficient bridges are eligible for federal funding. The condition of the nation's bridges is summarized in Table 1.2

Many states, able to finance improvement projects for only a fraction of their deficient bridges, have developed methods of prioritizing bridge projects. Some use engineering

TABLE 1.2. CONDITION OF THE NATION'S BRIDGES

Bridges	On Federal-Aid System	Off Federal-Aid System	Total
Total Bridges	269,781	304,948	574,729
Structurally Deficient	35,433	100,303	135,736
Percent of Total	13.1	32.9	23.6
Funcitonally Obsolete	40,499	67,682	108,181
Percent of Total	15.0	22.2	18.8
Load Posted	20,147	92,375	112,522
Percent of Total	7.5	30.3	19.6
Additional Bridges That Should Be Posted	8,990	24,861	33,851
Percent of Total	3.3	8.2	5.9
Total Number That Are or Should Be Posted	29,137	117,236	146,373
Percent of Total	10.8	38.4	25.5
Closed	628	4,271	4,899
Percent of Total	0.2	1.4	0.9

Source: Ref 1, p 6

judgement schemes while others use numerical rating procedures. Current methods of bridge project prioritization are reviewed in Chapter 2.

STATE OF TEXAS' BRIDGES

Texas has more than 43,000 bridges, over 8 percent of the nation's total. As a consequence, Texas has a large number of potential bridge problems. Texas has 4,579 deficient bridges on the Federal-Aid Highway system and 11,734 deficient bridges off the Federal-Aid Highway system according to the 1985 National Bridge Inventory (Ref 1, pp 57 and 58). The condition of Texas' bridge system is summarized in Table 1.3.

Bridges on the Federal-Aid Highway system in Texas are generally in good structural condition. Only 3.9 percent of Texas' bridges on the Federal-Aid Highway system are structurally deficient. However, Texas has a larger number of functionally obsolete bridges.

TABLE 1.3. CONDITION OF TEXAS' BRIDGES

Bridges	On Federal-Aid System	Off Federal-Aid System	Total
Total Bridges in Inventory	25,201	18,546	43,747
Non-Deficient	20,622	6,812	27,434
Percent of Total	81.8	36.7	62.7
Structurally Deficient	980	6,636	7,616
Percent of Total	3.9	35.8	17.4
Functionally Obsolete	3,599	5,098	8,697
Percent of Total	14.3	27.5	19.9
Total Number Deficient	4,579	11,734	16,313
Percent of Total	18.2	63.3	37.3

Source: Ref 1, pp 57 and 58

Over 14 percent of Texas' bridges on the Federal-Aid Highway system are functionally obsolete.

Almost two thirds of all Texas bridges off the Federal-Aid Highway system are deficient (see definition of deficient on page 2) in one way or another. However, these bridges typically carry less traffic than the bridges on the Federal-Aid system and risk to the public is consequently lower than the numbers initially suggest. Furthermore, many bridges are classified as functionally obsolete because they were built for lower design loads than the current standards. These bridges can serve most traffic if properly posted for maximum loads.

Not all of Texas' deficient bridges are eligible for federal funding for replacement or rehabilitation. Only those deficient bridges with Sufficiency Ratings less than 80 may be rehabilitated using federal aid, and only those with Sufficiency Ratings less than 50 may be replaced using federal aid. Many of the deficiencies causing bridges to be labeled functionally obsolete have little effect on Sufficiency Rating, and hence many functionally obsolete bridges are not eligible for federal funds. This is consistent with the Federal Highway Administration's intent to "...remove from service highway bridges most in danger of failure..." (Ref 3, p 240).

In terms of structural deficiency, bridges on Texas' State Highway system show less deterioration than the national average for bridges on the Federal-Aid Highway system. Off-State system bridges show deterioration levels similar to the national average for bridges off the Federal-Aid Highway system. Texas' On-State system bridges and its Off-State system bridges are functionally obsolete to approximately the same degree as the national averages.

RESEARCH AT THE UNIVERSITY OF TEXAS FOR BRIDGE REPLACEMENT STRATEGIES

This report is part of a research effort aimed at developing an improved strategy for bridge replacement. The report is a part of the total on–going effort. To help the reader understand the function of the Safety Indices developed in Chapter 4, we will present a brief overview of the total effort here, a summary of some existing strategies and criterion in Chapter 2, and a more detailed explanation of the proposed strategy for Texas in Chapter 3.

The proposed selection process for Texas is computerized. The input for the computerized system is an existing data base which contains inventory and appraisal information for each bridge in the state. The complete bridge inventory is first processed using existing FHWA criteria to reduce the number of structures to be further considered. This smaller set is then processed in the computerized system using SDHPT criteria to produce even smaller sub–sets. The elements of these smaller sub–sets are then given final selection consideration by the user of the computerized system. The Safety Indices developed in Chapter 4 are proposed for use as SDHPT criteria for the formulation of the smaller sub–sets.

The SDHPT criteria presently used in the computerized system has been taken from previously developed selection processes, and is explained in Chapter 3. The proposed criteria falls into two broad categories; criteria concerned with the service and existing structure provides, and criteria concerned with the safety of an existing structure. The level of service criteria has not been developed here, but will evaluate characteristics of the existing structure such as its essentiality, cost–effectiveness, and load capacity. The characteristics of an existing structure's safety are evaluated under two divisions, structural safety and geometric safety (Fig 1.1). These criteria have been proposed as a Structural Safety Index and Geometric Safety Index and are developed in Chapter 4.

The developed indices then, compose a portion of the SDHPT criteria used to sub–set projects already evaluated with existing FHWA criteria. The final selection is made then, using three divisions of criteria; FHWA, SDHPT, and user. The primary elements of the FHWA criteria will now be discussed in Chapter 2.

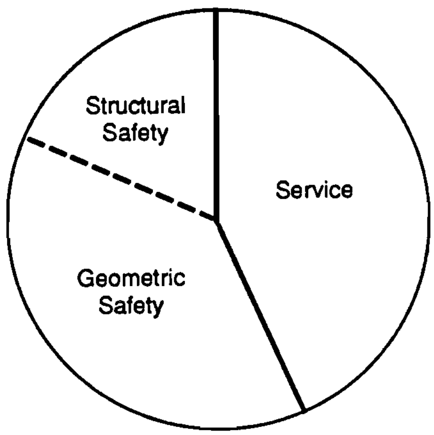

Fig 1.1. Divisions of the proposed SDHPT criteria.

CHAPTER 2. CURRENT BRIDGE PROJECT PRIORITIZATION PROCEDURES

INTRODUCTION

Some funding for bridge replacement and rehabilitation projects comes from the federal government as part of the Highway Bridge Replacement and Rehabilitation Program (HBRRP). Many states base their plans to some degree on whether or not bridges are eligible for federal funds under the HBRRP. This chapter presents the federal HBRRP eligibility criteria and an overview of some of the prioritization methods used by states. A history of legislation relating to federal bridge programs is presented in Appendix B.

THE FEDERAL SUFFICIENCY RATING

The Federal Highway Administration determines a bridge project's eligibility for federal funding based on whether or not the bridge is deficient and whether or not its Sufficiency Rating is in the proper range. Deficient bridges with Sufficiency Ratings less than 80 but greater than 50 are eligible for HBRRP funds for rehabilitation only. Deficient bridges with Sufficiency Ratings below 50 are eligible for HBRRP funds for rehabilitation or replacement.

The Sufficiency Rating formula, defined by the Federal Highway Administration as "...a method of evaluating factors, which are indicative of bridge sufficiency to remain in service..." (Ref 5, p 3-9), was developed out of a need to prioritize bridges for federal funding. The Special Bridge Replacement Program, established in 1970, did not specify how federal bridge replacement funds were to be distributed to the states. After initially allotting funds based on the states' priorities, the Federal Highway Administration soon realized that some sort of prioritizing index would be extremely useful as comparisons were made between bridges. The regulations for the Highway Bridge Replacement and Rehabilitation Program (HBRRP) state that "...the sufficiency rating will be used as a basis for establishing eligibility and priority for replacement or rehabilitation of bridges; in general the lower the rating, the higher the priority..." (Ref 3, p 240). The 1981 report "Better Targeting of Federal Funds Needed to Eliminate Unsafe Bridges... (Ref 7, p 44) provides background on the Sufficiency Rating:

FHWA developed the original formula and implemented it in 1972. After the formula received substantial criticism, FHWA asked the AASHTO Technical Committee on Bridge Replacement Survey and Inspection Standards to review the formula and suggest modifications. The AASHTO committee, working directly with FHWA, revised the formula and sent it to all the States for vote in 1976. Forty-four States approved the committee's proposed changes; 1 State abstained; and 5 States voted against it. According to FHWA Bridge Division officials, FHWA adopted AASHTO's proposed revisions in 1977, and no other changes have been made in the formula. In addition, the formula was described in the proposed regulations for the Highway Bridge Replacement and Rehabilitation Program that were published in the Federal Register for comment. FHWA received no substantial objection to the formula.

The Sufficiency Rating formula is rather lengthy and is not reproduced in this chapter. The complete formula may be found in Appendix C. Very little is found in the literature concerning the Sufficiency Rating; most of the literature on bridge project prioritization states the rating's existence and its use as a federal HBRRP eligibility criterion. It is clear, however, that the Sufficiency Rating is not universally accepted as a complete method for prioritizing bridge projects at the state level. Most states use Sufficiency Ratings as only one part of their prioritization schemes. The Federal Highway Administration continues to use the Sufficiency Rating as a criterion for eligibility for federal funds, and states cannot afford to disregard the important question of eligibility when prioritizing bridge projects for funding.

It is possible for two completely different bridges to receive identical Sufficiency Ratings. The Sufficiency Rating does not describe a bridge's structural condition, geometric characteristics, or use as well as the data used to compute the Sufficiency Rating do. The degree to which information is hidden behind the Sufficiency Rating is illustrated in Fig 2.1. It is not clear that the two bridges in Fig 2.1 are "equally sufficient to remain in service."

Sufficiency Ratings cannot be used to compare structural conditions of bridges. A Sufficiency Rating of 80 does not necessarily indicate a bridge twice as sound as one with a Sufficiency Rating of 40. In fact, it is possible for a bridge in relatively poor structural condition to receive a Sufficiency Rating higher than one in relatively good structural condition. In Fig 2.2, the condition ratings for the main structural components

	Bridge A	Bridge B
Sufficiency Ratings	58.3	58.3
Condition Ratings		
Substructure	8	7
Superstructure	8	7
Roadway	8	7
Appraisal Ratings		
Structural Condition	4	3
Roadway Geometry	3	8
Under clearances	9	9
Waterway Adequacy	7	7
Approach Roadway	3	9
Other Information		
Inventory Rating*	H15	H12
Number of Lanes	2	2
Average Daily Traffic	1200	500
Approach Roadway Width	28 feet	28 feet
Roadway Width	38 feet	20 feet
Detour Length	8 miles	11 miles
Main Span Type**	Concrete	Steel

NOTE: The bridges in this figure exist in Texas. Both bridges are in reasonably good structural condition. All information used in the Sufficiency Rating calculation is given.

* Inventory Ratings describe the maximum load bridges can carry indefinitely. They are given in terms of standard AASHTO H-trucks (Ref 6, p 17). Bridge A can safely carry a two-axle truck weighing fifteen tons. Bridge B can safely carry a two-axle truck weighing twelve tons.

** Bridge A is 165 feet long, made of three continuous concrete slabs. Bridge B is 180 feet long, made of six simple steel I-beams.

Fig 2.1. Different bridges, same sufficiency rating.

	Bridge C	Bridge D
Sufficiency Ratings	81.0	55.1
Condition Ratings		
Substructure	6	8
Superstructure	5	7
Roadway	5	7
Appraisal Ratings		
Structural Condition	4	4
Roadway Geometry	8	8
Under clearances	4	9
Waterway Adequacy	9	8
Approach Roadway	8	8
Other Information		
Inventory Rating*	HS36	2 axle, 28T
Number of Lanes	2	2
Average Daily Traffic	7300	800
Approach Roadway Width	38 feet	32 feet
Detour Length	0 miles	16 miles
Main Span Type**	Concrete	Concrete

NOTE: The bridges in this example exist in Texas. Bridge C appears to be more critical by virtue of its structural condition, but Bridge D has a much lower Sufficiency Rating.

* Bridge C may carry standard three-axle HS-trucks weighing up to 36 tons as specified by AASHTO (Ref 6, p 19). Bridge D is load restricted to tandem axle vehicles weighing less than 28 tons.

** Bridge C is 120 foot long, made of concrete slabs and girders in three 40 foot spans. Bridge D is a continuous flat-slab concrete bridge 125 foot long, in five 25 foot spans.

Fig 2.2. Sufficiency ratings seemingly misordered.

(substructure, superstructure, and deck) suggest a higher Sufficiency Rating for Bridge D relative to Bridge C.

The Sufficiency Rating is calculated by adding three sub–indices. The sub–indices and their weights are Structural Adequacy and Safety (55 percent), Serviceability and Functional Obsolescence (30 percent), and Essentiality (15 percent). The subindex labels indicate that the Sufficiency Rating does address the key items in bridge prioritizing. However, the way the Sufficiency Rating addresses the items can be misleading. Consider the following:

(1) Inconsistent Importance Given to Roadway Condition Rating. The condition ratings on three items can cause a bridge to be labeled structurally deficient. Two of the three (substructure and superstructure) are part of the Structural Adequacy and Safety subindex and can affect the Sufficiency Rating by 55 points (Ref 5, pp 3-10). The other (roadway) is considered under the Serviceability and Functional Obsolescence subindex and can affect the Sufficiency Rating by a maximum of only five points.

The roadway condition rating is used as a structural condition indicator to determine whether or not a bridge is deficient but as a serviceability indicator in the Sufficiency Rating calculation. It receives heavy weight in the determination of structural deficiency but very low weight in the Sufficiency Rating formula. It is difficult to determine the importance of bridge decks by examining federal eligibility criteria.

(2) The Special Reduction. A Special Reduction subindex is used to reduce the Sufficiency Rating when the sum of the Structural Adequacy and Safety, Serviceability and Functional Obsolescence, and Essentiality sub–indices is greater than 50. The reduction is not used when the sum is less than 50. Eligible bridges therefore belong to one of two groups: deficient bridges with Sufficiency Ratings less than 50 without the Special Reduction, and deficient bridges with Sufficiency Rating less than 50 after the Special Reduction has been applied. The Special Reduction subindex can reduce the Sufficiency Rating by up to 13 points and consequently strongly affects the relative Sufficiency Ratings of bridges. Meaningful comparison between bridges cannot be made using the Sufficiency Rating because the ratings for some bridges include the Special Reduction and the ratings for others do not In Fig 2.3, it appears that Bridge E should be funded before Bridge F. However, Bridge E receives its low Sufficiency Rating in part due to the Special Reduction subindex. Bridge F's Sufficiency Rating does not include the Special Reduction subindex. Including the Special Reduction in the

	Bridge E	Bridge F
Structural Adequacy and Safety	29.4	31.9
Serviceability and Functional Obsolescence	7.0	3.0
Essentiality	14.7	15.0
Subtotal	51.1	49.9
Special Reductions	(-3.0)	(-2.0)*
Sufficiency Rating	48.1	49.9

NOTE: The following bridges exist in Texas. Bridge E receives a lower Sufficiency Rating than Bridge F does because the Special Reduction is not applied to Bridge F.

* The Special Reduction cannot be applied to Bridge E because the subtotal is already less than 50. Its Sufficiency Rating would be 47.9 if the Special Reduction were allowed.

Fig 2.3. The special reduction.

Sufficiency Rating calculation for Bridge F would produce a rating of 47.9, lower than the rating for Bridge E.

SUFFICIENCY RATING CONCLUSION

While the Sufficiency Rating formula may be useful for screening and tentative selection of projects, it is not well suited to prioritizing bridge projects at the state level. It is difficult to compare bridges by comparing only Sufficiency Ratings because so many data items are hidden inside the formula. It may be more useful to keep the sub–indices separated and to compare them individually. The Structural Adequacy and Safety, Serviceability and Functional Obsolescence, and Essentiality sub–indices offer good information individually, which may be hidden when they are summed.

The Special Reduction might more appropriately be applied uniformly. The current method of using the special reduction only when a bridge's Sufficiency Rating would otherwise be greater than 50 makes prioritizing bridge projects more difficult.

The Sufficiency Rating can be counter intuitive and states must include other factors when prioritizing bridge projects for funding. Sufficiency Ratings cannot be ignored, since the Federal Highway Administration uses them to determine each bridge's eligibility for federal funds, but it would be unwise to rank eligible bridges by Sufficiency Ratings alone.

OVERVIEW OF METHODS CURRENTLY USED BY STATES

The Federal Highway Administration encourages states to distribute funds "...on a fair and equitable basis..." (Ref 3, p 240). Several states have defined specific programs to prioritize their bridge projects in order to make the best use of the available funds. Selected bridge project prioritization procedures are presented below.

Minnesota's Method

Minnesota's Department of Transportation uses an index called the "Minnesota Replacement Priority Index" (Ref 8, p 44). The index is similar to the federal Sufficiency Rating in that it uses a mathematical formula to combine several data items into a single rating. The index is divided into three sub–indices, and weights are assigned to them much as in the Sufficiency Rating procedure: Structural Adequacy and Safety is weighted 50 percent, Serviceability and Functional Obsolescence is weighted 25 percent, and Essentiality for Public Use is weighted 25 percent. The Structural Adequacy and Safety rating is the product of point values corresponding to scores on the appraisal rating for safe load capacity and on average daily traffic (ADT). The Serviceability and Functional Obsolescence rating is the sum of points corresponding to several appraisal ratings (deck geometry, under clearances, waterway adequacy, approach roadway, and structural condition), points corresponding to the ADT, and points assigned according to the structural material (timber, iron, steel, concrete, masonry, or prestressed concrete) and the type of structure (truss or culvert). The sum is multiplied by a factor dependent on the age of the bridge. This factor, the so-called Age Point, accounts for normal deterioration and fatigue. Essentiality for Public Use is the sum of scores representing detour length, ADT, road system designation, the defense system status (whether or not the bridge is on the federal defense system of highways), and the functional classification of the route the bridge is on. The points on the Structural Adequacy and Safety, Serviceability and Functional Obsolescence, and Essentiality for Public Use sub–indices are added to produce the Priority Rating.

Pennsylvania's Method

Pennsylvania's Department of Transportation is developing a complete bridge management system (Ref 9, p 64) scheduled to become operational in 1987. This system will include a Bridge Rehabilitation and Replacement Subsystem (BRRS). The BRRS will assign priorities to bridge projects based on deficiencies in level of service and bridge condition. It is similar to the "Level of Service Deficiency" system developed and used by North Carolina's Department of Transportation but includes part of the Sufficiency Rating as well. Level of service and condition deficiencies are added to give a score for total deficiency on a scale from zero to one hundred. Bridge condition is evaluated using "deficiency points" assigned to substructure, superstructure, deck, and estimated remaining life. The level of service deficiency is calculated by comparing load capacity, vertical clearances, and horizontal clearances to current standards for the route the structure is part of. Three levels of standards have been developed: minimum acceptable, minimum design, and desirable design.

Pennsylvania's Bridge Rehabilitation and Replacement Subsystem requires several data items not included in current databases. Currently, the system suffers from a lack of data. Pennsylvania's Department of Transportation will quantify the benefits which accrue from improving bridges once the data problems have been solved. Benefit-cost ratios would then be available for ranking bridge projects.

Wisconsin's Method

The Wisconsin Department of Transportation has developed a computer model to evaluate choices between replacement and rehabilitation of bridges (Ref 9, p 64). The computer model uses life-cycle cost analyses to find the optimal number of bridges which should be replaced in Wisconsin each year. It does not determine which bridges to fund. The model helps the Wisconsin Department of Transportation to anticipate the cost of maintaining

Wisconsin's bridge system. The model estimates the costs of performing different bridge repairs and forecasts bridge conditions. The problem of estimating the least-cost set of bridge replacement, rehabilitation, and maintenance work is treated as an unconstrained optimization problem in that budget limitations are not considered. The program does consider the inflation rate, the discount rate, and the number of years a cost is carried.

A lack of good data on the cost history of bridges in Wisconsin has hampered implementation efforts. User benefits, budget constraints, and the ability to adjust forecasting equations to reflect repairs are some of the hoped-for improvements to the program. The program is currently used as a long-term forecasting tool with short-term decisions being made using engineering judgement.

CHAPTER 3. TEXAS' BRIDGE PROJECT PRIORITIZATION PROCEDURE

TEXAS' 1985-86 HBRRP SORTING METHOD

The Highway Bridge Replacement and Rehabilitation Program (HBRRP) provides federal funds to every state for bridge replacement and rehabilitation projects. In Texas, the 1985-86 HBRRP began with bridge inspections and collection of data. Federal regulations require each state to inspect its bridges at least once every two years; Texas stores its inspection data in the BRINSAP (Bridge Inventory, Inspection, and Appraisal Program) datafile. The BRINSAP datafile contains the federally required data for each bridge in Texas, along with additional information for use by the Texas State Department of Highways and Public Transportation (SDHPT). Ninety items are recorded for each bridge, making BRINSAP a fairly extensive database.

BRINSAP data were used to compute Sufficiency Ratings for every bridge in Texas. BRINSAP data were also used to determine whether or not bridges were deficient. Knowing which bridges were deficient, and knowing Sufficiency Ratings for each, the SDHPT prepared lists of bridges eligible for federal funding (herein termed eligible) and distributed them to the twenty-four SDHPT Districts within the state. Districts ranked their bridges, indicating their priorities for funding, and returned the results to SDHPT.

A screening procedure (Fig 3.1) was developed to sort eligible bridges on the State Highway system into qualifying and non-qualifying groups on a statewide basis using SDHPT criteria. The procedure was followed by hand. A similar procedure was used for bridges off the State Highway system. According to SDHPT Bridge Division officials, bridge projects on the State Highway system totalling up to $180,000,000 could be funded under the Texas 1985-86 HBRRP allotment. Passing levels for the screens were chosen (based on engineering experience) to produce a set of bridge projects that would use as much of the allotment as possible. In a few special cases the algorithm was overriden for bridges with "...other strong considerations..." (Ref 11, p. ii). This procedure produced a set of 442 bridges on the State Highway system with a total accumulated project cost of $178,394,000.

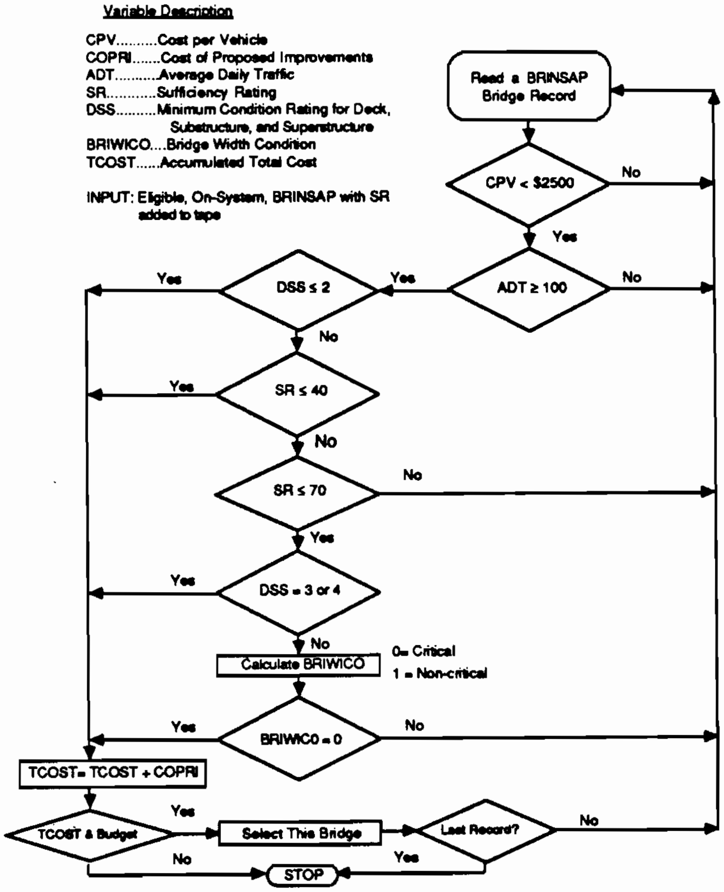

Fig 3.1. Texas' 1985-86 HBRRP selection procedure.

IMPROVEMENTS TO TEXAS' 1985-86 HBRRP SORTING METHOD

The SDHPT's main concerns with the 1985-86 sorting method were that the procedure was too laborious and that numerous decisions have to be made on whether to override the algorithm or not. An automated, better-justified method for selecting or prioritizing bridges was sought. The SDHPT suggested that the improved selection procedure continue the use of the BRINSAP datafile, as BRINSAP provides a ready database helpful both for research purposes and for the implementation of resulting computer programs.

The current procedure was computerized as a first step toward an improved prioritization method. Like the hand procedure, the computer program sorted bridges into two groups using SDHPT criteria on the set of bridges eligible for federal funding. The original program was subsequently modified to provide a third group. The third group, termed "marginal," contains bridges requiring further evaluation by hand. Marginal bridges are those which may become qualified for funding due to "other strong considerations." The presence of the marginal group provides SDHPT personnel the flexibility of selecting bridge projects due to "other strong considerations," but the procedure has been formalized and control has been added. The improved prioritization algorithm is split into two programs: SURE1 (Sufficiency Rating Evaluation Version 1), and TEBS1 (Texas Eligible Bridge Sorter version 1). SURE1 determines each bridge's eligibility for federal funding. TEBS1 sorts the eligible bridges from SURE1 into qualifying, marginal, and non-qualifying groups. A flowchart diagramming the entire data stream, from BRINSAP data to the qualifying, marginal, and non-qualifying groups, is shown in Fig 3.2. SURE1 and TEBS1 are described in the following sections.

The SURE1 Program

The SURE1 program computes Sufficiency Ratings according to the BRINSAP Manual of Procedures (Ref 5, pp. 3-10 to 3-14) and compares them to FHWA thresholds. SURE1 also checks for structural deficiency and functional obsolescence. The SURE1 program saves eligible bridges (deficient bridges with Sufficiency Ratings below 80) in a dataset for use in the TEBS1 program. Ineligible bridges are not analyzed further.

It is necessary to run the SURE1 program only once. The set of eligible bridges can be used and re-used as input to TEBS1 as many times as desired, allowing the passing levels and other inputs to be changed and the subsequent results to be studied.

The TEBS1 Program

TEBS1 evaluates bridges using the variables the SDHPT used in the 1985-86 HBRRP sorting procedure, to retain as much commonalty between the two methods as possible. The variables used are the estimated project cost per vehicle using the bridge (CPV); the average daily traffic (ADT); the Sufficiency Rating (SR); the minimum condition rating given to the deck, substructure, or superstructure (DSS); and the bridge width condition rating (BWC). BWC compares lane widths and traffic to minimum acceptable standards to determine whether the bridge width condition is critical or not. Bridges are sorted using the weighted-screening procedure described below.

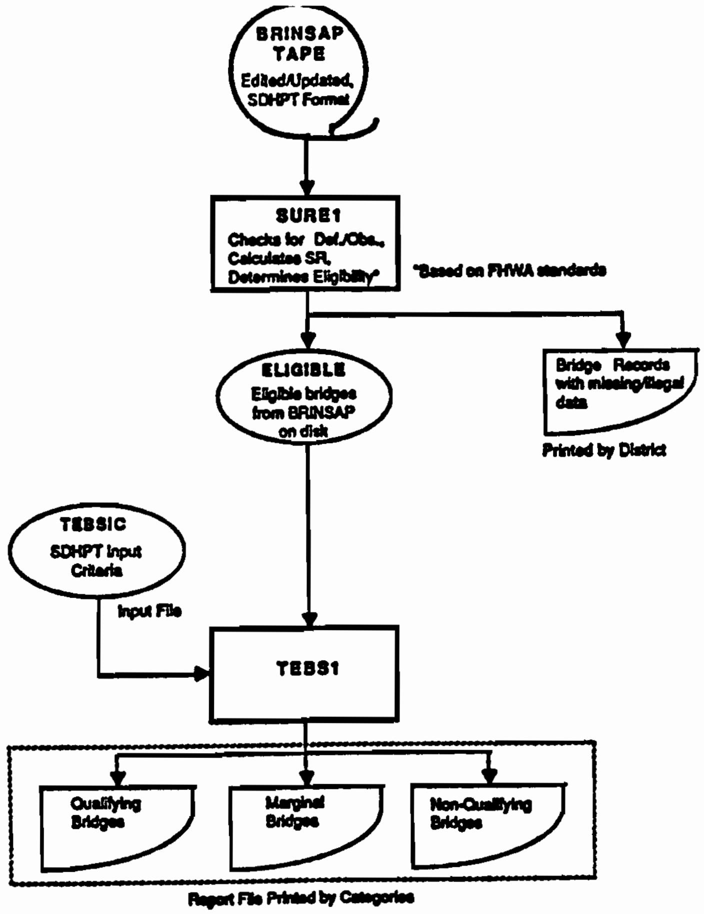

Fig 3.2. Flow diagram of the Computerized Bridge Selection Program for Texas.

Each variable considered (CPV, ADT, SR, DSS, and BWC) is checked against a "passing level" for the variable. These passing levels are analogous to the values used to screen bridges in the 1985-86 HBRRP and serve the same purpose. TEBS1 assigns points to bridges depending on which screens are passed. The points assigned for passing the various screens are termed weights. The total score for a bridge is computed by adding the points from the screens it passes. For example, a bridge that passes the CPV, SR, and DSS screens receives points from those three screens, but none from ADT or BWC. TEBS1 also checks each variable against "automatic qualifying levels." These levels allow the decision maker the option of specifying some value for a particular variable which makes a bridge qualifying regardless of the other variables.

After computing a bridge's total score and checking automatic qualifying criteria, TEBS1 sorts bridges into groups. Bridges passing at least one automatic qualifying level are termed qualifying regardless of their total scores. Scores for bridges which do not qualify automatically are checked against qualifying and marginal thresholds set by the user. Bridges with scores greater than the qualifying threshold are termed qualifying, bridges with scores less than the marginal threshold are termed non-qualifying, and bridges with scores between the marginal and qualifying thresholds are termed marginal. The sorting procedure is illustrated in Fig 3.3.

Output from TEBS1 is shown in Fig 3.4. It is important to note that bridges within each group are ranked not by score but by CPV. This procedure follows the SDHPT lead from the 1985-86 HBRRP list of selected projects. Accumulative project cost can be read at each line, specifying the amount of money needed to fund a bridge and all bridges above it within the list. Qualifying bridges and marginal bridges are printed in separate lists.

The qualifying threshold, properly chosen, will produce a qualifying group with a total accumulated project cost just under the allowable budget. All qualifying projects should be considered equally qualified for funding. Bridge projects from the marginal group may, after closer examination, appear qualified for funding. Typically, funding a project from the marginal group will require not funding at least one bridge from the qualifying group.

DESIRED ENHANCEMENTS TO THE COMPUTERIZED SORTING METHOD

The computerized bridge sorting method represents a potentially significant improvement to the current SDHPT bridge project selection procedure. The level of effort expended with the computerized version is much lower than that required for sorting by hand. However, some aspects of TEBS1 could be improved. Additionally, some of the difficulties present in the current SDHPT method remain unresolved in the computerized version.

The weights in TEBS1 cause many people difficulty. Many seem reluctant to specify a set of weights, preferring to use no weights at all. However, this procedure is equivalent to specifying all the weights to be equal. TEBS1 includes default weights chosen by the programmers. The default weights effectively rank structural safety first, geometric safety second, and cost effectiveness third. Hence, variables measuring structural safety (such as condition ratings for deck, substructure, and superstructure) are give high weights, while variables measuring cost effectiveness are given relatively low weights. The default weights would be improved if they captured the preferences of SDHPT bridge experts rather than those of the programmers.

		Levels			
Screen	Weight	Passing	Automatic Qualifying	Bridge X	Passed ?
CPV	10%	< $1000	< $10	$275	Yes
ADT	10%	> 300	> 50,000	200	No
SR	35%	< 60	< 10	47	Yes
DSS	25%	< 5	< 2	4	Yes
BWC	20%	= 0 (Critical)	none	1	No

Qualifying Threshold: 80.
Marginal Threshold: 65.

Bridge X receives 10 points (or 10 percent) for passing the CPV screen, 35 points (or 35 percent) for passing the SR screen, and 25 points (or 25 percent) for passing the DSS screen. The bridge's total score is 10 + 35 + 25 = 70. The bridge does not pass any of the automatic qualifying levels. Bridge X is in the marginal group and should receive additional evaluation beyond that given by TEBS1.

NOTE: Bridge X is a fictitious bridge used to illustrate the TEBS1 score calculation and sorting procedure.

Fig 3.3. TEBS1 score calculation and sorting procedure.

The benefits of replacing and rehabilitating bridges is disregarded in TEBS1 as they are in the current hand selection procedure. Other items not considered include essentiality and the question of whether or not deferring a qualified bridge project might be cost effective. These items may be included in future versions of TEBS.

The choice of variables used in TEBS1 could be improved. TEBS1 uses the variables used in the current SDHPT sorting procedure. These variables do not appear ideally suited for use in a bridge project prioritization procedure. Two new variables, the Structural Safety Index and the Geometric Safety Index, are presented in Chapter 4. Other variables which quantify the level of service a particular structure provides have yet to be developed.

One problem introduced with the computer program is that the qualifying and marginal thresholds cannot be properly chosen without knowledge of the weights used on the screens. This problem arises because the computer algorithm produces discrete scores which are sums of the weights in various combinations. If the weight for each screen is a multiple of ten, for

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TEXAS BRIDGE SORTER 12:03 WEDNESDAY, SEPTEMBER 17, 1986 1

VERSION 1.0

QUALIFYING BRIDGE PROJECTS

DATA SET: BRIDGES ELIGIBLE FOR FEDERAL FUNDING

CRITERIA USED FOR SCREENING

QUALIFYING: SCORE >= 90
MARGINAL: 65 <= SCORE < 90

REHAB COST = $25/SQ FT
REPLACE COST = $28/SQ FT

	CPV		ADT	SR		DSS	BWC
WEIGHTS:	10%		5%	25%		40%	20%
AUTO. QUALIFYING LEVELS:	NONE	>=	NONE	NONE	<=	2	NONE
PASSING LEVELS:	<=19		>=6,100	<=47.0		<=4	<=0

* = ESTIMATED
M = MISSING

DIST	COUNTY	CONT-SEC-STR	TYPE WORK	CPV RANK	SCORE	CPV	ADT	SR	DSS	BWC	RDWY WIDTH	PROJECT COST	ACCUMULATIVE PROJECT COST
18	DALLAS	8050-18-032	RH	9	55* AQ	$1	10,200	68.6*	0*	1	44.0	$12,000	$12,000
18	DALLAS	8167-18-004	RH	10	55* AQ	$1	11,000	78.5*	0*	1	46.2	$13,000	$25,000
18	DALLAS	8050-18-040	RH	12	75* AQ	$1	11,400	63.1*	0*	0	22.5	$15,000	$40,000
18	DALLAS	8075-18-006	RH	27	75* AQ	$2	12,000	62.6*	0*	0	22.0	$25,000	$65,000
18	DALLAS	8232-18-005	RP	30	100* AQ	$2	8,100	44.2*	0*	0	20.0	$17,000	$82,000
18	DALLAS	8079-18-022	RH	34	55* AQ	$2	12,000	77.6*	0*	1	51.8	$26,000	$108,000
1	HUNT	0009-13-104	RH	46	55* AQ	$2	13,600	71.1	0*	1	132.0	$33,000	$141,000
11	NACOGDOCHES	0176-01-045	RH	48	55* AQ	$2	14,900	79.6	0*	1	75.0	$37,000	$178,000
18	DALLAS	8073-18-006	RH	54	55* AQ	$3	12,200	77.6*	0*	1	25.8	$32,000	$210,000
18	DALLAS	8113-18-003	RH	56	55* AQ	$3	7,200	63.6*	0*	1	24.5	$19,000	$229,000
1	HUNT	0009-13-105	RH	58	55* AQ	$3	13,200	72.2	0*	1	126.0	$35,000	$264,000
18	DALLAS	8074-18-004	RP	64	80* AQ	$3	19,400	24.2*	0*	1	81.0	$55,000	$319,000
15	BEXAR	8001-15-004	RH	72	55* AQ	$3	9,800	72.1*	0*	1	54.7	$29,000	$348,000
18	DALLAS	8110-18-006	RH	79	70* AQ	$3	3,900	63.1*	0*	0	22.3	$12,000	$360,000
18	NAVARRO	0162-09-041	RH	86	50* AQ	$3	5,400	79.0*	0*	1	32.0	$18,000	$378,000
18	DALLAS	8095-18-005	RH	89	55* AQ	$3	12,000	76.6*	0*	1	52.0	$41,000	$419,000
11	ANGELINA	0200-13-053	RH	90	55* AQ	$3	13,400	72.1*	0*	1	52.0	$46,000	$465,000
18	DALLAS	8257-18-012	RH	100	50* AQ	$4	4,700	67.2*	0*	1	53.7	$18,000	$483,000
18	DALLAS	8232-18-020	RP	102	75* AQ	$4	5,900	34.2*	0*	1	25.0	$23,000	$506,000
18	DALLAS	8257-18-011	RH	126	50* AQ	$4	4,700	66.9*	0*	1	62.1	$20,000	$526,000
20	JASPER	0710-01-004	RH	151	50* AQ	$5	3,700	72.5*	0*	1	26.0	$18,000	$544,000
1	HUNT	0203-01-016	RH	165	50* AQ	$5	4,800	78.6*	0*	1	47.8	$24,000	$568,000
18	DALLAS	8232-18-019	RH	165	70* AQ	$5	6,000	73.4*	0*	0	8.1	$30,000	$598,000
19	BOWIE	0046-04-028	RH	167	50* AQ	$5	4,700	75.5	0*	1	46.0	$24,000	$622,000
1	HUNT	1017-03-005	RH	168	50* AQ	$5	4,100	72.6*	0*	1	40.0	$21,000	$643,000
18	DALLAS	8225-18-001	RH	177	55* AQ	$5	6,800	72.4*	0*	1	43.0	$36,000	$679,000
14	BASTROP	0265-06-016	RH	197	50* AQ	$6	5,200	78.6	0*	1	58.0	$30,000	$709,000
18	DALLAS	8186-18-001	RH	198	50* AQ	$6	5,000	66.8*	0*	1	80.1	$29,000	$738,000
18	COLLIN	0619-06-011	RH	219	50* AQ	$6	3,500	59.8*	0*	1	26.0	$22,000	$760,000
18	DALLAS	8146-18-003	RH	221	55* AQ	$6	14,600	52.7*	0*	1	85.9	$93,000	$853,000
18	DALLAS	8041-18-020	RH	224	55* AQ	$6	8,400	65.5*	0*	1	61.0	$54,000	$907,000
18	DALLAS	8106-18-002	RH	235	50* AQ	$7	2,900	65.9*	0*	1	24.0	$19,000	$926,000
1	HUNT	1017-03-006	RH	240	50* AQ	$7	4,100	71.6*	0*	1	40.0	$27,000	$953,000
18	DALLAS	8076-18-007	RH	241	55* AQ	$7	13,600	66.1*	0*	1	79.8	$90,000	$1,043,000
1	HUNT	0203-01-017	RH	245	50* AQ	$7	6,000	74.6*	0*	1	59.0	$40,000	$1,083,000
18	DALLAS	8232-18-011	RH	246	50* AQ	$7	6,000	69.6*	0*	1	80.0	$41,000	$1,124,000

Fig 3.4. TEBS1 output.

example, all scores will be multiples of ten as well. In this case, the qualifying set will not change if the qualifying threshold is changed, for example, from 80 to 75. This is only a minor inconvenience but could be misleading.

CHAPTER 4. THE SAFETY INDICES

INTRODUCTION

It is important that the goals of a bridge project prioritization procedure are clearly stated and understood. While "Safety" and "Cost Effectiveness" are typical goals many interpretations and processes to quantify these characteristics are possible.

Safety could be addressed by giving top priority to bridges in danger of structural failure. It could also be addressed by giving top priority to bridges with a high accident rate. Minimizing the risk of accidents involving bridges and minimizing the annual cost of accidents on bridges are additional ways to address safety. Similarly, several interpretations of cost effectiveness can be made. Critical bridges could be ranked according to the area of bridge roadway improved per dollar spent, or perhaps by the number of vehicles served per dollar spent.

Goals which are measurable in terms of readily available data are preferred for reasons of practicality. Knowledge of existing databases, coupled with knowledge of the prioritiziation problem to be solved, can lead to an excellent set of goals. The authors' work with the Texas BRINSAP database provided knowledge of its attributes and limitations. Participation in bridge inspections gave first-hand knowledge of the data's precision. As a result, the following interpretations of SDHPT's criteria are proposed as goals:

(1) Maximize the amount of safety gained by the public as a result of replacing and rehabilitating bridges. Two sources of safety gain will be considered: gains due to structural improvements and gains due to geometric improvements.

(2) Maximize the amount of safety gained per dollar spent on bridge projects.

The above goals are addressed in this chapter. Indices for measuring structural and geometric safety levels and methods for using the indices are also provided.

THE STRUCTURAL SAFETY INDEX

The Structural Safety Index (SSI) indicates a bridge's structural condition by combining the six condition ratings recorded for each bridge. A bridge's gain in structural safety is determined by comparing its level of structural safety in its present condition to its level of structural safety after the bridge project's completion. The Structural Safety Index considers only condition ratings. Clearances, lane width, and guardrails are considered in the Geometric Safety Index (GSI).

The structural safety of a bridge is generally agreed to be related to its level of deterioration. Deterioration levels are conveniently available in the BRINSAP database in the form of condition ratings. The six main bridge components (roadway, superstructure, substructure, channel and channel protection devices, retaining walls, and approaches) are given scores, from zero to nine, reflecting the effect their levels of deterioration have on the bridge they are components of. The scores, as discussed in Chapter 1, are termed condition ratings. The components are described thoroughly in Banks (Ref 12, p. 113):

> The roadway component sits atop and transmits the loads to the superstructures. The roadway component's primary element is the bridge deck, but it also includes the wearing surface, joints, railings, median barrier, curbs, sidewalks and drainage system.
>
> The superstructure component is the span portion of the bridge and usually includes the main member, floor system, secondary member and bearing elements.
>
> Substructures transmit loads from the superstructure down to the ground and are of two types--abutments and intermediate supports, which can be either bents or piers. Elements include the cap, above ground portion and below ground portion or foundation. Where present, the navigation fender system is also included as a substructure element.
>
> Channel and channel protective devices are also considered a component. Streams, waterways, canals, drainage ditches and the like are all considered channels.... Channel protection devices maintain stream stability....
>
> Retaining walls are used to hold back earth at locations where there is not enough room to construct a slope flat enough to remain stable....

The approach component includes the approach slab, side drains, approach guard fence and delineation....

Understanding the Condition Ratings

Condition ratings range from zero to nine. Descriptions of the ratings are given in Table 4.1. Discussion with SDHPT personnel and participation in bridge inspections indicate that it is difficult to absolutely guarantee the precision of the zero to nine rating scales. Although condition ratings are recorded on the zero to nine scale, the description of condition ratings in the Texas BRINSAP Manual of Procedures (Ref 5, Pl. III-1) suggests that lumping condition ratings into four groups (good, fair, poor, and critical) may be appropriate. This change in scale is consistent with generally accepted limits of a person's ability to perceive differences. This report proposes that condition ratings may be considered good, fair, poor, or critical, consistent with the precision of the data and the BRINSAP Manual of Procedures (Ref 5).

Each bridge component is composed of elements. The condition rating for a component begins with ratings for each of its elements. Each element is rated using the zero to nine condition rating scale. A component's condition rating is the minimum rating given to any of its elements. This procedure can be misleading. For example, a condition rating of zero for a superstructure could be caused by rating one element zero or by rating four elements zero. The elemental condition ratings are not part of the National Bridge Inventory, nor are they part of the BRINSAP database.

The forms used to gather bridge inspection data reveal that lower bounds are placed on some elemental condition ratings. These in effect place lower limits on the condition ratings for components. The lower limits are intended to indicate the maximum effects deteriorated components can have on bridges. Substructures, for example, can have condition ratings as low as zero. Zero on the condition rating scale corresponds to "Critical condition. Bridge is closed and beyond repair..." (Ref 5, Pl. III-1). Retaining walls can have condition ratings only as low as five. A condition rating of five corresponds to "Generally fair condition. Potential exists for minor rehabilitation..." (Ref 5, Pl. III-1). The minimums are used even if the component itself appears to be completely deteriorated. In other words, retaining walls

TABLE 4.1. CONDITION RATING DESCRIPTIONS

9--New condition
8--Good condition- no repairs needed
7--Generally good condition- potential exists for minor maintenance
6--Fair condition- potential exists for major maintenance
5--Generally fair condition- potential exists for minor rehabilitation
4--Marginal condition- potential exists for major rehabilitation
3--Poor condition- repair or rehabilitation required immediately
2--Critical condition- bridge should be closed until repairs are complete
1--Critical condition- bridge closed but repairable
0--Critical condition- bridge closed and beyond repair
N--Not applicable

(Source: Ref 5, Pl. III-1)

NOTE: Under the four level scale proposed in this report, condition ratings nine, eight, and seven are termed "good", ratings six and five are termed "fair," ratings four and three are termed "poor," and ratings two, one, and zero are termed "critical."

receive condition ratings indicating generally fair condition or better even when the walls have deteriorated beyond repair. This is because the ratings are intended to indicate the condition of the bridge as a whole, not of the component. The components, their elements, and the lower limits on the elemental condition ratings are summarized in Table 4.2.

Condition ratings offer a great deal of information about the structural condition of bridges despite their shortcomings. However, using the ratings to compare bridges is difficult because there are 162,000 combinations of condition ratings possible for any bridge with all six components. Some states favor a method of using the minimum condition rating on any component as an indicator of a bridge's structural condition. Texas modified this procedure in the 1985-86 HBRRP bridge project selection process, using the minimum condition rating on the roadway, substructure, and superstructure to indicate structural condition. Such a procedure is reasonable in that even one severely deteriorated component can make a bridge unsafe. However, this type of procedure does not differentiate between bridges with one

TABLE 4.2. MINIMUM RATINGS (CR) FOR COMPONENTS AND THEIR ELEMENTS

(A) ROADWAY (MINIMUM CR IS 1)

Element	Minimum Condition Rating
Deck	1
Wearing Surface	6
Joints, Expansion, Open	6
Joints, Expansion, Sealed	6
Joints, Other	6
Drainage System	6
Curbs, Sidewalks and Parapets	6
Median Barrier	6
Railings	6
Railing Protective Coating	7
Delineation (curve markers)	7

(B) SUPERSTRUCTURE (MINIMUM CR IS 0)

Element	Minimum Condition Rating
Main Members, Steel	0
Main Members, Concrete	0
Main Members, Timber	0
Main Member Connections	0
Floor System Members	1
Floor System Connections	1
Secondary Members	5
Secondary Member Connections	5
Expansion Bearings	6
Fixed Bearings	6
Steel Protective Coating	6

(C) SUBSTRUCTURE (MINIMUM CR IS 0)

Element	Minimum Condition Rating
Abutments	0
Intermediate Supports	0
Collision Protection System	5
Steel Protective Coatings	6

(D) CHANNEL AND CHANNEL PROTECTION (MINIMUM CR IS 4)

Element	Minimum Condition Rating
Channel Banks	4
Channel Bed	4
Rip Rap	5
Dikes	5
Jetties	5

TABLE 4.2. (CONTINUED)

(E) RETAINING WALLS (MINIMUM CR IS 5)

Element	Minimum Condition Rating
Abutment Backwalls and Wingwalls	5
Embankment Retaining Walls	5
Culvert Headwalls and Wingwalls	5

(F) APPROACHES (MINIMUM CR IS 4)

Element	Minimum Condition Rating
Embankments	4
Slope Protection	5
Slabs or Pavements	5
Relief Joints	6
Drainage	6
Guardfence	6
Delineation	7
Sight Distance	7

Source: Ref 5, Plate II-1

deteriorated component and bridges with several deteriorated components. This information is important for prioritization purposes.

Combining the Condition Ratings

The Structural Safety Index (SSI) uses all six condition ratings and produces a single integer rating from zero to nine. The zero to nine scale is used to provide ten levels of overall structural safety. The SSI reflects an overall structural condition for a bridge, a weighted average of the condition ratings on the six components. The weights may be derived by examing the effects components can have on the total structural condition of a bridge or they may be provided by the user of the formula. The following rational might be used for the determination of the values of weights in the formula. However, a review of Eq 4.1 reveals that other values for the weights may be developed, and that some of these values may even be zero, if the user of the formula does not want any consideration given to some component of the index.

Consider a new bridge. All condition ratings would be nines. The total of the six condition ratings would be fifty-four. Now consider a completely deteriorated bridge. Because of the minimum scores specified above, the total of the six condition ratings would not be zero, but fourteen. In terms of condition rating points, the difference between a new bridge and a completely deteriorated one is therefore forty points.

The forty point difference between a new bridge and a completely deteriorated one is not distributed evenly among a bridge's components. Some components have more of an effect on a bridge's total number of condition rating points than others. This can be seen in the minimum condition ratings specified for the various components.

Weights may be determined by considering the maximum possible effect a deteriorated component can have on a bridge. These effects can be measured in terms of the maximum reduction in condition rating points a deteriorated component can cause. For example, the condition rating for the substructure can be as low as zero. A completely deteriorated substructure reduces the total amount of condition rating points by nine points. However, the condition rating for a retaining wall can only be as low as five. A completely deteriorated retaining wall will therefore only reduce the total amount of condition rating points by four points. Weights can be determined by dividing a component's possible contribution to the total condition rating points by the total deterioration points possible, which, as mentioned above, is forty. A summary of the component weights derived by this method is given in Table 4.3.

The weights should be adjusted when components are rated "N" for "not applicable." The adjustment procedure is straightforward: compute the total possible difference between a new bridge and a completely deteriorated one, and use that number as the denominator in the calculation of weights. For example, if a bridge does not have retaining walls, the condition rating for retaining walls will be scored "N." The total of the condition rating points for a new bridge is no longer fifty-four, because only five components are available to contribute points. In this case with five condition ratings, a new bridge receives a total of forty-five condition rating points. The total number of condition rating points for a completely deteriorated bridge changes from fourteen to nine because the mandatory five points from the retaining wall condition rating are not considered. Therefore, the total point difference between a new bridge and a completely deteriorated one is thirty-six condition rating points when the bridge has no retaining walls. Thirty-six should be used to obtain weights for the

TABLE 4.3. MAXIMUM EFFECT ON CONDITION RATING POINTS AND WEIGHTS BY COMPONENT

Component	Maximum Effect	Weight (Percent)
Superstructure	9/40	22.5
Substrucure	9/40	22.5
Deck	8/40	20.0
Channel	5/40	12.5
Approaches	5/40	12.5
Retaining Walls	4/40	10.0

These weights are valid only for bridges with numeric condition ratings for all six components. Weights for bridges with fewer than six numeric condition ratings should be calculated using the two step procedure outlined in the text.

components; for example, the substructure weight will be nine points out of 36, or 25 percent. This procedure should be used in all cases where a component's condition rating is "N." This method for obtaining weights is generalized in the two–step procedure below.

One Procedure for Obtaining Weights

Step 1. Obtain the difference between a new bridge and a completely deteriorated one by summing the maximum effects the components present can have on the total number of condition rating points. Do not sum those which are not present. Maximum effects are given below.

Component	Maximum Effect
Superstructure	9
Substructure	9
Deck	8
Channel	5
Approaches	5
Retaining Walls	4

Step 2. Divide the maximum effect a bridge component can have on the total number of condition rating points by the total obtained in Step 1. The quotient is the component's weight. Do not perform calculations for components coded "N."

Modified condition ratings may also be used when calculating the Structural Safety Index. The modified condition ratings might be used in place of the actual condition ratings from bridge inspections to account for small variations that may occur in the gathering of the data. Modified condition ratings, if chosen to be used, are obtained by sorting condition ratings from the BRINSAP database into the good, fair, poor, and critical groups discussed previously in this chapter (Table 4.1). Condition ratings in the "Good" group are all considered to be threes. Ratings in the "Fair" group are all considered to be twos. Ratings in the "Poor" group are considered to be ones, and ratings in the "Critical" group are considered to be zeros. The modification procedure is summarized in Table 4.4.

Weights and condition ratings are used to calculate the Structural Safety Index as shown in Eq 4.1. One method for the determination of weights has been presented above. It has also been suggested that the condition ratings might be modified to a zero to three scale before weighted combination. If this modification is made, Eq 4.1 should be multiplied by three to convert the results back to a zero to nine scale, for reference. A series of uses of the formula is presented below in Example 4.1. In this example the implied weights and modified ratings described above are demonstrated as well as actual condition ratings and user provided weights.

Structural Safety Index Calculation Procedure

$$\begin{aligned} SSI = & [(SUBWT \times SUBCO) + (SSWT \times SSCO) \\ & + (DKWT \times DECO) + (CPWT \times CPCO) \\ & + (ARWT \times ARCO) + (RWWT \times RWCO)] \end{aligned} \qquad (4.1)$$

where

SSI = Structural Safety Index,

SUBWT = Substructure weight,

SSWT = Superstructure weight,
DKWT = Deck (roadway) weight,
CPWT = Channel and channel protection devices weight,
ARWT = Approach weight,
RWWT = Retaining wall weight,
SUBCO = Substructure condition rating,
SSCO = Superstructure condition rating,
DECO = Deck (roadway) condition rating,
CPCO = Channel and channel protection condition rating,
ARCO = Approach condition rating, and
RWCO = Retaining wall condition rating.

TABLE 4.4. CONVERTING CONDITION RATINGS TO MODIFIED RATINGS

Condition Rating (from Bridge Inspection)	Modified Group	Modified Rating
9,8, or 7	Good	III
6 or 5	Fair	II
4 or 3	Poor	I
2, 1, or 0	Critical	0

Roman numerals are used to distinguish the modified ratings from the condition ratings obtained directly from bridge inspection data.

The Structural Safety Index will be used with the Geometric Safety Index to evaluate the overall safety level for a bridge in its present condition. This pre-project level of safety might be compared to the post-project level of safety to determine which projects will produce the biggest gains in safety.

Example 4.1 Calculating the Structural Safety Index

The Structural Safety Index Calculation is illustrated using the bridges from Example 2.2. Additional data from BRINSAP are shown. SSI should be rounded to the nearest integer.

	Condition Ratings		Modified Ratings	
Variable	Bridge C	Bridge D	Bridge C	Bridge D
Substructure	6	8	II	III
Superstructure	5	7	II	III
Roadway	5	7	II	III
Channel and protection	N	7	N	III
Retaining walls	7	8	III	III
Approaches	6	7	II	III

USING BRINSAP IMPLIED WEIGHTS AND MODIFIED CONDITION RATINGS

Bridge C Calculation:

Structural Safety Index = {(9/35) x (II) + (9/35) x (II) + (8/35) x (II) + (5/35) x (III) + (4/35) x (II)} x 3 = **6.43**
SSI for Bridge C is 6.

Bridge D Calculation:

Structural Safety Index = {(9/40) x (III) + (9/40) x (III) + (8/40) x (III) + (5/40) x (III) + (5/40) x (III) + (4/40) x (III)} X 3 = **9** SSI for Bridge D is 9.

Bridge C has a lower Structural Safety Index than Bridge D. Recall that the Sufficiency Ratings for the bridges were 81.0 for Bridge C and 55.1 for Bridge D.

USING BRINSAP IMPLIED WEIGHTS AND ACTUAL CONDITION RATINGS

Bridge C Calculation:

Structural Safety Index = [(9/35) x 6 + (9/35) x 5 + (8/35) x 5 + (5/35) x 7 + (4/35) x 6] = 5.66
SSI for Bridge C = 6

Bridge D Calculation:

Structural Safety Index = [(9/40) x 8 + (9/40) x 7 + (8/40) x 7 + (5/40) x 7 + (5/40) x 8 + (4/40) x 7] = 7.35
SSI for Bridge D = 7.

USING USER WEIGHTS AND ACTUAL CONDITION RATINGS

Bridge C Calculation:

Structural Safety Index = [(0.40) x 6 + (0.35) x 5 + (0.25) x 5 + (0.00) x 7 + (0.00) x 6] = 5.4
SSI for Bridge C = 5.

Bridge D Calculation:

Structural Safety Index = [(0.30) x 8 + (0.25) x 7 + (0.15) x 7 + (0.30) x 7 + (0.00) x 8 + (0.00) x 7] = 7.3.
SSI for Bridge D = 7.

THE GEOMETRIC SAFETY INDEX

Accidents involving bridges in Texas occurred at a rate of one accident every sixty-four minutes in 1985 (Ref 13, p. 54). If the present desirable geometric criteria (as specified by the various AASHTO specifications) are assumed to correspond to safe conditions, it is reasonable to expect decreases in the numbers of accidents on bridges as existing geometries approach those criteria. Of course, no bridge can be made entirely free of accidents; many accidents are caused by deficiencies in a driver's capabilities and not by bridge characteristics. But it is generally agreed that bridges should be made as safe as possible. The following is from AASHTO's "A Policy on Geometric Design of Highways and Streets..." (Ref 14, p. 46):

> It is generally not possible for a design or operational procedure to reduce errors caused by innate driver deficiencies. However, designs should be as forgiving as possible to lessen the consequences of these kinds of failures. Errors committed by competent drivers can be reduced by proper design and operation. Most individuals possess the attributes and skills to drive properly....

The proposed Geometric Safety Index (GSI) is based on accident data in the state of Texas and indicates the relative safety levels of bridges in terms of their geometries. There are several data items available in the National Bridge Inventory data which indicate geometric characteristics of bridges. The most useful of these are in appraisal rating form, as appraisal ratings compare existing bridge features to present desirable design standards.

The general form of the Geometric Safety Index formula is similar to the general form of the formula for the Structural Safety Index. Each formula is a weighted combination of several characteristics recorded for a structure on the BRINSAP data tape. As in the formula for SSI, the weights for each characteristic may be provided by the user of the formula, and while they might range in value from zero to one, their total must equal one. The Geometric Safety Index formula is shown here as Eq 4.2.

$$GSI = [(DGWT \times DGAR) + (AGWT \times AGAR) + (TGWT \times TGR) + (WDW \times WD)] \quad (4.2)$$

where

GSI = Geometric Safety Index,
DGWT = Deck Geometry Weight,
AGWT = Approach Geometry Weight,
TGWT = Transformed Guardrail Weight,
WDW = Width Differential Weight,
DGAR = Deck Geometry Appraisal Rating,
AGAR = Approach Geometry Appraisal Rating,
TGR = Transformed Guardrail Rating, and
WD = Width Differential.

One possible combination of weights, for use in the formula is presented below. This derivation uses as a basis, Texas accident data.

One Derivation of Weights

McFarland (Ref 15) has analyzed the Texas accident data for 1978-79 and proposes costs per accident as shown in Tables 4.5 and 4.6. These costs consider the various types of accidents occurring on bridges, their frequencies of occurrence, their severities, and their locations. Both direct and indirect costs are included. Direct costs were derived on the basis of vehicle involvement costs and Texas accident data on numbers of involvements per accident. Indirect costs per fatality were based partly on a market-oriented approach to estimating the value of an accident victim's life to himself and partly on National Highway Traffic Safety Administration estimates of other indirect costs. Indirect costs for injury accidents were developed using Texas accident data and the National Highway Traffic Safety Administration-based indirect costs.

Tables 4.5 and 4.6 present costs for fatal accidents, injury accidents, and property damage only (PDO) accidents. Fatal accidents are those in which at least one fatality results.

TABLE 4.5. COSTS PER ACCIDENT (RURAL)

Bridge Accident	Fatal	Injury	Property Damage Only	Average
Struck Pier	$710,000	$17,200	$1,600	$126,500
Struck Bridge End	581,400	14,000	1,600	65,800
Struck Bridge Rail	626,200	13,300	1,600	23,400
Struck Underside*	- -	7,100	1,600	2,300

*No fatalities for this type of accident.

Source: Ref 15, p 133

TABLE 4.6. COSTS PER ACCIDENT (URBAN)

Bridge Accident	Fatal	Injury	Property Damage Only	Average
Struck Pier	$570,000	$13,700	$650	$38,300
Struck Bridge End	590,400	14,800	650	43,100
Struck Bridge Rail	543,100	11,400	650	12,700
Struck Underside	520,500	11,200	650	5,700

Source: Ref 15, p 134

Injury accidents are those which cause at least one injury, and PDO accidents are those in which neither an injury nor a fatality were caused. McFarland assumed the same figure for PDO costs regardless of the cause. Injury costs vary because the different accident types cause injuries of varying severity (Ref 15).

Table 4.7 shows the average weighted costs of bridge accidents on Texas roads. The figures are developed by multiplying rural and urban accident costs by the number of rural and urban accidents of a particular type, adding the products, and dividing their sum by the total number of accidents of the type in question. This procedure gives the state-wide average costs for four types of bridge accidents. The results are the starting point one derivation of weights that might be used in the general formula of the Geometric Safety Index.

Table 4.8 contains the percentages of total bridge accident costs by accident type. The figures reflect not only the costs per accident from Table 4.7, but the relative frequency of accidents by type as well. This combination quantifies the significance of the various types of bridge accidents more realistically than accident frequencies or unit costs alone can. Note for example that accidents involving bridge rails have a relatively low cost on a per-accident basis, but because this type of bridge accident occurs almost seven times as often as any other, bridge rail accidents make up 60 percent of the total cost of all accidents involving bridges. The frequency data used in Table 4.8 are for 1985, the most recent data available, and are from Ref 13. In practice, the most recent frequency data available should always be used, because the Geometric Safety Index will reflect the values in Table 4.8 and these should represent the current condition of the bridge system. It is assumed that the unit costs for the four bridge accident types do not vary relative to each other. The assumption allows McFarland's figures to be used to determine the relative significances for the four bridge accident types in any year.

Table 4.9 lists the four main types of bridge accident and the geometric conditions which are likely to cause them. The table is based on the authors' judgement and experience and should be updated as knowledge of bridge-related accidents improves. Relative weights for the causes listed in Table 4.9 are found by using Table 4.9 with Table 4.8. The weights for the accident types in Table 4.8 are distributed among the variables likely to cause the accidents. It is assumed that the causes for any particular type of accident are equally responsible for accidents of that type. For example, accidents involving bridge rails have a weight of 60 percent in Table 4.8; therefore, "narrow bridge" and "substandard guardrails" each receive

TABLE 4.7. COSTS PER ACCIDENT (RURAL AND URBAN AVERAGE)

Bridge Accident	Average
Struck Pier	$42,300
Struck Bridge End	56,200
Struck Bridge Rail	16,900
Struck Underside	5,400

TABLE 4.8. PERCENT OF TOTAL ACCIDENT COSTS, BY TYPE OF ACCIDENT

Bridge Accident	Percent
Struck Pier	20
Struck Bridge End	19
Struck Bridge Rail	60
Struck Underside	1

TABLE 4.9. BRIDGE-RELATED ACCIDENTS AND THEIR PROBABLE GEOMETRIC CAUSES

Bridge Accident	Probable Geometric Causes
Struck Pier	Inadequate guardrails around pier.
Struck Bridge End	Narrow Bridge. Poor alignment with approach roaday. Bridge narrower than approach roadway.
Struck Bridge Rail	Narrow bridge. Substandard guardrails.
Struck Underside	Low overhead clearance.

a weight of 30 percent. The weights for each accident type are distributed in this manner, and the sums of the weights for each variable are shown in Table 4.10.

Geometric Safety Index Calculation Procedure

The variables in Table 4.10 are part of the National Bridge Inspection Data taken by the states. In Texas, these variables are found on the BRINSAP data tape. Bridge geometry is BRINSAP item number 68. It is an appraisal rating, ranging from zero to nine. The bridge geometry appraisal rating compares lateral and overhead clearances to present desirable criteria. The approach geometry is also an appraisal rating, BRINSAP item number 72. This appraisal rating indicates how well a bridge is aligned with the road it is on. Guardrails are evaluated in BRINSAP item number 36, and the width differential can be found by subtracting the approach roadway width (BRINSAP item number 32) from the bridge's roadway width (BRINSAP item number 51). These variables are used to form the Geometric Safety Index. Transformations of the guardrail and width differential variables are necessary to make them comparable to the appraisal ratings for bridge geometry and approach geometry.

TABLE 4.10. WEIGHTS FOR VARIABLES CONTRIBUTING TO ACCIDENTS ON BRIDGES

Variable	Accident Involving a Bridge's ... Pier (percent)	End (percent)	Rail (percent)	Underside (percent)	Derived Variable's Weight (percent)
Bridge Geometry	- -	4.75	30	1	35.75
Guardrails	20	4.75	30	- -	54.75
Width Differential	- -	4.75	- -	- -	4.75
Approach Geometry	- -	4.75	- -	- -	4.75
Column Totals	20	19	60	1	100

"--" indicates that the variable does not contribute significantly to this type of accident.

The guardrail variable is a four digit code. Each digit represents one aspect of a bridge's guardrails. The first digit represents the bridge railing's physical attributes, including its height, material, strength, and geometric features. The second digit represents the approach guardrail transitions. The third digit represents the approach guardrail itself, and the fourth digit represents the approach guardrail ends. Each digit is coded without regard to the others. Digits are coded as "1" (the guardrail feature meets currently acceptable standards), as "0" (the guardrail feature does not meet currently acceptable standards), or as "N" (this feature is not required). The sum of the numeric digits should be obtained and divided by the number of numeric digits, giving an average score on those railing features which are required. This average should then be multiplied by nine to put it on the same scale as the appraisal ratings for deck geometry and approach geometry. A nine on the appraisal rating scale represents "...conditions superior to present desirable criteria..." (Ref 5, Pl. III-3). The scores on the guardrail variable may appear better matched to appraisal ratings of six, since a six represents "conditions equal to present minimum criteria," but the present minimum criteria and the present desirable criteria are the same. Only one set of specifications exists; a nine is therefore used.

The width differential is determined by subtracting the approach roadway width from the bridge roadway width. AASHTO (Ref 14, p. 515) specifies that the minimum roadway width for a new or reconstructed highway bridge is equal to the approach roadway width, including the approach roadway shoulders when surfaced. As with guardrails, only one set of specifications is given. All bridges which have roadway widths at least as wide as their approach roadways are therefore assigned nines. Bridges with roadway widths less than approach roadway widths are given a score of zero. Ideally, the width differential should be able to take on all values from zero to one; however, the procedure is adequate as stated for the weights derived above. If greater weight is given to width differential by the user of the formula, zero to nine scale could be used. The value of the width differential variable (0-9) might be proportionally equated to the actual width difference.

The four variables (deck geometry and approach geometry appraisal ratings, and the transformed guardrail and width differential ratings) deemed here, might be combined using the weights derived in Table 4.10. The equation for this combination is given as Eq 4.2. The Geometric Safety Index should, like the Structural Safety Index, be rounded to the nearest integer.

In Example 4.2 presented below, the transformed guardrail rating is equal to the sum of the numeric digits in the guardrail rating, times nine, divided by the number of the numeric digits. The transformed width differential is equal to nine when the bridge's roadway width is wider than or as wide as the approach roadway width, including the shoulders, and zero for all other cases. These variable values have been used with various combinations of weights in Example 4.2.

Neither bridge in Example 4.2 exhibits good geometric characteristics. Recall that the top GSI possible is nine. Both of these bridges lack good guardrails, reducing their GSIs significantly. Bridge D has a roadway width 12 feet narrower than the approach roadway width and its GSI is reduced for this as well.

USING THE SAFETY INDICES

The Structural Safety Index (SSI) and the Geometric Safety Index (GSI) are combinations of available data. They are constructed using the units derived they may be combined using a simple formula based on the frequency of fatalities due to bridge failures and

Example 4.2 Calculating the Geometric Safety Index

The bridges from Example 2.2 are used to illustrate the Geometric Safety Index calculation. Recall that the geometric safety index is rounded to the nearest integer.

Geometric Information

Variable	Bridge C	Bridge D
Deck Geometry Appraisal	8	8
Approach Geometry Appraisal	8	8
Guardrail Code	0001	0000
Bridge Roadway Width	38 feet	20 feet
Approach Roadway Width	38 feet	32 feet
Transformed Guardrail Codes	9 / 4	0 / 4
Transformed Width	9	0

CALCULATION WITH ACCIDENT IMPLIED WEIGHTS

Bridge C Calculation:

Geometric Safety Index = 0.3575 x (8) + 0.0475 x (8) + 0.5475 x [(1x9)/4] + 0.0475 x (9) = 4.90

GSI for Bridge C is 5.

Bridge D Calculation:

Geometric Safety Index = 0.3575 x (8) + 0.0475 x (8) + 0.5475 x [(0x9)/4] + 0.0475 x (0) = 3.24

GSI for Bridge D is 3.

CALCULATIONS WITH USER PROVIDED WEIGHTS

Bridge C Calculations:

Geometric Safety Index = 0.54 x 8 + 0.23 x 8 + 0.0 x [(1x9)/4] + 0.23 x 9 = 8.23.

GSI for Bridge C = 8.

Bridge D Calculation:

Geometric Safety Index = 0.54 x 8 + 0.23 x 8 + 0.0 x [(0x9)/4] + 0.23 x 0 = 6.16.

GSI for Bridge D = 6.

the frequency of fatalities due to poor bridge geometry. The indices should be viewed individually when possible to obtain a better understanding of each bridge's condition. However, combining them is convenient for rough ranking and sorting and gives a general indication of a bridge's level of safety. This, however, should not over shadow their intended use in combination with service indices in the computer program TEBS.

National accident records indicate that more than 90 percent of all bridge-related fatalities are caused by poor bridge geometry (Ref 16). Less than 10 percent are caused by structural failures. In Texas, so few bridges ever fail that records of bridge failures are not regularly kept. Most of those failures which do occur are washouts during flashfloods; consequently, there are few deaths associated with Texas bridge failures. Because of the relative infrequency of bridge failures, these statistics can be used only as rough estimates of the proportions of fatalities caused by each type of deficiency. Further, it is unclear how much of an effect current bridge program funding has on the proportion of structural failures. Certainly, there is some effect, since federal funding apportionments are based on structural conditions to a large degree. However, the current situation is one in which geometry-related fatalities dominate, suggesting that attention be focused on improving geometric characteristics of bridges. It is proposed that an overall safety index be formed by multiplying the Structural Safety Index and the Geometric Safety Index by their respective proportions of total bridge-related deaths, then summing the weighted indices. Ten percent and ninety percent are used herein to weight the SSI and the GSI respectively. New weights could, and certainly should be substituted, as they become available.

The simplest way to use the indices follows the federal Sufficiency Rating procedure in which bridges with low ratings receive high priority for funding. This procedure considers the bridge problem from the perspective of bridges. Bridges with the worst scores are funded first. The amount by which a candidate bridge project could be improved is not considered using this "worst first" method of prioritizing bridges for funding. For replacement projects, this is not an issue, since all replacement projects may be assumed to produce bridges which meet all current specifications. Replacement projects meeting current specifications will always result in "post-project" ratings of nine each for SSI and GSI. For replacement projects, prioritizing by the possible amount of improvement will produce the same ordering as prioritizing based on present conditions. Rehabilitation projects should be treated differently, because not all components of each bridge will be rehabilitated. The post-project indices will not necessarily both be nines. Different types of rehabilitation projects will raise the safety indices by different amounts. For example, improving guardrails will raise the GSI significantly, whereas improving the approach geometry will have less of an effect. Funding those bridges with the lowest safety indices does not consider the post-project safety levels of bridges and is therefore not recommended for rehabilitation projects. A better procedure for prioritizing rehabilitation projects would involve computing the post-project weighted-sum total of the safety indices. Assuming only one component will be rehabilitated for any single bridge, the component causing the largest increase in the combined safety indices should be assumed to be the rehabilitation project of choice.

For prioritizing replacement projects, the Structural Safety Index could replace the minimum condition rating on the roadway, substructure, and superstructure currently used in TEBS1. The Geometric Safety Index could similarly replace the bridge width condition variable currently used in TEBS1 but, again, only for replacement projects. The safety indices describe structural safety and geometric safety much better than the variables currently used in TEBS1 and could improve the program significantly.

Another way to use the Structural Safety and Geometric Safety Indices involves multiplying the potential safety gains by the average daily traffic counts to produce the public's total safety gain. This is a user-oriented approach, as it acknowledges the fact that safety gains are felt by every user of the bridge. Using this procedure allows decision makers to compare bridges which previously had been essentially incomparable. This procedure is explained in Example 4.3. Safety gains for bridges are in safety-gain-per-user units. Safety gains for the users are the total safety gains, that is, a bridge's safety gain multiplied by its average daily traffic.

Example 4.3 shows that a good decision from the point of view of a bridge may be less good from the point of view of a bridge's users. Because the bridge's safety gain is felt by each user, the gain in safety is much greater for the heavily used bridge. Note, however, that if Bridge G had an ADT of 3500, its users' safety gain would be 26,250 safety units, giving Bridge G approximately the same priority as Bridge H in terms of safety.

The method of comparing the users' safety gain can be improved by considering the cost of the proposed project. This procedure addresses the second goal of the program, that of maximizing the safety gained per dollar. Dividing the total safety gain by the project cost gives an index for cost effectiveness. Bridge G in the previous example had a project cost of $740,000 and Bridge H had a proposed project cost of $1,019,000. Replacing Bridge G would cost $987 for every unit of its users' safety gain. Replacing Bridge H would cost $39

Example 4.3 Using the Safety Indices

Bridges G and H are used to illustrate the concept of the public's total safety gain in bridge project prioritization. Both bridges are considered for replacement. The bridges exist in Texas.

	Bridge G	Bridge H
Sufficiency Ratings	49.5	29.6
Condition Ratings		
Superstructure	7	6
Substructure	4	4
Roadway	6	6
Channel	7	8
Approaches	6	6
Retaining Walls	7	7
Appraisal Ratings		
Roadway Geometry	2	5
Approach Roadway	3	8
Other Information		
Approach Roadway Width	20 feet	42 feet
Roadway Width	21.3 feet	30 feet
Guardrails	0000	0000
Average Daily Traffic	100	4000

Present Conditions		SSI	GSI	Combined*
Bridge G	6	1	1.5	
Bridge H	6	2	2.4	

Proposed Conditions	Combined*	Bridge's Gain	ADT	Public's Gain
Bridge G	9	7.5	100	750
Bridge H	9	6.6	4000	26,400

*The combined safety index equals 90 percent of GSI plus 10 percent of SSI.

for every unit of its users' safety gain. Bridge H is by far the cost effective choice in terms of the largest gain in safety for a given amount of funding.

The implementation of these indices into the present format of the computer program TEBS, however, does not require their direct combination with users and costs. The framework of TEBS has been established to allow the user of the program to distribute relative importance to variables which quantify the service a structure provides and variables which quantify the level of safety an existing structure has. The number of users and costs associated with a structure primarily compose the service that structure provides. But, within the framework of TEBS might be better quantified than by the combination of ADT and cost of proposed improvements shown above. While this combination above, may be demonstrative, these indices are proposed primarily for use within the Computerized Bridge Project Selection Program for Texas.

CHAPTER 5. CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH

Safety indices useful in evaluating the benefits resulting from replacing and rehabilitating bridges can be generated using existing data. The Structural Safety Index addresses safety from the point of view of bridge failures. The Geometric Safety Index addresses safety from the point of view of traffic accidents caused by substandard bridge geometry. Research reveals that geometric deficiencies are by far the major problem with bridges where safety is concerned.

Several assumptions were necessary during the course of this work. The most basic of these assumptions involved the National Bridge Inspection data. It was assumed that subjective ratings are made consistently and that data are recorded correctly. Without this, no index can completely succeed. It was also assumed that bridges are properly posted when necessary. This is extremely important from a structural safety perspective. The third assumption involved the relationship between accidents and the safety indices. The relationship was assumed to be linear.

The authors are aware that evaluating safety is only one part of a complete bridge project prioritization program. The level of service a bridge provides its users must also be considered. It is important to recognize that a bridge failure affects many more people than the unfortunate person who may happen to be on the bridge when it fails. A bridge failure can cost its users by requiring them to spend extra time on detours and by causing increased wear on alternate routes. Detours may be long enough to discourage trade in some areas.

It is suggested that the indices developed herein be used in place of current safety indicators. Eventually, the Structural Safety Index and the Geometric Safety Index could become part of a prioritization program based on user benefits and costs. Such a program requires substantial additional research, including:

(1) development of indices to measure the potential gain in the level of service provided by a bridge if chosen for replacement or rehabilitation,

(2) development of scales relating increases in the safety indices and level of service indices to dollars, and

(3) better methods of estimating costs for bridge work, particularly rehabilitation projects.

Bridge projects are considered individually in most selection algorithms. Optimization theory shows that a group of items optimized individually may not form an optimum group. Network optimization techniques should be applied to bridge project prioritization programs. Including the temporal variable, or when to fund a selected bridge project, would add another dimension to the solution.

Minor changes to the National Bridge Inspection Standards could lead to more sophisticated prioritization procedures than those currently in use. One change would be to retain the elemental condition ratings instead of the condition ratings for components. These data are collected during the course of every bridge inspection, but they are not recorded permanently. The ratings for elements are more descriptive of bridge conditions than are the ratings for components.

A second change to the National Bridge Inspection Standards is designed to use bridge inspectors more efficiently. Currently, every bridge in the country is thoroughly inspected every two years. These inspections involve gathering over 80 data items. Relatively brief bridge inspections focussing on critical features of bridges could be used to determine which bridges require the complete inspection to be made. This procedure would help bridge inspectors by giving them more time to inspect the bridges which deserve more attention. The current inspection procedure forces inspectors to fully inspect even bridges in nearly new condition.

The scale for condition ratings is more precise than the data can be. The condition rating procedure should be examined and better guidelines for determining ratings should be developed.

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APPENDIX A

CATALOG OF BRIDGE DEFICIENCIES BY BRIDGE TYPE

APPENDIX A. CATALOG OF BRIDGE DEFICIENCIES BY BRIDGE TYPE

The following information is from "Extending the Service Life of Existing Bridges," by R.H. Berger and Stanley Gordon, Transportation Research Record 664, 1978. This catalog of deficiencies lists the deficiencies in the order of frequency of occurrence.

SUPERSTRUCTURE

I. Primary Support System

A. Steel

1. Multiple Beam or Girder (Simple or Continuous Span)
   - Paint deterioration
   - Flange and/or web corrosion
   - Bearings inoperable
   - Collision damage to fascia stringers
   - Stiffener and other detail corrosion
   - Brittle fracture

2. Thru Girder or Twin Deck Girder (Simple or Continuous Span)
   - Paint deterioration
   - Flange and/or web corrosion
   - Bearings inoperable
   - Connections, stiffener and miscellaneous detail corrosion
   - Bracing member corrosion and damage
   - Collision damage to girders and/or kneebraces

3. Deck Truss, Thru Truss, Pony Truss (Simple Span)

Paint deterioration

Flange and/or web corrosion on stringers and floor beams

Bearings inoperable

Truss member corrosion

Collision damage to portal, truss member, or sway frame

Bracing member corrosion or failure

Connection corrosion

Inadequate design

B. Concrete

1. Slab (Simple or Continous Span)

Surface delamination

Surface spall, rebar exposure and corrosion

2. Multiple Beam and T beam (Simple or Continuous Spans)

Web crack

Surface spall, rebar exposure and corrosion

Collision damage

Bearings inoperable

3. Prestress or Post Tensioned Beams (Simple or Continuous Spans)

Surface spall, tendon exposure

Web and flange cracks

Bearings inoperable

C. Timber

1. Multiple Stringer (Simple or Continuous Spans)

Timber rot, surface weathering, and splits

Bearings inoperable

II. Decks

A. Reinforced Concrete

Wearing surface breakdown
Delamination
Surface spall and cracks
Joint inoperable

B. Open Grid Steel

Connection failure
Corrosion

C. Corrugated Metal

Wearing surface breakdown
Protective coating deterioration
Corrosion

D. Timber

Wearing surface breakdown
Weathering, splits, cracks, and rot
Failure of connections to support members

SUBSTRUCTURE

I. Abutments

A. Masonry

Mortar deterioration
Bearing seat deterioration
Scour

B. Concrete, Stub/Spill Thru

- Cracking and surface spall
- Bearing seat deterioration
- Settlement and/or rotation
- Back wall failure
- Erosion and/or scour

C. Concrete, Full Height

- Cracking and surface spall
- Bearing seat deterioration
- Settlement and/or rotation
- Back wall failure
- Erosion and/or scour

D. Timber-Bulkhead

- Decay and rot
- Insect infestation

II. Piers

A. Reinforced Concrete- Hammerhead/Solid Wall

- Cracks
- Bearing seat deterioration
- Pier nose deterioration
- Settlement and/or tilting
- Scour

B. Reinforced Concrete- Rigid Frame

- Cap beam spall, rebar exposure and corrosion
- Cracking in cap
- Bearing seat deterioration
- Column concrete deterioration
- Settlement and/or tilting

C. Masonry

- Mortar deterioration
- Erosion and/or scour

III. Bents

A. Timber Piles and Cap

- Pile decay and rot
- Cap weathering, splits, and cracks
- Insect infestation (marine borers)
- Scour

B. Concrete Pile and Cap

- Longitudinal cracks in pile
- Bearing seat deterioration
- Pile spall, rebar exposure and corrosion
- Cap spall, rebar exposure and corrosion
- Collision damage
- Scour

C. Steel H Pile- Concrete Cap

- Pile corrosion and section loss
- Cap spall, rebar exposure and corrosion
- Bearing seat deterioration
- Scour

MISCELLANEOUS

A. Drainage

Inadequate deck drainage (number and/or size of scuppers)
Drainage discharge on primary members
Snow and ice storage in contact with primary members
Leaking deck joints
Ground erosion at discharge point.

B. Geometrics

Inadequate roadway width
Inadequate vertical clearance
Approach alignment poor

C. Safety

Narrow roadway
Inadequate railing
Alignment and sight distance
Roadway surface deterioration

APPENDIX B

FEDERAL BRIDGE PROGRAM LEGISLATION

APPENDIX B. FEDERAL BRIDGE PROGRAM LEGISLATION

INTRODUCTION

Federal bridge programs contribute nearly three billion dollars toward bridge replacement and rehabilitation projects each year. This figure represents nearly 25 percent of the Federal Highway Administration's annual budget and includes funds from the Highway Bridge Replacement and Rehabilitation Program (HBRRP), the Interstate 4R (Resurfacing, Restoring, Reconstruction, and Rehabilitating) Program, and the Highway Safety Fund. The Highway Bridge Replacement and Rehabilitation Program is by far the largest single source of funds; its evolution through federal legislation is presented below.

HISTORY

The Silver Bridge between West Virginia and Ohio collapsed December 15th, 1967. Forty-six people died as a result of the collapse and another nine were injured, making it the worst American bridge disaster of the 20th century. The Silver Bridge collapse is almost universally cited as the event that alerted the public to the national bridge problem (Ref 7, p 1).

Immediately following the Silver Bridge collapse, President Lyndon Johnson established three task forces. The first was to determine the cause of the Silver Bridge collapse, the second to ensure a timely replacement for the bridge, and the third to examine the effectiveness of then-current bridge inspection techniques and procedures (Ref 17, p 7). The efforts of the third group are of interest here.

The third task force found that there was no national inventory of bridges and that inspection standards varied state to state. These findings prompted Congress to establish two major bridge safety programs: one to provide periodic bridge inspections for identifying bridge conditions, safety problems, and maintainance needs, and one to provide funding to assist states in replacing unsafe bridges. The first of these programs was established through passage of the Federal-Aid Highway Act of 1968 (Public Law 90-945, sec. 26, 82 Stat 815). This Act applied only to bridges on the Federal-Aid Highway system. The Federal-Aid Highway system consists of the national system of interstate and defense highways, the Federal-Aid urban system, the federal primary system, and the federal secondary system. These are described below.

"(a) The national system of interstate and defense highways consists of routes of highest importance to the nation, which connect the principal metropolitan areas, cities and industrial centers, including important routes into, through and around urban areas, serve the national defense, and connect at suitable border points with routes of continental importance in the Dominion of Canada and the Republic of Mexico.

(b) The Federal-Aid urban highway system is designated within urban areas of population over 5,000.

(c) The Federal-Aid primary system consists of routes of the national system of interstate highways and other important state routes, with their urban extensions, including important loops, belt highways and spurs. The latter are principal state highways which are usually through routes between population centers.

(d) The Federal-Aid secondary system consists of the principal secondary and feeder routes, including farm-to-market roads, rural mail and public school bus routes, local rural roads, and urban roads (Ref 18, p 2A-10)."

THE FEDERAL-AID HIGHWAY ACT OF 1968

The Federal-Aid Highway Act of 1968 established the National Bridge Inspection Program, requiring the Secretary of Transportation to specify standards for bridge inspections. The standards were to address inspection methods, the minimum time lapse between inspections, and the qualifications of bridge inspectors. The act also required the Secretary of Transportation to develop bridge inspection training programs for state and federal employees.

National Bridge Inspection Standards were published in the Federal Register (Ref 3, p 237) on April 27, 1971. These Standards require each state highway department to have "...a bridge inspection organization capable of performing inspections, preparing reports, and determining ratings in accordance with the provisions of the AASHTO Manual..."(Ref 19). Among the Standards are requirements for inspection procedures, frequency of inspection, qualifications of inspecting personnel, inspection reports, and inventories. The Standards also require bridges which cannot withstand the maximum state legal load to be posted for lower loads. Posting must conform either to AASHTO specifications or the applicable state law.

The first inspection inventory of Federal-Aid bridges was to be completed by July 1, 1973, just over two years from the date the specifications were made. Subsequent inspections are made "...at intervals not to exceed 2 years in accordance with section 2.3 of the AASHTO Manual..." (Refs 3 and 19). The Standards require the person in charge of each state's bridge inspection program to be either a registered professional engineer, qualified for registration under the laws of his State, or have a minimum of 10 years experience in bridge inspection assignments, "...in a responsible capacity..." (Refs 3 and 19). Persons qualifying under the latter must in addition complete a course in bridge inspection based on the Bridge Inspector's Training Manual. Persons leading inspection teams must also pass minimum qualification standards. If not meeting the above qualifications, the inspection team leader must have a minimum of five years experience in bridge inspection assignments, again "in a responsible capacity," and must additionally pass the bridge inspection course based on the Bridge Inspector's Training Manual. These requirements recognize that bridges are complex structures and that reliable inspections come only from reliable inspectors.

The National Bridge Inspection Standards require inspection findings to be published on standard forms. These forms include space for 90 data items but two are no longer recorded. Eighty-two items, ranging from the condition of the bridge deck to the minimum vertical clearance to the bridge's latitude and longitude, are required for all bridges; the remaining six items are used only if work is proposed for the bridge. These last data items include estimated project cost and the type of work proposed, among others. A complete list of inspection items is in Appendix D.

The National Bridge Inspection Program authorized states to use Federal-Aid Highway planning and research funds to finance their bridge inspections. However, it was not until passage of the Federal-Aid Highway Act of 1970 (Public Law 91-605, sec 204, 84 Stat 1713) that federal funds were available to assist states in replacing deficient bridges.

THE FEDERAL-AID HIGHWAY ACT OF 1970

The Federal-Aid Highway Act of 1970 established the Special Bridge Replacement Program (SBRP) and represented a change from previous federal policy. Initially, each state was to be responsible for maintaining its part of the national highway sytem, including its bridges, using only state funds (Ref 20, p 1). However, with increasing financial problems and increasing mileage to maintain, many states simply were not able to keep their bridges from deteriorating, and the Federal Highway Administration (FHWA) was forced to assume responsibility for replacement funding as well as new construction. One hundred million dollars were authorized for fiscal year 1972, and another $150 million were authorized for fiscal year 1973 in an effort to assist the states' efforts to replace unsafe bridges (Ref 7, p 3). The federal share of a bridge replacement project was allowed to be no more than 75 percent of the total project cost.

The Special Bridge Replacement Program did not specify how funds, appropriated from the Highway Trust Fund, were to be allotted (Ref 7, p 3). Rather, the Secretary of Transportation was instructed to inventory and classify all Federal-Aid bridges over water or topographical barriers in terms of their safety, essentiality, and serviceability (the degree to which a bridge serves its traffic). The Secretary was then to assign each bridge a priority for replacement, and, when states applied for assistance to fund a bridge under the program, the Secretary could authorize federal funding if the priority system showed the bridge was eligible. This procedure was somewhat vague and resulted, initially, in funding being distributed based on the priorities of the states. A procedure to distribute the remaining funds was developed based on states' needs and on the cost of previously selected projects.

The FHWA developed an index called the Sufficiency Rating and applied it to the as-yet-incomplete national inventory of bridges. The Sufficiency Rating is a number from zero to one hundred used to describe the sufficiency of a bridge to remain in service in its present condition. Structural adequacy and safety combined are given up to 55 points, serviceability and functional obsolescence are given up to 30 points, and essentiality for public use is given up to 15 points. The complete Sufficiency Rating formula is in Appendix C. A rating of zero represents an extremely deficient bridge, one in critically poor structural condition and with a high average daily traffic count. A rating of 100 represents an entirely sufficient bridge. Such a bridge requires no work. In general, the lower the rating, the higher the priority for funding (Ref 3, p 240). The FHWA sent a list of bridges with the lowest Sufficiency Rating scores to each state; states chose bridges from those lists and applied to the FHWA for funding.

As the initial inventory of the bridges was completed, the Secretary of Transportation allotted the remaining federal funds to states based primarily on each state's need relative to the total national need. The FHWA provided the states with larger lists of eligible bridges to choose from and the states determined how to spend the money allotted to them.

THE FEDERAL-AID HIGHWAY ACTS OF 1973 AND 1976

The next legislative action concerning bridge replacement was the Federal-Aid Highway Act of 1973 (Public Law 93-87, sec. 204, 87 Stat. 250). This law and the Federal-Aid Highway Act of 1976 (Public Law 94-280, sec. 202, 90 Stat. 425) continued the Special Bridge Replacement Program by committing $585 million from the Highway Trust Fund for fiscal years 1974 through 1978 (Ref 7, p 4). The distribution of funds is shown in Table B.1. These monies were available for funding replacement bridge projects so long as the bridge was eligible.

THE SURFACE TRANSPORTATION ASSISTANCE ACT OF 1978

The Surface Transportation Assistance Act of 1978 (Public Law 95-599, secs. 124 and 202, 92 Stat. 2689) replaced the Special Bridge Program with the Highway Bridge Replacement and Rehabilitation Program (HBRRP). This Act expanded the scope of the Special Bridge Replacement Program in two important directions. First, it allowed funds to be allocated for rehabilitating bridges. Previously, federal bridge program funds were used only for replacement projects. Second, the Act included bridges off the Federal-Aid Highway system for the first time. The Act defined "rehabilitation" as substantial repairs necessary to restore not only the structural integrity of a bridge but to correct major safety defects as well. Hence, projects to widen narrow bridges, for example, could now be eligible for federal funds. Deficient bridges with Sufficiency Ratings between 50 and 80 were eligible for rehabilitation funds, and deficient bridges with Sufficiency Ratings less than 50 were eligible for both replacement funds and rehabilitation funds. Deficient status was given to structurally deficient and functionally obsolete bridges as defined in Chapter 1. An additional provision of the Surface Transportation Assistance Act of 1978 was the requirement that bridges off the Federal-Aid Highway system be inspected and inventoried by December 31, 1980. Subsequent inspections were required at no more than two year intervals. States could

TABLE B.1. SBRP FUNDS AUTHORIZED, 1974-78

Fiscal Year	Amount Authorized
1974	$25 million
1975	$75 million
1976	$125 million
1977	$180 million
1978	$180 million
Total	$585 million

TABLE B.2. HBRRP FUNDS AUTHORIZED, 1979-82

Fiscal Year	Amount Authorized
1979	$900 million
1980	$1.1 billion
1981	$1.3 billion
1982	$900 million
Total	$4.20 billion

use federal funds to pay for the inspections, similar to the procedure used for the bridges on the Federal-Aid system.

Substantially more money was committed to the bridge program through this Act as shown in Table B.2. Funds were apportioned to the states based on their share of the total amount of money necessary to repair all deficient bridges nationwide by either replacement or rehabilitation. Each state received at least 0.25 percent but not more than 10 percent of the total funds available (Ref 1, p 3). States were given the authority to select any eligible bridge project for funding within the constraints of their appropriations.

This total federal appropriation of $4.2 billion was more than five times the $835 million allotted through the previous Acts combined. However, due to the facts that bridges off the Federal-Aid Highway system were now included and that the federal level of participation was increased to 80 percent, the money was used at a faster rate. The Act required 65 percent of the total apportionment to each state to be spent on bridges on the Federal-Aid Highway system and 15 percent to be spent on bridges off the the Federal-Aid Highway system. The remaining 20 percent could be spent either for bridges on the Federal-Aid Highway system or off it, at each state's discretion.

The Discretionary Bridge Fund

The Surface Transportation Assistance Act of 1978 also created the Discretionary Bridge Fund. This fund, $200 million of each year's appropriation, is used for replacing or rehabilitating bridges whose project costs are either over $10 million or more than twice the state's normal annual apportionment. The federal share of selected projects is 80 percent of total project cost. A rating factor is used to evaluate each candidate project's priority for the discretionary funds. The formula for the factor can be found in Ref 3, page 245. Special consideration is given to bridges with a load restriction of less than ten tons. Other considerations may influence the decision to fund, ultimately made at the Secretary of Transportation's discretion.

THE SURFACE TRANSPORTATION ASSISTANCE ACT OF 1982

The Surface Transportation Assistance Act of 1982 increased funding for the Highway Bridge Replacement and Rehabilitation Program to $7.05 billion, spread over fiscal years 1983 through 1986. These unprecedented funding levels were direct results of an increase in the federal gasoline tax from four to nine cents per gallon. The authorization for 1986 was reduced to $1.90 billion from $2.05 billion by the Consolidated Omnibus and Reconciliation Act of 1985, making the four-year total $6.90 billion (Ref 1, p 12). Appropriations for fiscal years 1983 through 1986 are summarized in Table B.3.

Under the 1982 Act, apportionments to states are made based on their relative needs. Bridge projects are eligible for federal funds if their Sufficiency Ratings are less than 80 (for rehabilitation projects) or 50 (for replacement projects). In addition, candidate bridges must be structurally deficient or functionally obsolete.

TABLE B.3. HBRRP FUNDS AUTHORIZED, 1983-86

Fiscal Year	Amount Authorized
1983	$1.6 billion
1984	$1.65 billion
1985	$1.75 billion
1986	$1.90 billion
Total	$6.90 billion

APPENDIX C

SUFFICIENCY RATING FORMULA

APPENDIX C. SUFFICIENCY RATING FORMULA

The sufficiency rating is calculated from the BRINSAP data as follows:

SUFFICIENCY RATING = $S_1 + S_2 + S_3 - S_4$ where

S_1, S_2, S_3, and S_4 are as given below. In the following calculations the # symbol refers to the item numbers in Texas' BRINSAP data file. Numbering for data files kept by other states may be different.

(1) S_1, STRUCTURAL ADEQUACY AND SAFETY (55 maximum, 0 minimum)

$S_1 = 55 - (A + I)$ where neither A nor I shall exceed 55 and neither shall be less than 0.

(a) Reduction for Deterioration

If the lowest of #59 (Superstructure Rating) or #60 (Substructure Rating) is

≤ 2	then	$A = 55$
$= 3$	then	$A = 40$
$= 4$	then	$A = 25$
$= 5$	then	$A = 10$
≥ 6 (or = N)	then	$A = 0$

(b) Reduction for Load Capacity

$$I = (36 - AIT)^{1.5} \times 0.2778$$

where

AIT (Adjusted Inventory Tonnage) is calculated as follows. If the 1st digit of #66 (Inventory Rating) is

1	then	AIT	=	the 2nd and 3rd digits x 1.56
2	then	AIT	=	the 2nd and 3rd digits x 1.00
3	then	AIT	=	the 2nd and 3rd digits x 1.56
4	then	AIT	=	the 2nd and 3rd digits x 1.00
5	then	AIT	=	the 2nd and 3rd digits x 1.21
6	then	AIT	=	the 2nd and 3rd digits x 1.21
9	then	AIT	=	the 2nd and 3rd digits x 1.00

(2) S_2, SERVICEABILITY AND FUNCTIONAL OBSOLESCENCE (30 maximum, 0 minimum)

$$S_2 = 30 - [J + (G + H) + I]$$

where

J shall not exceed 13, (G + H) shall not exceed 15, and I shall not exceed 2.

(a) Rating Reductions

If #58 (Roadway Condition) is

≤ 3 A = 5
= 4 A = 3
= 5 A = 1
$\geq$ 6 (or = N) A = 0

If #67 (Structural Condition) is

≤ 3 B = 4
= 4 B = 2
= 5 B = 1
$\geq$ 6 (or = N) B = 0

If #68 (Roadway Geometry) is

≤ 3 C = 4
= 4 C = 2
= 5 C = 1
≥ 6 (or = N) C = 0

If #69 (Underclearances) is:

≤ 3 D = 4
= 4 D = 2
= 5 D = 1
≥ 6 (or = N) D = 0

If #71 (Waterway) is

≤ 3 E = 4
= 4 E = 2
= 5 E = 1
≥ 6 (or = N) E = 0

If #72 (Approach Road Alignment) is

≤ 3 F = 4
= 4 F = 2
= 5 F = 1
≥ 6 (or = N) F = 0

$$J = (A + B + C + D + E + F)$$

(b) Width of Roadway Insufficiency

Y = #51 (Roadway Width) Π First two digits of #28 (Lanes)
If Item 5.6 = 1, 2, or 8: X = #29 (ADT) ÷ First two digits of #28 (Lanes)

If Item 5.6 = 3 or 4: X = #29A (ADT) ÷ First two digits of #28.
Item 5.6 is used to describe the structure's function.

i. For all bridges except culverts. Use when #43.4 (Structure Type, Culvert) is blank or 0.

If (#51 + 2') < #32 (Appr. Rdwy. Width): G = 5
If (#51 + 2") ≥ #32: G = 0

ii. For one-lane bridges only (culverts included).

If the first 2 digits of #28 = 01 and

$Y > 14$	$H = 15$
$Y \leq 14 < 18$	$H = 15 \frac{18 - Y}{4}$
$Y \leq 18$	$H = 0$

iii. For two or more lane bridges (culverts included).

If first 2 digits of #28 = 02 & Y ≥ 16; H = 0
If first 2 digits of #28 = 03 & Y ≥ 15; H = 0
If first 2 digits of #28 = 04 & Y ≥ 14; H = 0
If first 2 digits of #28 ≥ 05 & Y ≥ 12; H = 0

Note: If one of the above four conditions are met, do not continue on with iii as no lane width reductions are allowed.

If $50 < x \leq 125$ and:

$Y < 10$	then	$H = 15$
$Y \geq 10 < 13$	then	$H = 15 \frac{13-Y}{3}$
$Y \geq 13$	then	$H = 0$

If $125 < X \leq 375$ and:

$Y < 11$	then	$H = 15$
$Y \geq 11 < 14$	then	$H = 15 \frac{14-Y}{3}$
$Y \geq 14$	then	$H = 0$

If $375 < X \leq 1350$ and:

$Y < 12$	then	$H = 15$
$Y \geq 12 < 16$	then	$H = 15 \frac{16-Y}{4}$
$Y \geq 16$	then	$H = 0$

If $X > 1350$ and:

$Y < 15$	then	$H = 15$
$Y \geq 15 < 16$	then	$H = 15 (16 - Y)$
$Y \geq 16$	then	$H = 0$

(c) Vertical Clearance Insufficiency

If #12 (Defense Road) > 0 and:

#53	≥	1600	then	I	=	0
#53	<	1600	then	I	=	2

Item 53 describes the minimum vertical clearance over the bridge roadway. The first two digits represent feet, the last two digits represent inches.

If #12 = 0 and:

#53	≥	1400	then	I	=	0
#53	<	1400	then	I	=	2

(3) S_3, ESSENTIALITY (15 maximum, 0 minimum)

$$S_3 = 15 - (A + B)$$

(a) Public Use

$$A = \frac{*\,(\text{ADT}) \times *\,(\text{Detour Length})}{200{,}000 \times K} \times 15 \text{ where}$$

$$K = \frac{S_1 + S_2}{85}$$

(b) Military Use

If #12	>	0	B	=	2
If #12	=	0	B	=	0

(4) SPECIAL REDUCTIONS (Use only when $S_1 + S_2 + S_3 \geq 50$)

$$S_4 = A + B + C$$

(a) Detour Length Reduction:

$$A = *(\text{Detour Length})^4 \times (5.205 \times 10^{-8}) \qquad \text{Max.} = 5$$

(b) Structure Type Reduction:

If the 1st digit of #43.1 is a 7 or 8, or if the 2nd digit is a 2, 3, 4, 5, 6, or 7, then;
B = 5

(c) Highway Safety Feature Reduction:

If 2 digits of #36 = 0; C = 1
If 3 digits of #36 = 0; C = 2
If 4 digits of #36 = 0; C = 3

*If Item 5.6 = 1, 2 or 8 use #29 (ADT) and #19 (Detour Length)
If Item 5.6 = 3 or 4 use #29A (ADT) and #19A (Detour Length) for the so-called "other route." Data for the other route is used when the bridge is an under pass.

APPENDIX D

NATIONAL BRIDGE INVENTORY DATA

APPENDIX D. NATIONAL BRIDGE INVENTORY DATA

National Bridge Inventory data are recorded for every bridge in the country. Data are gathered through visual inspections and review of plans. The National Bridge Inspection Standards require each bridge "...to be inspected at regular intervals not to exceed two years..." (Ref 3, p. 237). The National Bridge Inventory data are listed below. Detailed descriptions may be found in Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges 1979 (Ref 21).

IDENTIFICATION CODES

Item 1	State Code
Item 2	State Highway Department District
Item 3	County or Parish
Item 4	City or Town Code
Item 5	Inventory Route
Item 6	Feature Intersected
Item 7	Facility Carried by Structure
Item 8	Structure Number
Item 9	Location
Item 10	Minimum Vertical Clearance
Item 11	Milepoint
Item 12	Road Section Number
Item 13	Bridge Description
Item 14	Defense Milepoint
Item 15	Defense System Length
Item 16	Latitude
Item 17	Longitude
Item 18	Physical Vulnerability
Item 19	Bypass Detour Length
Item 20	Toll

Item 21 Custodian
Item 22 Owner
Item 23 Federal-Aid Project Number

CLASSIFICATION CODES

Item 24 Highway System
Item 25 Administrative Jurisdiction
Item 26 Functional Classification

STRUCTURE DATA

Item 27 Year Built
Item 28 Lanes On and Under the Structure
Item 29 Average Daily Traffic
Item 30 Year of Average Daily Traffic
Item 31 Design Load
Item 32 Approach Roadway Width
Item 33 Bridge Median
Item 34 Skew
Item 35 Structure Flared
Item 36 Traffic Safety Features (Guardrails)
Item 37 This item is left blank.
Item 38 Navigation Control
Item 39 Navigation Vertical Clearance
Item 40 Navigation Horizontal Clearance
Item 41 Structure Open, Posted, or Closed to Traffic
Item 42 Type of Service
Item 43 Structure Type, Main
Item 44 Structure Type, Approach Spans
Item 45 Number of Spans in Main Unit

Item 46	Number of Approach Spans
Item 47	Total Horizontal Clearance
Item 48	Length of Maximum Span
Item 49	Structure Length
Item 50	Curb or Sidewalk Widths
Item 51	Bridge Roadway Width, Curb-to-Curb
Item 52	Deck Width, Out-to-Out
Item 53	Minimum Vertical Clearance Over Bridge Roadway
Item 54	Minimum Vertical Underclearance
Item 55	Minimum Lateral Underclearance on Right
Item 56	Minimum Lateral Underclearance on Left
Item 57	Wearing Surface and Protective System
Item 58	Roadway Condition Rating
Item 59	Superstructure Condition Rating
Item 60	Substructure Condition Rating
Item 61	Channel and Channel Protection Condition Rating
Item 62	Culvert and Retaining Walls Condition Rating
Item 63	Estimated Remaining Life
Item 64	Operating Rating
Item 65	Approach Condition Rating
Item 66	Inventory Rating
Item 67	Structural Condition Appraisal Rating
Item 68	Deck Geometry Appraisal Rating
Item 69	Underclearances, Vertical and Horizontal (Appraisal Rating)
Item 70	Safe Load Capacity Appraisal Rating
Item 71	Waterway Adequacy Appraisal Rating
Item 72	Approach Roadway Alignment Appraisal Rating

PROPOSED IMPROVEMENTS

Item 73	Year Needed
Item 74	Type of Service

Item 75	Type of Work
Item 76	Length of Improvement
Item 77	Proposed Design Loading of Improvement
Item 78	Proposed Roadway Width
Item 79	Proposed Number of Lanes
Item 80	Design ADT
Item 81	Year of Estimated ADT
Item 82	Year of Proposed Adjacent Roadway Improvements
Item 83	Type of Proposed Roadway Improvements
Item 84	Cost of Improvements
Item 85	Preliminary Engineering Cost
Item 86	Demolition Cost
Item 87	Substructure Cost
Item 88	Superstructure Cost
Item 89	This item is no longer used
Item 90	Inspection Date