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16. Abstract

This report presents a discussion of selected techniques that can be used to rank major highway construction projects. A study advisory committee provided recommendations on factors and weights to be used in project ranking. A limited sensitivity analysis of some suggested changes in current sufficiency ratings is presented. Possible techniques that can be used on projects of three types are discussed: (1) added-capacity, (2) upgrade-to-standards, and (3) new location (bypasses, loops, and other new locations). Emphasis is placed on comparing nine different techniques for ranking added-capacity projects by comparing 1,942 added-capacity projects.

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NEW APPROACHES TO PROJECT RANKING:

COMPARISONS USING ADDED CAPACITY PROJECTS IN TEXAS

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Research Report No. 337-1F
Research Study No. 2-8-84-337
New Approach to Project Ranking and
Allocation of Construction Funds

Sponsored by

Texas State Department of Highways and Public Transportation
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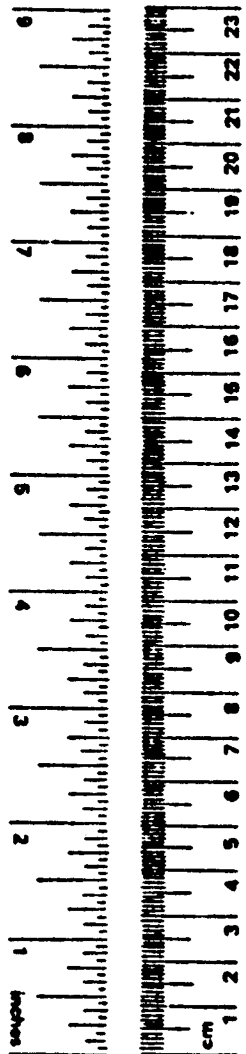
November 1985

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas

METRIC CONVERSION FACTORS

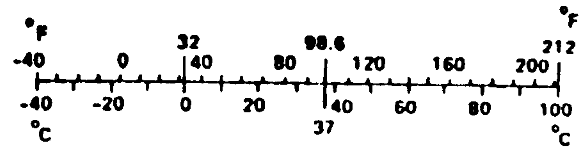
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

PREFACE

This report represents the results of a cooperative research effort and the authors are indebted to several employees of the Texas State Department of Highways and Public Transportation (DHT) for their assistance throughout the study. Byron Blaschke, formerly head of the Design Division and now Deputy Director, Design and Construction, was instrumental in setting up the study. Frank Holtzmann, current head of the Design Division (D-8), and other D-8 staff members assisted researchers with the study and developed several of the ranking techniques tested in the study. The authors are especially indebted to Harold Cooner, the Study Contact Representative, for his special input and assistance throughout the project. Billy Rogers of the Design Division and Bubba Williamson, formerly with the Design Division, also assisted with and made contributions to the study.

Special thanks are due the DHT District Engineers who served on a Study Advisory Committee: Bobby Evans, Bill Lancaster, J. R. Stone, and Raymond Stotzer, and also Bill Ward (formerly Engineer-Director of the Houston Urban Office).

The authors are indebted to several TTI staff members for their assistance with the study. Dr. J. L. Buffington assisted with the literature review and the evaluation of Advisory Committee ratings. Ms. Margaret Chui assisted with computer analyses. Mr. Eric Schulte assisted with the evaluation of Advisory Committee ratings. Ms. Pat Holmstrom assisted with the study and typed this report.

This study was prepared by the Texas Transportation Institute for the Texas Department of Highways and Public Transportation. It was prepared in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

SUMMARY OF FINDINGS

This report presents nine techniques that can be used to rank added-capacity projects. Six of these nine techniques have previously been considered for use by the State Department of Highways and Public Transportation (DHT) and three of the techniques were developed in this study. The three new techniques are the Texas Priority Formula, the Texas Ranking Formula, and the Modified HEEM-II benefit-cost technique. The Texas Priority Formula is based on changes in the sufficiency rating, as rated using the Texas Sufficiency Rating schedule, developed previously by personnel in DHT's Design Division (D-8). The Texas Ranking Formula is a composite technique that develops a ranking of projects based on a weighted average of rankings from three other techniques and is based on a concept used previously in Florida. The Modified HEEM-II technique was developed by making modifications to the HEEM-II benefit-cost program, a program that has previously been used in Texas.

A Study Advisory Committee provided suggestions on the categories and weights for factors that should be considered in ranking different types of construction projects. Most of the major factor categories that were considered important by the Advisory Committee already are included in the Texas Sufficiency Rating schedules but several new factors were recommended. The most important of these factors were accident rates, district priority, maintenance costs, drainage deficiencies, pavement condition, and passing opportunity. The Advisory Committee also gave recommended weights for the existing sufficiency rating categories. These weights agreed quite well with existing weights. A sensitivity analysis indicated that rankings using the recommended weights were almost identical to rankings using the existing category weights.

The nine ranking techniques for added-capacity projects were compared using a group of 1,942 added-capacity projects, including almost all of the major added-capacity projects that currently are being considered for improvement in Texas during the next twenty years.

Based on the criteria used in this study to compare techniques, the best overall method appears to be the Modified HEEM-II benefit-cost technique. It is clearly the best technique if benefits are being measured accurately. For a ten-year budget of $5.7 billion, the Modified HEEM-II ranking resulted in projects with over $22 billion more benefits than the Sufficiency Rating technique or the Cost per Vehicle Mile, Present ADT technique. Since benefits are calculated using Modified HEEM-II, the critical question is whether this program considers all benefits and estimates benefits accurately. The magnitude of the difference in benefits between techniques, nevertheless, is substantial and, at a minimum, is deserving of further study. It is recommended that a continuing effort be made to improve techniques for estimating expected benefits.

For projects other than added-capacity projects, several ranking techniques are presented, but no comparisons of rankings are made because additional data are needed. It is recommended that such data be compiled and that these ranking techniques be compared using projects in the twenty-year planning list, as was done with added-capacity projects.

IMPLEMENTATION STATEMENT

This report presents a comparison of techniques for ranking added-capacity projects. Some of these techniques are currently used by the State Department of Highways and Public Transportation and other techniques were developed during this study. Results of the comparisons of techniques indicate that the Modified HEEM-II technique is one of the better techniques by each of the criteria considered. By explicitly comparing the expected motorist benefits, less any increase in maintenance costs, to the initial cost of the project, the Modified HEEM-II rankings have the desirable property of maximizing expected future benefits for a given budget for added-capacity projects. It is recommended that the Modified HEEM-II rankings be used, together with other relevant information, to set priorities for funding added-capacity projects. Also, a continuing effort should be made to improve techniques for estimating expected benefits, expected maintenance costs, and expected initial costs.

Techniques for ranking projects other than added-capacity projects should be further developed and tested prior to implementation. This report gives an indication about which techniques appear most promising for these other project types.

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CHAPTER I. INTRODUCTION

This report presents the results of a research study entitled "New Approach to Project Ranking and Allocation of Construction Funds". There are three major objectives of this study: (1) identify the relevant goals and factors to be used in ranking highway projects, (2) determine the weighting scheme to be used in the ranking process, and (3) develop a computer program to rank projects within categories.

In this report, emphasis is placed on added-capacity projects which include projects that provide additional lanes or that convert the highway from non-freeway to freeway, or changed the highway from undivided to divided. In addition, information is presented on possible techniques that can be used to rank upgrade-to-standards projects and some types of new location projects. Before techniques can be compared for ranking these other types of projects, however, additional data would need to be collected on different types of projects.

In Chapter II, different techniques that can be used to rank highway projects are discussed. Emphasis is placed on added-capacity projects with some discussion of techniques for upgrade-to-standards and new location projects. In Chapter III, an evaluation is given of the categories and weights that are included in sufficiency ratings. This evaluation includes presentation of the recommendations of a study advisory committee and also the results of selected sensitivity analyses of possible changes in the current Texas Sufficiency Rating schedule for added-capacity projects. Chapter IV presents and compares the rankings of 1,942 added-capacity projects given by nine different ranking techniques. Rankings from the nine techniques also were compared to DHT selections, but there are several limitations to these comparisons, as discussed on page 41 of the report. Comparisons are made of the benefits provided by different rankings at selected budget levels. This chapter also has a discussion of rank correlation coefficients and comparisons of rankings by deciles of project cost. Chapter V presents the summary and conclusions for the study.

CHAPTER II. PROJECT RANKING TECHNIQUES

Types of Techniques Studies

A survey of literature identified five basic types of techniques that are used for ranking highway projects in the United States: (1) sufficiency rating techiques, (2) priority formulas or cost-effectiveness techniques based on changes in sufficiency ratings, (3) cost-effectiveness techniques other than those based on sufficiency ratings, (4) benefit-cost analysis, and (5) combinations of two or more of the first four listed techniques.

Prior to the time this study began, the Texas State Department of Highways and Public Transportation (DHT) had used, or studied for use, three of the above types of techniques. Existing DHT techniques included: (1) sufficiency ratings for different types of highway projects with different rating categories and numbers of points for added-capacity projects and upgrade-to-standards projects [1]; (2) cost-effectiveness formulas that consider present or projected traffic volume (relative to capacity), project length, project cost; and (3) benefit-cost techniques, two of which have been developed for use by DHT, a revised and updated version of the Highway Economic Evaluation Model, HEEM-II [2], and the Delay Savings Model [3]. The HEEM-II benefit-cost model was designed to analyze a large variety of urban and rural projects but has mainly been used in Texas to assist in comparing alternative designs for large urban projects and had not been used for ranking large numbers of projects.

In addition to the techniques that existed at the time this study began, this research included evaluation of two other cost-effectiveness techniques developed by DHT in response to requests by others, referred to as cost per present vehicle mile of travel and cost per future projected vehicle mile of travel; and three new techniques proposed by the study staff, as discussed below.

Based on the literature review and discussions with the Project Advisory Committee, a decision was made to develop three new (or modified) techniques in addition to the existing techniques for testing in Texas. These new techniques are: (1) a new version ("Modified HEEM-II") of the HEEM-II benefit-cost model that is modified to be used with less data than the original HEEM-II, (2) Priority Formula based on changes in the Texas sufficiency rating and other variables for added capacity projects, and (3) a Ranking

Formula that develops a ranking based on a weighted average of rankings developed from the other techniques.

Figure 1 presents a summary listing of the nine specific techniques considered in this study and are shown in the five general categories that were delineated. The formulas used for each of these techniques are discussed in more detail in the following sections of this chapter.

Highway Sufficiency Ratings

Highway sufficiency ratings are used to evaluate existing highways using engineering standards. These ratings are the outgrowth of procedures developed beginning in 1933, "...to describe on maintenance inspection reports the condition, safety, and service features of completed Federal-aid highway improvements that had deteriorated or become obsolete to the degree that reconstruction was warranted because of unduly high maintenance costs." [4]. Later, in 1946 and 1947, the Bureau of Public Roads, "...field tested a system for numerically rating the three elements of highway condition (structural, safety, and service) which would provide greater precision and uniformity and would permit complete coverage of the rural portions of the Federal-aid primary highway system." In 1947, Region IX of the Bureau of Public Roads adopted the rating plan and by 1951 it was extended to the remaining division offices in the continental United States as a part of maintenance inspection procedures.

Many state administrators faced with increased public demand for road improvements also adopted sufficiency ratings for state use. By June 1960, according to a Highway Research Board survey, thirty-eight states used some type of sufficiency rating [5, p. 84].

Sufficiency ratings are an index usually consisting of three categories, each having several subunits with weights that typically sum to 100 points if the highway is totally sufficient. Highways with the lowest ratings are considered to be the ones most in need of improvement.

The principal strengths of sufficiency ratings are that they are objective, fairly easy to use, and are easy to explain to the public. There are two principal weaknesses of sufficiency ratings. First, originating as they did from maintenance inspection reports, there historically has not been

1. SUFFICIENCY RATINGS

- o Texas Sufficiency Rating, Added Capacity Projects and Upgrade-to-Standards Projects

2. COST-EFFECTIVENESS BASED ON SUFFICIENCY RATINGS

- o Texas Priority Formula, Added Capacity Projects

3. OTHER COST-EFFECTIVENESS TECHNIQUES

- o Future Cost Index
- o Present Cost Index
- o Cost/Vehicle Miles, Present ADT
- o Cost/Vehicle Miles, Future ADT

4. BENEFIT-COST ANALYSIS

- o Delay Savings Ratio
- o Modified HEEM-II

5. COMBINATION OF OTHER TECHNIQUES

- o Ranking Formula

Figure 1. Types of Ranking Techniques and Specific Formulations Considered in This Study.

enough emphasis on capacity in rating highways that have deficient capacity and geometric standards. Second, the ratings are a measure only of how deficient the existing highway is and do not give an indication of the benefit and cost associated with improvements to correct deficiencies.

Even though many states have evaluated highways using sufficiency ratings, it is not clear how much these ratings have been used to set improvement priorities. Many states undoubtedly use other techniques and evaluations in addition to sufficiency ratings. The Texas Department of Highways and Public Transportation (DHT) in the past has not relied on sufficiency ratings as much as have some other states. However, two different sufficiency rating schedules have been developed in Texas for possible use, along with other evaluations, is setting priorities. The Texas ratings are somewhat different from typical ratings in several respects. First, the rating schedules are set up so that the highways most in need of improvement are given higher ratings with a maximum of 100 points. Second, and more important, two different schedules have been developed, one for added-capacity projects (mainly adding lanes, providing medians, and controlling access) and upgrade-to-standards projects. The Texas schedules represent a major improvement over typical schedules for purposes of setting priorities because they focus more on the categories of deficiency that would be affected by improvements. The added-capacity schedule emphasizes present and future capacity for the existing highway relative to present and forecasted traffic volumes. The upgrade-to-standards schedule focuses on items that cause the need for upgrading. These schedules are presented in Chapter III.

Cost-Effectiveness Techniques Based on Sufficiency Ratings

Recognizing the shortcomings of sufficiency ratings for setting priorities for highway improvement, the Federal Highway Administration and several states have developed other priority formulas. This type of technique is referred to here as a cost-effectiveness technique based on sufficiency ratings because the formulas represents a ratio of effectiveness to cost (or cost per highway or lane mile). Effectiveness is measured by the change in the sufficiency rating between the existing and improved highways, multiplied by the annual average daily traffic. The change in the sufficiency rating is taken to represent the effectiveness of the proposed highway improvement per vehicle mile and is then weighted by vehicle miles to obtain total effectiveness. There are several variations of this general procedure; examples include the technique used by Minnesota [6], the PRIPRO formula developed by FHWA [7], and the cost-effectiveness procedure used in the Highway Performance Monitoring System [8].

In this study a somewhat similar technique was developed for testing in Texas. In this report this technique is referred to as the Texas Priority Formula since it is based on the Texas sufficiency rating and has other features that distinguish it from other formulations used elsewhere. There are two variations on this Priority Formula, one for added-capacity projects and one for upgrade-to-standards projects. Only the added-capacity formulation is discussed extensively in this report. The general equation for this Priority Formula is:

$$PF = (SR_E - SR_P)(1 + \frac{P}{100})(\frac{2}{3}CADT + \frac{1}{3}FADT)(LTH)/CST$$

where:

PF = priority formula rating

SR_E = sufficiency rating for existing facility

SR_P = sufficiency rating for proposed facility

P = sufficiency points for categories that do not change with improvement

CADT = current annual average ADT

FADT = forecasted (typically 20 years in the future) annual average ADT

LTH = project length in miles

CST = initial highway construction and right-of-way cost in thousands of dollars

The first factor in the Priority Formula represents the change in the sufficiency points as a result of the improvement. Because the Texas Sufficiency Ratings give higher point totals to more deficient highways, this change is obtained by subtracting the sufficiency rating for the proposed highway from the sufficiency rating for the existing highway. This can be viewed as a proxy for the benefits per vehicle of the project. The second factor is an adjustment for those categories in the sufficiency rating which do not change as a result of the improvement and are, therefore, not reflected in the first term. In Table 1 in Chapter III, these are shown as categories 4, 5, and 6. The third factor is a weighted average of the current and future ADT. If the first two terms are viewed as adjusted benefits per vehicle, then multiplying by the total vehicles gives a measure of total benefits. The weighting of current and future ADT represents both the increasing number of vehicles over time and the lower present value of future benefits through discounting. The formula is then multiplied by project length and divided by project cost the produce a measure of the desirability of a project.

The Texas Priority Formula is not a benefit-cost ratio because the benefits are not measured in dollars. It is a cost-effectiveness index measuring the amount of benefits (or effectiveness) per dollar of construction cost. Each variation of the sufficiency rating, presented in Chapter III, can be used in the Priority Formula so there is a separate Priority Formula ranking associated with each sufficiency ranking.

Other Cost-Effectiveness Techniques

Four cost-effectiveness formulas based on criteria other than sufficiency ratings have been developed by DHT for possible use in ranking projects [1]. Two of these are referred to as the Present Cost Index (or Index One) and the Future Cost Index (or Index Two). These are essentially ratios of the amount of congestion on the existing facility, as measured using present or future ADT, divided by project cost. These two formulas are:

$$C = \frac{(CADT - T2)\ (LTH)}{CST}$$

$$F = \frac{(FADT - T2)\ (LTH)}{CST}$$

where

C = Present Cost Index (or Index 1)

F = Future Cost Index (or Index 2)

CADT = Current ADT

FADT = Future ADT

T2 = upper limit of average daily traffic volume for a "tolerable" level of service (shown as the higher volume for level of service C-D in Table 3 on page 18 of this report), on the existing facility

LTH = project length in miles

CST = initial highway construction and right-of-way cost in thousands of dollars

In both of these formulas, if the ADT is less than the congestion level (T2) the index is zero. However, for ranking purposes, this would produce numerous ties at zero. Therefore, for purposes of ranking projects in this study, both formulas are allowed to be negative.

The other two cost-effectiveness formulas provide an estimate of the cost per vehicle mile traveled on the existing road section to be improved where the two formulations use either current or future traffic. These formulas are referred to as the Cost per Vehicle Mile Traveled, Present ADT and the Cost per Vehicle Mile Traveled, Future ADT. These two formulas are ratios of cost of the highway improvement to effectiveness, so higher priority is given to proposed improvements having lower values of the ratio. These formulas are:

V = CST/(CADT)(LTH)

M = CST/(FADT)(LTH)

where:

V = the Cost per Vehicle Mile Traveled, Present ADT

M = the Cost per Vehicle Mile Traveled, Future ADT

CST = initial highway construction and right-of-way cost in thousands of dollars

CADT = present average daily traffic volume in vehicles per day

FADT = future forecasted average daily traffic volume in vehicles per day

LTH = project length in miles

Benefit-Cost Analysis

Two different benefit-cost models are used in this study to rank added capacity projects. The first of these, the Delay Savings Ratio, was developed in previous research [3] and is an abbreviated benefit-cost technique that calculates the ratio of the reduction in delay cost, provided by a highway improvement, to the initial project cost. The second benefit-cost model, referred to as Modified HEEM-II, was developed in this study by simplifying the HEEM-II program [2] so that the modified version could be run efficiently with a large number of added-capacity projects. The Modified HEEM-II technique calculates the ratio of expected project benefits to project costs where benefits are calculated as reductions in time costs, vehicle operating costs, accident costs, and maintenance costs resulting from the highway improvement. Expected project benefits are calculated as the present value of annual benefits taken over a twenty year analysis period.

Combinations of Other Techniques

Some ranking techniques have been developed by combining ratings from other techniques. Good examples of this approach are the formulas used by Minnesota [6]. Minnesota's combined rating for resurfacing and reconditioning projects is a weighted average of the condition rating (70%), the cost-effectiveness ratio (20%), and a rating for the highway's functional class (10%). The combined rating for reconstruction and major construction projects is more complex in that it is a weighted average of the sufficiency rating (35%); the cost-effectiveness rating based on the change in the condition rating sub-category of the sufficiency rating (20%); a rating for goods movement (20%); a rating for peak month traffic (5%); and a rating for functional class (20%). One difficulty with this type of formula is that it is a weighted average of such diverse elements that the resulting number is difficult to interpret. Also, the rating is directly dependent on the scale of the variables used in the different ratings.

A somewhat different formula was developed in this study from a concept used by Florida [9]. Called the Ranking Formula, it is a combination formula that develops a ranking from the weighted average of other rankings, not from a weighted average of other ratings. Florida's ranking formula uses an average of rankings from using a sufficiency rating, a change in the sufficiency rating, and a cost-effectiveness index, each weighted one-third.

The Ranking Formula developed in this study is an equally weighted average of the rankings given by the Texas Priority Formula, the Delay Savings Ratio, and the Modified HEEM-II benefit-cost program:

$$R = (R_P + R_H + R_D)/3$$

where:

R = the project rating using the Ranking Formula

R_P = the ranking of the project using the Texas Priority Formula

R_H = the ranking of the project using the Modified HEEM-II benefit-cost program

R_D = the ranking of the project using the Delay Savings Ratio

This formula is used to calculate a rating (or average ranking) which then is arrayed in ascending order to derive a new priority ranking for all projects. For example, if a project is ranked 7, 23, and 6 using the three techniques, its rating for the Ranking Formula would be (7+23+6)/3 = 12. This type of rating also can easily be changed to a scale of zero to 100 simply by dividing by the number of projects and multiplying by 100 where the project most in need of improvement would have the lowest value (or by taking 100 minus the rating, the project with the highest number would be the one most in need of improvement).

Techniques for Projects Other Than Added-Capacity Projects

In this report, emphasis is placed on the ranking of added-capacity projects, with the exception of the discussion in Chapter III, which presents sufficiency rating schedules for both added-capacity projects and upgrade-to-standards projects. Also given in Chapter III are some factors and weights that the Project Advisory Committee noted as being important for new location projects (including bypasses, loops, and other new locations). The purpose of the discussion in this section is to present some preliminary thoughts on how the different techniques discussed in this chapter can be used to rank projects other than added-capacity projects, including upgrade-to-standards projects and new location projects.

Upgrade-to-Standards Projects

As discussed previously, a sufficiency rating schedule, which is presented later in Chapter III, has been developed by DHT for possible use in ranking upgrade-to-standards projects. These types of projects typically entail improvements in lane width, shoulder width, and horizontal and vertical alignment. In addition, the pavement structure and riding surface typically are improved.

The same general Priority Formula that is used for added-capacity projects can also be used with upgrade-to-standards projects, the difference being that the changes between the existing and proposed highways would use factors in Table 2 instead of Table 1 (in Chapter III). In addition, additional data would have to be provided in the project data files to cover the rating categories for the proposed highway. Since this data is not currently available, no tests have been made of the Priority Formula with upgrade-to-standards projects.

Two of the cost-effectiveness formulas can be used with upgrade-to-standards projects, the formulas that calculate cost per vehicle mile traveled, with either present or future ADT. These formulas have the disadvantage, however, that no attempt is made to estimate the benefit per vehicle of the improvement. Therefore, it is relatively simple to distort the ratios through defining relatively low-cost improvements on highways with high ADT. The other two cost-effectiveness formulas, the Present Cost Index and the Future Cost Index, use reductions in congestion as the measure of effectiveness and, therefore, probably are not appropriate for upgrade-to-standards projects.

The Delay Savings Ratio also is not a very good technique for upgrade-to-standards projects since the delay calculation routines in the program are more related to changes in capacity than to upgrading.

The HEEM-II benefit cost program can be modified fairly easily for ranking upgrade-to-standards projects. It includes benefit calculations for variations in design variables, such as lane width, shoulder width, and horizontal and vertical alignment. It would be necessary, however, to provide more detailed data on current and proposed designs.

The Ranking Formula also can be used with upgrade-to-standards projects by using weighted averages of the rankings from, say, HEEM-II, the Priority Formula, and, perhaps, the Sufficiency Rating.

To summarize, it appears that the best techniques to test for use in ranking upgrade-to-standards projects are the Sufficiency Rating, the Priority Formula, a Modified HEEM-II program, and the Ranking Formula. To use the Priority Formula and HEEM-II, additional data would have to be collected on each project. The Ranking Formula would depend, in turn, on the availability of the other rankings.

New Location Projects

The sufficiency rating technique and other cost-effectiveness techniques apparently have not been developed for ranking new location projects because an existing facility is not being improved. The only possibility appears to be to develop a sufficiency rating for the existing route through the city and, perhaps, including some factors that are specific to bypass projects. It does appear possible, however, to construct a Priority Formula for bypass projects. This could be done as follows. First, determine the sufficiency rating for the primary route through the city. This rating probably should emphasize capacity but might have separate categories for intersections and other factors such as heavy peak periods (such as on weekends). The before condition would be represented by this sufficiency rating. Second, an estimate must be made of the percent of traffic that will divert to the bypass. Previous studies [10, 11] indicate that initially this would be about forty percent for small and medium-size cities. Given the amount of traffic diverted to the bypass, a sufficiency rating can be calculated for the proposed bypass facility using this traffic volume. Third, a new sufficiency rating can be calculated for the existing route through the city with lower traffic volumes, being about sixty percent of previous volume. These calculated values then could be included in a Priority Formula as follows:

$$P_B = \frac{[(1-d)(SR_E - SR_E^*)(L_T) + d(SR_E - SR_B)(L_B)]\ (\frac{2}{3}\ CADT + \frac{1}{3}\ FADT)}{CST}$$

where

P_B = priority formula value for a bypass

SR_E = sufficiency rating for the existing route through the city with existing traffic volume

SR_E^* = sufficiency rating for the route through the city with reduced traffic volume, after some traffic is diverted to the bypass

d = proportion of traffic diverted to the bypass, which often is about 40 percent

SR_B = the sufficiency rating for the bypass with bypass traffic volume

CADT = present ADT in vehicles per day

FADT = future forecasted ADT in vehicles per day

CST = initial project cost for the bypass

L_T = length of the route through town

L_B = length of the bypass

This formulation probably would work best if there is one main route through a small or medium-size city and fairly heavy through traffic. If there are several main routes converging on a city, the bypass typically becomes a loop and the above formulation must be extended to include several highway segments and through movements. The formula, as given, probably can also be used to develop a priority-ranking value for any situation within a travel corridor where a new highway is built to supplement one existing highway.

The other principal category of technique that can be used to evaluate new location projects is benefit-cost. The benefit-cost techniques can more easily be adapted to these types of projects, which mainly include bypasses, loops, new radial highways in urban areas, and major new facilities in rural travel corridors.

The existing HEEM-II program is designed to allow evaluation of a proposed facility and up to two alternatives in a corridor. Allocation of corridor travel among routes is handled automatically by equalizing marginal travel costs on each route.

The Delay Savings Ratio program also can be used to evaluate a new location project, including a bypass. The only additional information required is an estimate of the percent of traffic that will be diverted. The HEEM-II program cannot currently handle an assumed percent diversion, but could easily be modified to operate the same way the Delay Savings Ratio program does, through using an estimate of the percent of the corridor (route through town) traffic that will be diverted.

None of the aforementioned techniques is very well adapted to handling new circumferential or loop type projects, especially those in larger cities. These probably can best be evaluated in network simulation and benefit-cost studies.

CHAPTER III. EVALUATION OF CURRENT TEXAS SUFFICIENCY RATINGS

In this study, two types of changes in Texas Sufficiency Ratings were evaluated. First, a Project Advisory Committee gave recommendations on what factors should be included in sufficiency ratings and the weights that should be assigned to these factors. Second, changes in the structure of the current sufficiency rating procedures for added-capacity projects were studied; these changes mainly addressed different ways to use continuous functions instead of specific weights for measurement within categories. The remainder of this chapter presents the Texas Sufficiency Rating schedules, the two types of changes, and a sensitivity analysis of these possible changes.

Texas Sufficiency Ratings

As part of an ongoing effort to develop new methods in evaluating highway construction projects, DHT developed two sufficiency rating schedules--one to evaluate added-capacity projects and the other for upgrade-to-standards projects [1]. The various categories and points for each category are presented in Tables 1 and 2. The DHT sufficiency rating schedules give points for deficiencies in the existing facility. Therefore, the ideal highway would receive 0 points and the most deficient possible highway would receive 100 points. While it is more common for sufficiency ratings to go in the opposite direction--100 for the best facility and 0 for the worst--DHT's method will be used in the study since it is consistent with other ranking techniques--the higher the number the higher the project priority.

The first two categories in Table 1, traffic flow conditions, are based upon level of service (LOS). The table to convert ADT into LOS is presented in Table 3 and is based upon highway type and number of lanes. In the case of 2-lane rural undivided highways, there is also a distinction for the type of terrain. The third category of truck ADT volume does not use LOS, simply the current truck volume per lane on the existing highway. The next two categories are characteristics of the existing highway. The last category of gap considerations is the only category where the proposed project has any impact on the point total. The other categories are strictly a measure of the deficiencies on the existing facility.

Table 1. DHT Sufficiency Rating for Added Capacity Projects.

Category	Weights
1. Traffic Flow Conditions, Present ADT Volume on Existing Facility:	
a. Good (LOS A-B)	0
b. Tolerable (LOS C-D)	7
c. Undesirable (LOS E - Capacity)	14
d. Forced (1.0 to 2.0 X Capacity)	21
e. Forced (More than 2.0 X Capacity)	30
2. Traffic Flow Conditions, Future ADT Volume	
a. Good (LOS A-B)	0
b. Tolerable (LOS C-D)	6
c. Undesirable (LOS E - Capacity)	9
d. Forced (1.0 to 2.0 X Capacity)	12
e. Forced (More than 2.0 X Capacity)	20
3. Present Truck ADT Volume per Existing Lane	
a. 0 - 200	0
b. 201 - 400	3
c. 401 - 600	6
d. 601 - 800	8
e. More than 800	12
4. Principal Arterial System	
a. Off	0
b. On	5
5. Roadway Functional Classification	
a. Local or Collector Road or Street	0
b. Minor Arterial Road or Street	7
c. Rural Principal Arterials, Urban Connecting Links of Rural Principal Arterials, and Other Urban Principal Arterials	14
d. Interstate Highways and Other Freeways	17
6. Gap Considerations	
a. Does Not Eliminate Capacity Gap	0
b. Eliminates "One-End" Capacity Gap	9
c. Eliminates Capacity Gap on Both Ends or is System Gap	16
Total Sufficiency Rating	

Table 2. DHT Sufficiency Rating for Upgrading-to-Standards Projects

Category			Weights
1. Present ADT Volume Per Lane		< 500	0
		500 - 1000	7
		1000 - 1500	12
		1500 - 2000	16
		2000 - 2500	19
		> 2500	21
2. Present Truct ADT Volume Per Lane		0 - 200	0
		200 - 400	3
		400 - 600	6
		600 - 800	8
		> 800	9
3. Principal Arterial System		Off	5
		On	0
4. Roadway Functional Classification		5 & 6 & 7	0
		4	5
		3	9
		1 & 2	11
5. Crown Width Deficiency	<4'	ACCEPTABLE	0
	4' - 10	SUB STANDARD	6
	>10'	SEVERELY DEFICIENT	16
6. Roadway Alignment Deficiency	<10 mph	ACCEPTABLE	0
	10 - 19 mph	SUB STANDARD	6
	>20 mph	SEVERELY DEFICIENT	16
7. Eliminates Geometric Deficiency Gap		NO	0
		ONE END	6
		BOTH ENDS	11
8. Condition of Existing Pavement		GOOD	0
		FAIR	6
		SEVERELY DEFICIENT	11
		Total Sufficiency Rating	

Table 3. Average Daily Traffic (ADT) Volume Ranges of Various Highway Classes for Various Qualities of Flow.

Highway Class	Range in ADT Service Volumes: Good Flow L.O.S. A-B	Tolerable Flow L.O.S. C-D	Undesirable Flow L.O.S E(Capacity)
Urban Freeways:			
4 Lane	0 - 44000	44001 - 52800	52801 - 64400
6 Lane	0 - 66000	66001 - 79200	79201 - 96600
8 Lane	0 - 88000	88001 - 105600	105601 - 128800
Each Additional Lane	0 - 11000	11001 - 13200	13201 - 16100
Urban Divided Streets[1,2]			
4 Lane	0 - 16100	16101 - 19100	19101 - 23000
6 Lane	0 - 23500	23501 - 27900	27901 - 33000
8 Lane	0 - 29400	29401 - 34900	34901 - 42000
Urban Undivided Streets [1,2]			
2 Lane	0 - 7700	7701 - 9100	9101 - 11000
4 Lane	0 - 12600	12601 - 14900	14901 - 18000
6 Lane	0 - 19800	19801 - 23500	23501 - 28300
Rural Freeways:			
4 Lane	0 - 20800	20801 - 31600	31601 - 42000
6 Lane	0 - 31200	31201 - 47400	47401 - 63000
Rural Divided Highways[1,2]			
4 Lane	0 - 12000	12001 - 17500	17501 - 35000
6 Lane	0 - 18000	18001 - 26200	26201 - 52500
Rural Undivided Highways[1,2]			
Rolling Terrain, 2 Lane	0 - 2800	2801 - 4700	4701 - 14700
Level Terrain, 2 Lane	0 - 3700	3701 - 6100	6101 - 17400
4 Lane	0 - 9500	9501 - 13000	13001 - 26000
6 Lane	0 - 15000	15001 - 19500	19501 - 39000

[1]A "divided" facility includes a flush or depressed median with sufficient width for storage of left turning vehicles. On "undivided" facilities, left turns are made from a through lane.

[2]"Urban street", as opposed to "rural highway", conditions prevail whenever the intensity of roadside development, speed zoning, signals, stop/yield signs, etc., result in interrupted flow conditions and reduced traffic speeds.

Advisory Committee Recommendations On Categories and Weights for Sufficiency Ratings

The Project Advisory Committee, a five-member team of district engineers, and members of the Design Division have assisted the project staff in evaluating the categories and weights to be used in the Texas Sufficiency Rating schedules for different types of projects. To date, sufficiency rating schedules for five different types of projects have been discussed and evluated in a preliminary rating. These project types are: (1) added-capacity projects, (2) upgrade-to-standards projects, (3) new location projects, (4) new loop highways, and (5) new bypasses. Each advisory committee member provided a list of categories (not to exceed ten categories) for each of the different types of projects and assigned weights to each of the categories. An initial list of 26 categories was given to each member and they added 15 more categories for a total of 41 categories. The categories chosen and the ratings given each category are summarized in Table 4. The results summarized in Table 4 are for six individuals, five district engineers and one Design Division (D-8) engineer. Note that Item Number 30 has a rating of 16.7; this is because one of the district engineers stated that he thought benefit-cost analysis should be used for all rankings.

After committee members had met and discussed the different ratings, they were asked to provide a second rating for added-capacity projects, referred to as the second iteration. Average weights from the first iteration and second iteration for added-capacity projects are shown in Table 5. In the second iteration shown here, members could list no more than ten factors, the same as in the first iteration. The second iteration had the additional constraint that members were instructed to not list any highway cost except maintenance cost and also to omit benefit-cost analysis (i.e., omit Items 19, 30, and 32). These instructions were added because the initial project costs were going to be considered later when the sufficiency rating was used in a priority formula and because benefit-cost was going to be tested as a separate technique.

The top ten factors from the first and second iterations are shown in Tables 6 and 7. The top ten factors accounted for 75.8 percent of all factors in the first iteration and 83.3 percent in the second iteration.

Table 4. Average Weights Assigned by the Advisory Committee on the First Iteration with a Ten Factor Limit by Type of Project.

Factor No.	Factor Description	Upgrade to Standard	Added Capacity	Average Weight by Type of Project[a] New Location Bypass	Loop	Other
1	Present ADT relative to capacity	4.2	13.4	12.6	10.8	9.3
2	Future ADT relative to capacity	0.0	10.0	5.8	10.0	7.5
3	Present total ADT/lane	5.0	1.7	0.0	0.0	1.7
4	Present truck ADT/lane	1.7	2.5	4.2	2.5	0.0
5	Principal arterial system	3.3	2.5	1.7	0.0	0.0
6	Functional classification	1.7	2.5	1.7	0.0	0.0
7	Gap considerations	3.3	5.8	10.0	4.2	11.7
8	Crown width deficiency	3.3	0.0	0.0	0.0	0.0
9	Roadway alignment deficiency	4.2	0.0	0.0	0.0	0.0
10	Condition of pavement	4.2	1.7	0.0	0.0	0.0
11	Structural adequacy of pavement	0.0	0.8	0.0	0.0	0.0
12	Remaining pavement life	0.0	0.8	0.0	0.0	0.0
13	Accident experience	14.2	5.0	5.8	5.0	5.0
14	Crossing traffic	0.8	1.7	1.7	1.7	0.0
15	Average delay/vehicle	0.0	0.0	1.7	1.7	1.7
16	Passing opportunity	0.0	4.2	0.0	0.0	0.0
17	Traffic friction	0.8	0.0	0.0	0.0	0.0
18	Construction cost/lane mile	1.7	0.0	3.3	5.0	2.5
19	Construction cost/vehicle mile	3.3	5.8	3.3	2.5	4.2
20	District priority	13.3	8.3	8.3	8.3	9.2
21	City/county population growth	0.0	1.7	5.8	8.3	5.8
22	Accommodate land use, etc.	0.0	0.8	1.7	5.8	3.0
23	Special considerations	0.0	0.0	0.0	0.0	2.5
25	Design speed	4.2	0.0	0.0	0.0	0.0
26	Horizontal clearance	1.7	0.0	0.0	0.0	0.0
27	Drainage deficiency	0.8	0.0	0.0	0.0	0.0
28	Maintenance cost/lane mile	3.3	0.0	0.0	0.0	0.0
29	Construction cost/lane	2.5	0.0	0.0	0.0	0.0
30	Benefit-cost analysis	16.7	16.7	16.7	16.7	16.7
31	Capacity design life tenure	0.0	2.5	0.0	0.0	0.0
32	Cost index	0.0	1.7	2.5	2.5	1.7
33	Mobility (present average speed)	0.0	3.3	0.0	0.0	0.0
34	Departmental commitment	0.0	3.3	3.3	5.0	3.3
35	Environmental impact	0.0	0.0	0.8	1.7	0.8
36	Reduction of indirection	0.0	0.0	0.8	1.7	4.2
37	Projected growth patterns	0.0	0.0	0.8	0.8	0.0
38	Percent of trucks	0.0	2.5	2.5	2.5	1.7
39	Through-town speed vs. bypass speed	0.0	0.0	1.7	0.0	0.0
40	Corridor (parallel facility) mobility	0.0	0.0	0.0	0.0	2.5
41	Future ADT (5 yrs) for trucks	0.0	0.0	2.5	3.3	2.5
42	Degree of deficiency	5.0	0.0	0.0	0.0	2.5
43	Future ADT (5 yrs)/proposed lane	0.0	0.8	0.0	0.0	0.0
44	Proposed facility level of service	0.0	3.3	0.0	0.0	0.0
48	Present ADT adjusted for trucks	0.0	0.0	2.5	0.0	0.0
	Total weight for all factors	100.0	100.0	100.0	100.0	100.0

[a]Average weights of six advisory committee members.

Table 5. Average Weights Assigned by the Advisory Committee for Added Capacity Projects on the First and Second Iterations with a Ten Factor Limit

Factor No.	Factor Description	Average Weight[a] First Iteration	Average Weight[a] Second Interation[b]
1	Current ADT relative to capacity	13.3	19.8
2	Future ADT relative to capacity	10.0	12.9
3	Present ADT/lane	1.7	0.0
4	Present Truck ADT/lane	2.5	5.0
5	Principal arterial	0.0	1.7
6	Functional classification	2.5	2.5
7	Gap consideration	5.8	8.3
8	Crown width deficiency	0.0	1.7
10	Condition of pavement	1.7	0.0
12	Remaining pavement life	0.8	0.8
13	Accident experience	5.0	5.8
14	Crossing traffic	1.7	2.5
15	Average delay/vehicle	2.5	10.8
16	Passing opportunity	4.2	3.3
17	Traffic friction	0.0	0.8
19	Construction cost/vehicle mile	5.8	0.0
20	District priority	8.3	10.8
21	City/county population growth	1.7	2.5
22	Land use accommodation	0.8	0.8
27	Drainage deficiency	0.0	3.3
28	Maintenance cost/mile	0.0	3.3
30	Benefit-cost analysis	16.7	0.0
31	Capacity, design life	2.5	0.0
32	Cost index (mile cost/vehicle)	1.7	0.0
33	Mobility (present average speed)	3.3	0.0
34	Department commitment	3.3	1.7
38	Percent of trucks	0.0	1.7
43	Future ADT (5 years) per lane	0.8	0.0
44	Proposed facility and project level of service	3.3	0.0
	Total weight for 29 factors	100.0	100.0

[a]Average of weights given by six Advisory Committee members.

Table 6. Top Ten Factors in Rank Order with Average Weights for Added Capacity Projects, First Iteration.

Factor No.	Factor Description	Rank Order	Average Weight[a]
30	Benefit-cost analysis	1	16.7
1	Present ADT relative to capacity	2	13.4
2	Future ADT relative to capacity	3	10.0
20	District priority	4	8.3
7	Gap consideration	5	5.8
19	Construction cost/vehicle mile	6	5.8
13	Accident experience	7	5.0
16	Passing opportunity	8	4.2
33	Mobility (present average speed)	9	3.3
34	Department commitment	10	3.3
	Total weight for top 10 factors[b]		75.8

[a] Average weights of six advisory committee members.

[b] Total weight for all factors adds up to 100. For the complete listing, see Table 4.

Table 7. Top Ten Factors in Rank Order with Average Weights for Added Capacity Projects, Second Iteration

Factor No.	Factor Description	Rank Order	Average Weight[a]
1	Current ADT relative to capacity	1	19.8
2	Future ADT relative to capacity	2	12.9
20	District priority	3	10.8
15	Average delay/vehicle	4	10.8
7	Gap consideration	5	8.3
13	Accident experience	6	5.8
4	Present truck ADT/lane	7	5.0
16	Passing opportunity	8	3.3
27	Drainage deficiency	9	3.3
28	Maintenance cost/mile	10	3.3
	Total weight for top 10 factors[b]		83.3

[a] Average of weights given by six advisory committee members. Also, they were instructed to eliminate benefit-cost analysis and all cost factors, except maintenance cost/mile.

[b] Total weight for all factors adds up to 100.

This suggests that there was more of a concensus about what the most important factors were for added-capacity projects. However, this is partially because benefit-cost analysis, representing 16.7 points in the first iteration, was omitted (as instructed) in the second iteration. In the second iteration, increased weights were given to most of the top categories. Average delay per vehicle also became prominent in the second list, being tied for third at 10.8 points. The ratings for all of the 20 factors rated by at least one person in the second iteration are shown in Table 8.

Committee members also were asked to rate the six factors currently included in the Texas Sufficiency Rating schedule for added-capacity projects. That is, they were limited to the six categories currently used, which are Numbers 1, 2, 4, 5, 6, and 7 in the preceding tables. These ratings are shown in Table 9 as the "third iteration". The first two columns in Table 9 show the relative weights for the same six items from the first and second iterations.

Several factors recommended by the committee have not been tested or included in the added capacity sufficiency rating schedule. The most important of these omitted factors (based on the second iteration for added-capacity projects) are: (1) district priority - 10.8 points; (2) accident experience - 5.8 points; (3) passing opportunity - 3.3 points; (4) drainage deficiency - 3.3 points, and (5) maintenance cost/mile - 3.3 points.

One difficulty with including district priority in the sufficiency rating schedule is that this rating must of necessity be assigned by the district. Because of this, it is difficult to develop a rating method that gives points that are comparable between districts. It may be best to devise some way to allow the districts to set priorities without including this item directly in the rating. There are many important factors which are difficult to include in the sufficiency rating that districts may want to consider in determining priorities and scheduling. One possible way to do this would be to rank all statewide added capacity projects (i.e., those that made the statewide list) expected to cost X dollars per year. Then each year the district would be allowed some leeway to adjust priorities within the budget up to X dollars. This method would have the advantage of letting districts set priorities using not only the priority list for their district but also

Table 8. Factors Chosen by One or More Committee Members with Average Weights for Added Capacity Projects, Second Iteration[a]

Factor No.	Factor Description	Average Weight[b]
1	Current ADT relative to capacity	19.8
2	Future ADT relative to capacity	12.9
4	Present truck ADT/lane	5.0
5	Principal arterial	1.7
6	Roadway functional classification	2.5
7	Gap consideration	8.3
8	Crown width deficiency	1.7
12	Remaining pavement life	0.8
13	Accident experience	5.8
14	Crossing traffic	2.5
15	Average delay/vehicle	10.8
16	Passing opportunity	3.3
17	Traffic friction	0.8
20	District priority	10.8
21	City/County population growth	2.5
22	Lane use accommodation	0.8
27	Drainage deficiency	3.3
28	Maintenance cost/mile	3.3
34	Department commitment	1.7
35	Percent of trucks	1.7
	Total weight for all 20 factors	100.0

[a] Committee instructed to eliminate all benefit-cost analysis and index factors, except maintenance cost/mile.

[b] Average of weights given by six advisory committee members.

Table 9. Relative Weights Assigned by the Advisory Committee to the Six Factors Currently Used in the Added Capacity Sufficiency Rating Schedule.

Factor No.	Factor Description	First Iteration[a]	Second Iteration[a]	Third Iteration
1	Current ADT relative to capacity	39.0	39.4	31.6
2	Future ADT relative to capacity	29.4	25.7	20.0
7	Capacity gap	17.0	16.5	17.5
4	Present truck volume/lane	7.3	10.0	14.2
5	Principal arterial	0.0	3.4	10.0
6	Functional classification	7.3	5.0	6.7
	Total relative weight for all six factors	100.0	100.0	100.0

[a]Weights for these six factors from the first and second iterations were adjusted proportionately to sum to 100.

other factors not considered in developing the priority list. There also would be other advantages. Each district would have a definite budget constraint. They would have to make tradeoffs within the available funds. They also would have more incentive to be cost conscious since they would know that saving money on one project would allow them to spend it elsewhere.

For the other factors, two questions should be asked. First, will their inclusion in the sufficiency rating make any difference in the rankings? Second, is there a good, objective way of measuring the factor? These questions should be addressed in future research.

Alternate Formulations of the Sufficiency Rating and the Priority Formula

One weakness of an easy to use manual method of calculating a sufficiency rating, such as the Texas ratings presented in Tables 1 and 2, is the limited number of different characteristics which receive points within each category. If a large number of projects are being ranked, this results in many ties--projects receiving the same score. In a computerized version of the Texas Sufficiency Rating for added-capacity projects, the first three categories can easily be modified so the points are calculated directly using ADT. The points for each of the first two categories in traffic flow conditions can be approximated using the following formula:

$$P_{ADT} = \left(\frac{TRF - T1}{A1}\right)^{A2} \quad \text{if } T1 < TRF \leq T4$$

where $$A2 = \frac{\ln(S4) - \ln(S2)}{\ln(T4 - T1) - \ln(.5T2 + .5T3 - T1)}$$

$$A1 = e^{\ln(T4-T1) - \ln(S4)/A2}$$

TRF = ADT volume per lane on existing facility (either current ADT or future ADT)

T1 = ADT/lane for upper limit on LOS A-B

T2 = ADT/lane for upper limit on LOS C-D

T3 = ADT/lane for capacity volume

T4 = ADT/lane for two times capacity volume

S1 = points for tolerable conditions

S2 = points for undesirable conditions

S3 = points for forced flow up to 2 times capacity

S4 = points for forced flow above 2 times capacity

Texas Sufficiency Rating points for ADT on urban freeways, along with the continuous approximations of those points using the above equation are presented in Figure 2. Each curve starts where the first points are awarded, intersects the midpoint of the second step, and stops at two times capacity where maximum points are awarded.

The points for the truck ADT volume can be approximated using a simple linear equation.

$$P_{TRK} = -4.0 + .02(TK) \quad \text{if } TK > 200$$

where TK = current ADT truck volume per existing lane.

As can be seen in Figure 2, DHT's sufficiency points for traffic flow conditions are given in such a fashion that the approximation has a decreasing slope, the curve becomes flatter as ADT increases. If the points awarded are thought of as a proxy for the user costs generated by increased traffic volumes and congestion, then the curve should have an increasing slope, the curve becoming steeper as ADT increases. Therefore, a second modification was developed to approximate the points for both current and future ADT using the following equation.

$$P_{ADT} = \left(\frac{TRF}{A1}\right)^{A2} \text{ if } TRF \leq T4$$

where $$A2 = \frac{\ln(S4) - \ln(S1)}{\ln(T4) - \ln(.5T1 + .5T2)}$$

$$A1 = e^{\ln(T4) - \ln(S4)/A2}$$

This equation starts at zero, goes through the midpoint of the first step in Figure 2, and stops at the maximum points at two times capacity.

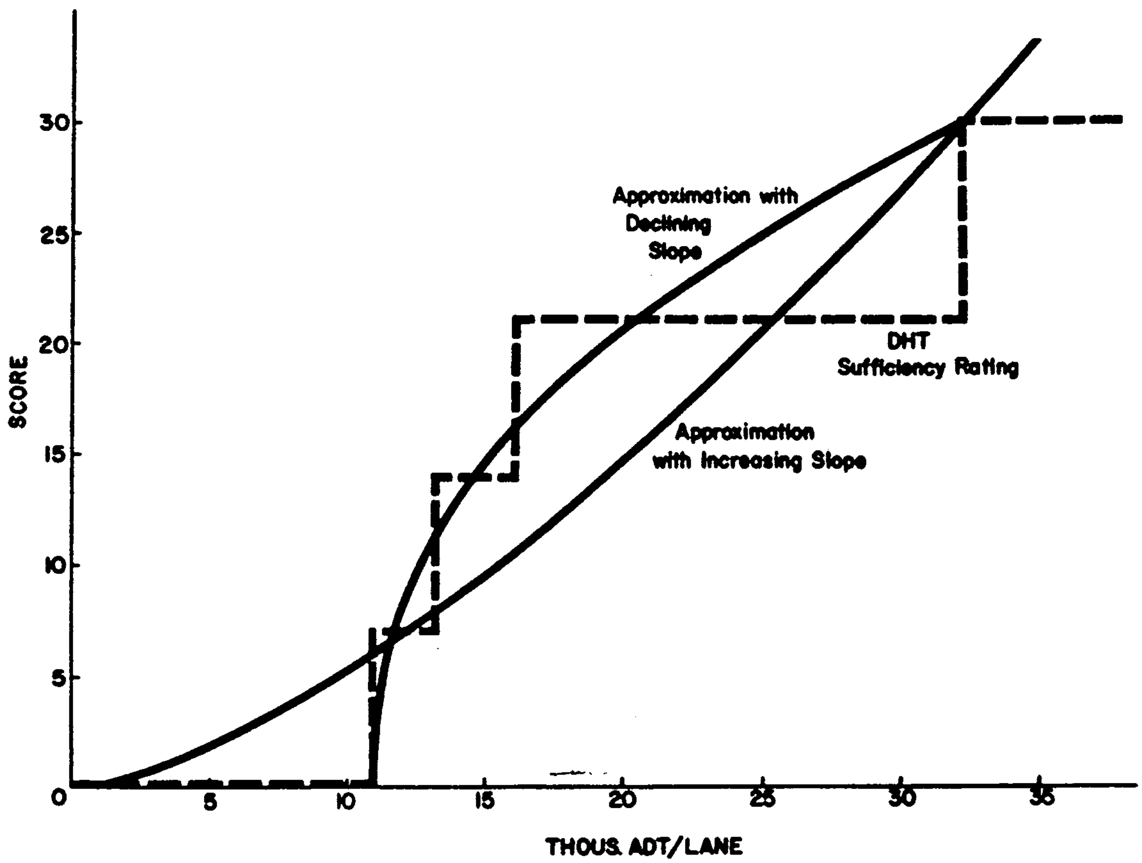


Figure 2. Continuous Approximation of Sufficiency Rating Scores for Traffic Flow Condition Categories as a Function of Average Daily Traffic Per Lane.

One of the advantages of a sufficiency rating is that it is capped on both ends. In this case, points can only vary between 0-100. It allows for an easy comparison of projects because each project can be compared to the best situation (0 points) and the most deficient situation (100 points). However, this system penalizes those projects which have conditions worse than the conditions necessary for maximum points in a category. In the case of ADT, existing facilities which have current and/or future ADT greater than two times capacity, receive no additional points. As a result, the above equation is also tested with no cap on points for those projects which have ADT's exceeding two times capacity.

Sensitivity Analysis of Sufficiency Rating and Priority Formula

A pilot study of 102 proposed added-capacity projects throughout the state of Texas was used to test and compare the variations of the Texas Sufficiency Rating and the Texas Priority Formula described in the previous section. A total of eight different rankings were analyzed, the Texas Sufficiency Rating and three variations of it, and four Priority Formula rankings corresponding to each of the sufficiency ratings.

Correlation of Rankings

The various project rankings are first compared to each other using Spearman's rank correlation coefficient. The coefficient measures the degree of correlation between two sets of rankings. A coefficient of 1.00 indicates the rankings are exactly the same, while a coefficient of -1.00 indicates they are exactly the opposite. A coefficient of 0.00 indicates the rankings are not correlated at all. The correlation coefficient is calculated using the following formula which includes an adjustment for ties [12]:

$$r = \frac{M-(\Sigma D^2 + T_x + T_y)}{[(M-2T_x)(M-2T_y)]^{1/2}} \text{ with } -1 \leq r \leq 1$$

where

r = Spearman's rank correlation coefficient

$M = 1/6(n^3-n)$

D = difference in the pair of rankings

n = number of projects

$T_x = 1/12 \ \Sigma (t_x^3 - t_x)$

$T_y = 1/12 \ \Sigma (t_y^3 - t_y)$

t_x = number of ties in consecutive groups of the x series

t_y = number of ties in consecutive groups of the y series

The comparisons of rankings using Spearman's rank correlation coefficient are presented in Table 10. The positive coefficients in the table indicate all the variations produce rankings which are positively correlated and the positive correlations are all statistically significant. While no rankings are exactly the same (a coefficient of 1.00), the highest correlations are for rankings using modifications of the same technique, between the sufficiency ratings and between the Priority Formulas. The Texas Sufficiency Rating (1) and the three versions of it, (2, 3, 4) have correlation coefficients above .96. The correlation between the Priority Formulas is generally not quite as high with the correlation of the Priority Formula (5) with the variations (6, 7, 8) ranging from .805 to .729. The correlations between 6, 7, and 8 are higher ranging from .971 to .916.

The results of the pilot study rankings comparisons using the correlation coefficient indicate that the particular version of the Texas Sufficiency Rating used doesn't make much difference in project rankings. But that is not the case with the Priority Formula. Therefore, the original Texas Sufficiency Rating (1) along with the last version of the Priority Formula (8) were selected for further analysis on the complete set of added-capacity projects in DHT's 20-year plan. The version of the Priority Formula with continuously increasing slopes and no cap on points, was chosen because it comes closest to representing the benefits generated by making an added capacity improvement, which can then be compared to the cost of the project in making comparisons among projects.

Table 10. Spearman's Rank Correlation Coefficient for Ranking Techniques of Sample Projects.*

1	2	3	4	5	6	7	8
1	.972	.967	.959	.403	.494	.478	.620
2		.987	.974	.365	.533	.517	.655
3			.963	.352	.515	.513	.638
4				.334	.482	.480	.660
5					.805	.769	.729
6						.971	.916
7							.926

*All coefficients are statistically significant at the one percent level.

Code for Ranking Techniques:

1. Texas Sufficiency Rating.
2. Texas Sufficiency Rating with continuous approximation for ADT and truck points.
3. Texas Sufficiency Rating with continuously increasing slope curves for ADT points.
4. Texas Sufficiency Rating with continuously increasing slope no cap on points.
5. Texas Priority Formula.
6. Texas Priority Formula with continuous approximation for ADT and truck points.
7. Texas Priority Formula with continuously increasing slope curves for ADT points.
8. Texas Priority Formula with continuously increasing slopes, no cap on points.

Sensitivity of Category Weights Using Motorist Benefits

Another aspect of the comparison of ranking techniques involves testing the sensitivity of weights within the procedure itself. As decribed in the previous chapter, the Advisory Committee was asked to provide weights to each of the six categories in the Texas Sufficiency Rating. While the weights were similar for most categories, there were significant differences for a few categories. A summary of these weights were presented in Table 9.

In the previous section, different versions of the Texas Sufficiency Rating and the Texas Priority Formula were compared using Spearman's rank correlation coefficient. While different techniques can have positive correlation coefficients, the rankings of individual projects may be quite different. This could affect the benefits to motorists as different projects are selected by the different techniques. Therefore, in this section the sensitivity of the weights within the sufficiency rating is evaluated using cumulative user benefits.

HEEM-II is used to calculate user benefits from a proposed highway project. Then each ranking technique or version can be compared for different construction budget levels. A simple method to accomplish this is to rank the projects with each technique and go down the list selecting projects until the assumed construction budget is exhausted. The user benefits for each of the projects can then be summed to give the cumulative total. Since no sophisticated switching rules are used for the last increment of the unused budget, linear interpolation is used. The benefits for the total construction budget are interpolated between the last project selected, which does not exceed the budget, and the next project which exceeds the budget. For a construction budget (C_T), the cumulative benefits (B_T) would be calculated using the following formula:

$$B_T = B_L + \frac{(B_H - B_L)\ (C_T - C_L)}{C_H - C_L}$$

where

B_L = cumulative benefits of last project which does not exceed the budget

C_L = cumulative cost of last project which does not exceed the budget

B_H = cumulative benefits of the next project which exceeds the budget

C_H = cumulative cost of the next project which exceeds the budget

Figure 3 depicts the comparison of accumulated benefits for Modified HEEM-II, the Texas Sufficiency Rating (1), and the modified Texas Priority Formula (8) for different accumulated construction costs. For most levels of construction costs, the Priority Formula does a much better job of maximizing the motorist benefits as estimated by Modified HEEM-II than does the Sufficiency Rating. The accumulated benefits can also be used to check the sensitivity of both the Sufficiency Rating and Priority Formula to changes in category weights taken from the Advisory Committee.

Two versions of the Advisory Committee weights are tested here--the second iteration and the third iteration from Table 9. The results are presented in Table 11. As can be seen, the cumulative benefits changed very little with the different sufficiency category weights. It also shows that one set of weights does not consistently have higher benefits than the other sets in this sample of projects. While the rankings for individual projects may change with these different weighting schemes, there seems to be little overall effect on the total user benefits. As a result, the weights in the Texas Sufficiency Rating are used for the analysis of the added-capacity projects in the 20-year plan presented in the next chapter.

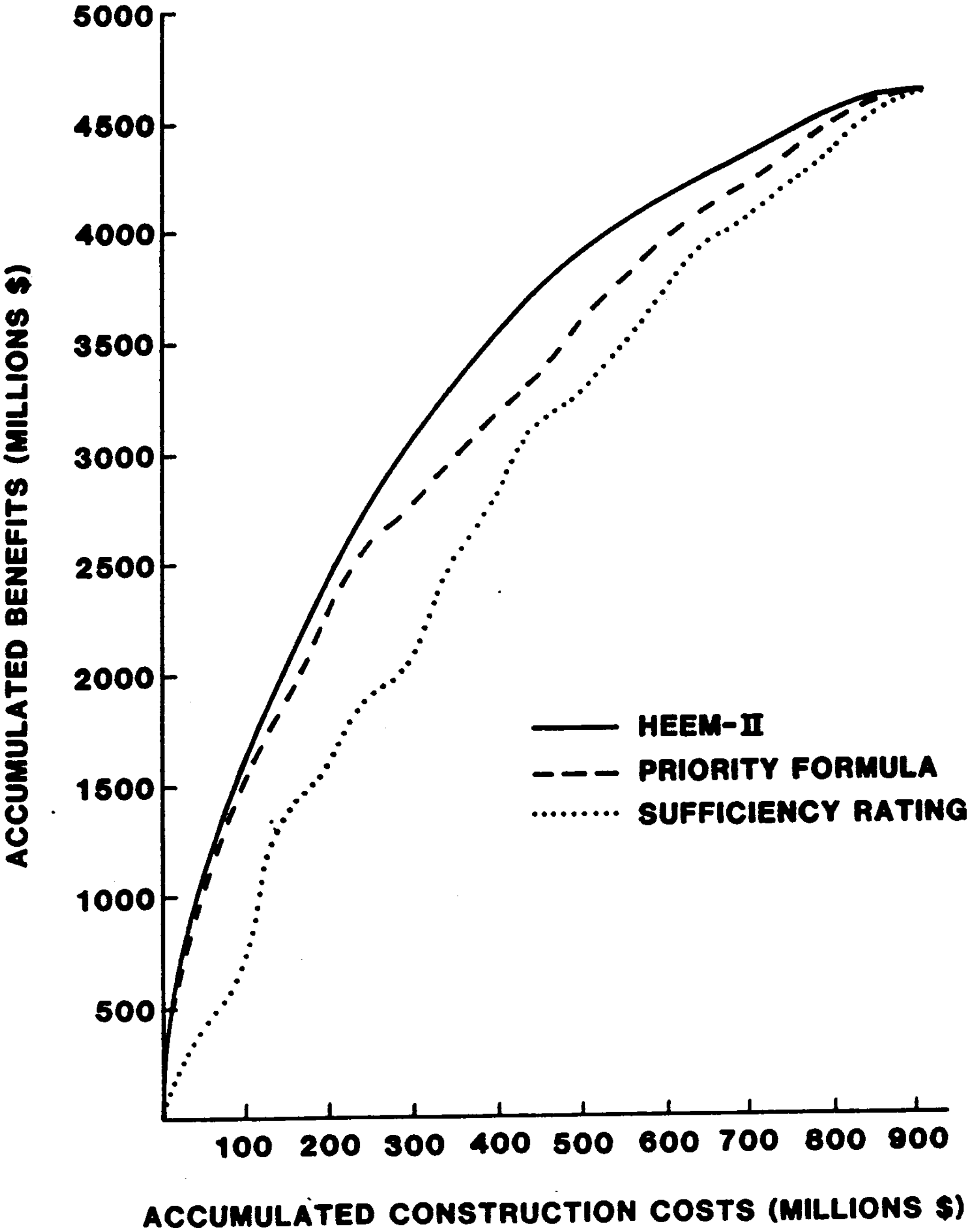


Figure 3. Cumulative Benefits Versus Cumulative Costs for Pilot Study Projects, for Three Techniques

Table 11. Comparison of Different Sufficiency Category Weights Using Cumulative User Benefits

Ranking Technique*	Cumulative Benefits for Various Construction Budgets (millions $)				
	200	300	400	500	600
Sufficiency Rating					
1 a	1,594.77	2,311.13	2,812.01	3,270.48	3,724.52
b	1,567.21	2,320.79	2,771.65	3,278.51	3,729.20
c	1,607.02	2,443.70	2,829.29	3,360.23	3,721.81
Priority Formula**					
4 a	2,028.39	2,409.84	2,823.24	3,291.71	3,752.32
b	2,013.45	2,396.29	2.791.42	3,316.71	3,742.74
c	1,872.27	2,477.00	3,000.30	3,455.84	3,820.96
5 a	1,725.64	2,300.49	2,577.82	3,105.13	3,670.89
b	1,785.04	2,297.52	2,581.33	3,065.18	3,646.41
c	1,726.18	2,114.24	2,490.52	3,012.51	3,670.89
8 a	2,290.49	2,757.31	3,171.61	3,585.33	3.959.92
b	2,290.49	2,757.31	3,111.42	3,585.33	3,952.91
c	2,254.82	2,728.52	3,147.06	3,536.82	3.961.24
HEEM-II	2,438.24	3,063.77	3,537.07	3,896.41	4,128.61

*The Codes for a, b, and c are:

a. DHT weights.
b. Third iteration Advisory Committee weights
c. Second iteration Advisory Committee weights

**For definitions of Priority Formulas 4, 5, and 8, see footnotes to Table 10 on Page 32.

Note: Cumulative benefits shown in this table were calculated using Modified HEEM-II.

CHAPTER IV. COMPARISON OF PROJECT RANKINGS

Criteria for Evaluating Rankings

One of the principal activities of this study has been to enumerate and evaluate different criteria that might be used to compare project ranking techniques. Two principal criteria have been identified for comparing ranking techniques: (1) logical comparison and (2) comparison of actual project rankings obtained with different techniques. The first of these two criteria is discussed briefly in Chapter II and also has been considered in previous studies [e.g., 13]. The second criterion, comparison of actual project rankings, has not been studied extensively in previous research but is emphasized in this study. Actual project rankings are compared for a large number (1,942) of added-capacity projects, representing most of the added-capacity projects that are currently being considered by DHT for funding in the next twenty years in Texas. Project rankings obtained with the nine different techniques discussed in Chapter II are compared in four ways. First, the total highway user benefits obtained at different budget levels are compared for different techniques; the improvement relative to random selection and DHT selection also is discussed. Second, a comparison is made of the project rankings from different techniques to determine the extent to which the rankings are similar, using rank correlation coefficients. Third, a comparison is made of the rankings from different techniques with recent rankings made by DHT personnel at selected budget levels. Fourth, a comparison of project rankings is made, by deciles of cost, to determine the location of projects being chosen (rural, urban, or "rural/urban", the latter category including projects in urban fringe areas that currently are rural but are expected to be urban within the analysis period) and the average size of projects selected.

Before presenting the results of the project rankings, it is, perhaps, worthwhile to mention three other subsidiary criteria for comparing ranking techniques that were noted in this study. These criteria are: (1) operational efficiency, (2) ease of understanding the technique, and (3) susceptibility of the technique to errors because of inaccurate input data. All of the nine techniques are now considered operationally efficient since the same basic data set is used for all techniques and all of the techniques are computerized and evaluations can be made quite easily. At the time the study began, this was not the case for the Modified HEEM-II benefit-cost procedure, but a new modified program was developed that now is easy to use.

Ease of understanding is a very important and desirable characteristic for a ranking technique. Ease of understanding, as used here, refers to understanding not only by the appropriate DHT personnel but also by the public. Probably the most easily understood techniques are the Sufficiency Rating, the benefit-cost ratio type of analysis (HEEM-II and the Delay Savings Ratio), the cost per vehicle miles traveled techniques, and, perhaps to a lesser extent, the Ranking Formula. The Texas Sufficiency Rating technique is easy to explain to the public in that the rating goes from zero for a highway needing no improvement to 100 points for a highway that is most deficient. However, the specific items in the rating are not as easy to explain because they are somewhat technical, such as level of service. The techniques that probably are more difficult for the public to understand are the Present Cost Index, the Future Cost Index, and the Texas Priority Formula. Nevertheless, even these techniques are relatively simple as compared to some composite ranking techniques used in other states that tend to "add apples and oranges" in ways that make the resulting numbers truly unfathomable. Examples of these techniques include weighted averages of sufficiency ratings, priority formula type ratings, and other miscellaneous ratings.

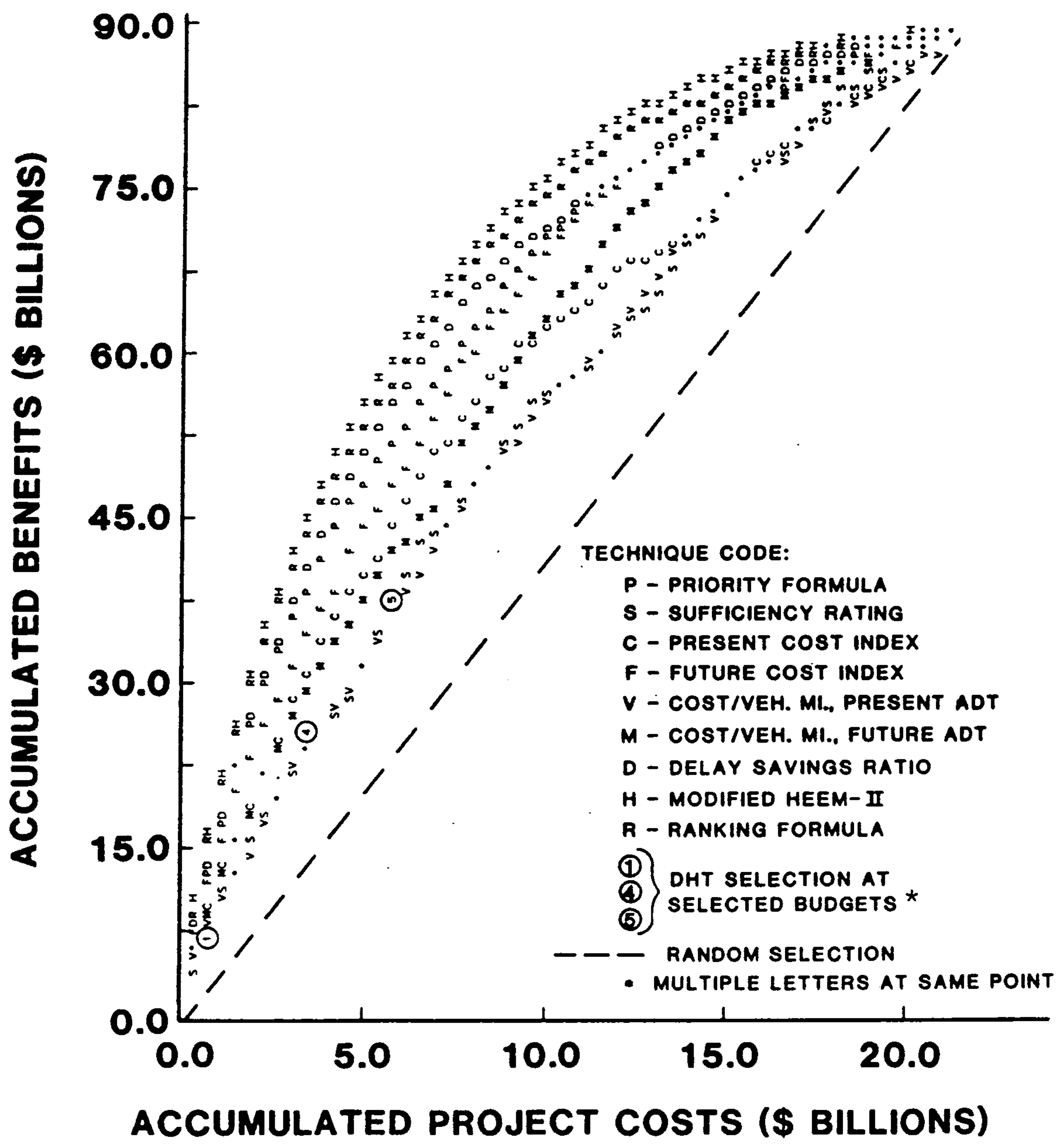
The third subsidiary criterion is the degree to which a technique is susceptible to errors because of inaccuracies in input data. Most of the input data, such as current ADT, probably is fairly accurate. However, the ADT forecasted twenty years in the future, which is used in most of the techniques, is susceptible to considerable error, partially because of the rapidly changing demographic and economic situation in Texas. One possible way of better understanding this data item would be to do a sensitivity analysis of forecasted ADT's and expected population growth under different conditions. In addition, it might be helpful to further analyze the design changes that are assumed for different levels of ADT.

Comparison of Benefits at Different Budget Levels

One of the principal criteria used to compare project rankings for the nine techniques is the level of benefits provided by each technique's ranking. Two different sets of rankings were compared on this basis. First, a pilot study was made of rankings for 102 added-capacity projects, as reported in Chapter III. The complete test reported in this section involved ranking the full set of 1,942 added capacity projects currently being considered for planned funding in Texas in the next twenty years. These 1,942 projects were ranked from first to last using each of the nine techniques described in Chapter II. The cumulative benefits were calculated using the modified HEEM-II computer program for rankings for each technique. The results of this exercise are presented in Figure 4. Each technique's cumulative benefits are plotted versus the cumulative cost for that techniques rankings. Each technique's benefit curve is represented by a series of letters coded to the technique. The techniques that give the most cumulative benefits, using Modified HEEM-II's measure of benefits, are HEEM-II (H), the Ranking Formule (R), the Delay Savings Ratio (D), the Texas Priority Formula (P), and the Future Cost Index (F). The techniques that show the least benefits are the Texas Sufficiency Rating (S) and the Cost per Vehicle Mile Traveled using present ADT (V).

In addition to showing the cumulative benefit curve for each of the nine techniques, Figure 4 shows the cumulative benefits that would result from random selection (represented by the straight, dashed line) and the benefits that would result from the projects selected in the current one-year, four-year, and five-year programs planned by DHT. The random selection line shows the benefits, at different levels of cumulative cost, that would be expected to result if projects were chosen randomly; the slope of this curve is determined by dividing the total benefits for all 1,942 projects by the total cost for all 1,942 projects, $89.062 billion divided by $21.228 billion.

The DHT one-year, four-year, and five-year programs are represented by circled numbers as the legend indicates. The one-year program represents the projects chosen by DHT to be built in (roughly) the first fiscal year of the plan (actually, this is a fourteen-month list plus a supplementary list of projects). This "one-year" plan has an expected cost of $0.785 billion. The four-year program represents projects selected for the four years succeeding



*There are several limitations to the comparison between the nine ranking techniques and the DHT Selection, as discussed on page 41.

Figure 4. Cumulative Benefits Versus Cumulative Costs for Rankings by Different Techniques and for DHT Selections at Selected Budgets.

the first year, and the five-year program represents the projects tentatively selected for years six through ten. Since Figure 4 shows cumulative benefits and costs, the circled "5" in the figure represents the cumulative benefits and cumulative costs for the ten years (the sum of the one, four, and five year programs).

In selecting projects for the 1, 4, and 5 year portions of the ten-year plan, DHT considered factors that are not represented in any of the tested ranking techniques. For example, there are scheduling restrictions that precluded inclusion of certain projects in the early years of the plan. In this regard, certain highly attractive, beneficial projects were selected but scheduled in the last five years of the plan to allow the necessary time for project development. Certain other attractive projects were judged infeasible for environmental or other reasons and were not selected regardless of the magnitude of the perceived benefits.

The DHT overall selection process included several types of added-capacity projects which have been excluded from the 1,942 projects that are ranked in this study. These included some second and third stage projects, highway interchanges, and highway-railroad grade separations. In other instances, candidate projects were within common limits and mutually exclusive--if one project is selected, the other must be rejected. The testing of techniques was across the board without taking into account these important considerations.

It is also important to recognize that for true benefits to occur there has to be a system concept in project planning. Arbitrary project selection by highest calculated rankings would very likely result in an overall selection that would not include adjacent system projects that are truly necessary for real benefits to occur. Also, gap projects may provide limited benefits over the project limits but, if selected, would allow adjacent sections to operate at a higher level.

All of the nine techniques provide expected benefits considerably above that provided by random selection. Table 12 presents the specific cumulative benefit estimates at the budget levels for the one-year, five-year (one-year plus 4-year programs), and ten-year programs. At a budget level of $0.785 billion, the DHT selection provides over 100 percent more benefits than would random selection. The HEEM-II and Ranking Formula rankings provide the most benefits--about 21 times the cumulative cost and five times the benefits from random selection.

Table 12. Cumulative Benefits at Selected Budget Levels, by Technique.

Ranking Technique	Cumulative Benefits ($ Billion) for Cumulative Cost of:		
	$ 0.785 B (One-Year Program)	$ 3.551 B (Five-Year Program)	$ 5.742 B (Ten-Year Program)
Texas Sufficiency Rating (S)	$ 7.316 B	$ 24.610 B	$ 36.512 B
Present Cost Index (C)	9.605	31.401	43.967
Future Cost Index (F)	12.220	34.784	48.173
Cost/Vehicle Mile, Present ADT (V)	8.221	24.004	36.361
Cost/Vehicle Mile, Future ADT (M)	8.828	29.410	41.831
Delay Savings Ratio (D)	13.500	41.137	54.750
Texas Priority Formula (P)	12.980	39.034	51.618
Modified HEEM-II (H)	16.780	45.723	59.202
Ranking Formula (R)	16.043	44.300	56.870
DHT Selection*	6.516	25.251	37.803
Random Selection (N)	3.293	14.898	24.091

*There are several limitations to the comparison between the nine ranking techniques and the DHT Selection, as discussed on page 41.

At the $5.742 billion level, representing the planned budget for added capacity projects for the next ten years, the different techniques give widely varying results. This is illustrated more clearly in Table 13, which presents the cumulative benefits for the projects ranked by each technique up to the ten-year budget level. Also shown is the percent improvement over random selection for each technique. The Texas Sufficiency Rating technique and the Cost per Vehicle Miles Traveled, Present ADT technique show the least improvement over random selection--about 51 percent. The Modified HEEM-II technique shows the largest percent improvement (145.6%), followed by the Ranking Formula (136.1%). The actual DHT selection shows an improvement of 56.8 percent over random selection.

It is not too surprising that the Modified HEEM-II technique gives the best ranking based on benefits because these benefits are calculated using the HEEM-II estimates of savings in travel time costs, vehicle operating costs, accident costs, and maintenance costs that are expected from these added capacity projects. Nevertheless, the magnitude of the improvement that HEEM-II provides, if the benefit calculations are correct, is quite impressive, being about $21.4 billion more than the current DHT selection and over $22 billion above that given by the Sufficiency Rating Technique. It should be noted that these benefits are calculated in present value terms over a twenty-year analysis period assuming the projects are built immediately. It should be emphasized that all references to benefits represent dollar savings in future benefits as estimated by Modified HEEM-II as opposed to savings in expenditure of tax dollars. Since the projects would be built over about a ten-year period, the assumption that they are built immediately has a tendency to overstate benefits. This would probably be more than offset by future traffic growth and benefits from the improvements being generated over a period greater than twenty years. Future research should include more precise calculations with phasing of the projects over time, allowance for traffic growth before the improvement is made, and discounting the future benefits from the time the projects will be completed to the present. As noted, however, the estimated difference between techniques probably would increase from the consideration of the budget over time.

Table 13. Total Benefits and Percent Improvement Over Random Selection for Different Techniques for the Ten-Year Program ($5.742 Billion) of Added Capacity Projects

Ranking Technique	Benefits for 10-Year Program (Billion $)	Improvement Over Random Selection
Texas Sufficiency Rating (S)	$ 36.5 B	51.5 %
Present Cost Index (C)	44.0	82.6
Future Cost Index (F)	48.2	100.0
Cost/Vehicle Mile, Present ADT (V)	36.4	51.0
Cost/Vehicle Mile, Future ADT (M)	41.8	73.4
Delay Savings Ratio (D)	54.8	127.4
Texas Priority Formula (P)	51.6	114.1
Modified HEEM-II (H)	59.2	145.6
Ranking Formula (R)	56.9	136.1
DHT Selection*	37.8	56.8
Random Selection (N)	24.1	0.0

*There are several limitations to the comparison between the nine ranking techniques and the DHT Selection, as discussed on page 41.

Rank Correlation Coefficients

Spearman's rank correlation coefficients were calculated for different pairs of rankings. The calculation technique used here is similar to that used in the pilot test discussed in Chapter III, the only difference being that the full twenty-year set of 1,942 added-capacity projects is used instead of the 102 projects in the pilot test.

The rank correlation coefficients are presented in Table 14. These values can be tested to determine if the pairs of rankings are positivly correlated. A rank correlation coefficient of only 0.053 is needed to reject the null hypothesis of no correlation or negative correlation at the 0.01 (one percent) level of significance and of only 0.108 at the extreme 0.000001 test level. Since the smallest value in Table 14 is 0.117, we reject the hypothesis that the pairs of rankings are randomly related or negatively related and accept the hypothesis that the pairs of rankings are positively related.

Nevertheless, this statistical test is only of limited value since the correlation coefficients range from 0.117 to 0.939. To better show the economic significance of these correlation coefficients, the coefficients for the ranking using HEEM-II and the other rankings are presented in Table 15. Also shown in this table are the benefits of each technique as a percent of the HEEM-II benefits with all benefits calculated at the 10-year budget level of $5.742 billion. Also included in the table are the benefits for the DHT selection and the benefits and correlation coefficient for random selection. The correlation coefficient for the DHT selection cannot be calculated since this selection does not rank projects from one through 1,942 but simply groups them into different budget programs. Because the random selection is defined as being random, its correlation coefficient is presumed to be 0.000.

The values from Table 15 are plotted in Figure 5 which designates each technique with the letter code shown in Table 15. A linear regression equation fitted to these points is shown in Figure 5 and runs roughly from point N for random selection to point H for selection by HEEM-II. This indicates that the level of the rank correlation coefficient between a technique and HEEM-II is a fairly good indicator of the percent of benefits the technique's ranking will give as compared to HEEM-II's ranking. It is concluded that, even though all of the techniques' rankings are positively correlated from a statistical viewpoint, they have widely varying economic implications.

Table 14. Spearman's Rank Correlation Coefficient Between Pairs of Ranking Techniques for Rankings of 1,942 Added Capacity Projects.*

	PRESENT COST INDEX	FUTURE COST INDEX	COST/VEHICLE MILE PRES ADT	COST/VEHICLE MILE FUT ADT	DELAY SAVINGS	PRIORITY FORMULA	HEEM-II	RANKING FORMULA
TEXAS SUFFICIENCY RATING	0.662	0.480	0.357	0.285	0.479	0.673	0.467	0.583
PRESENT COST INDEX		0.510	0.168	0.117	0.510	0.498	0.459	0.530
FUTURE COST INDEX			0.565	0.792	0.713	0.820	0.729	0.816
COST/VEHICLE MILE-PRESENT ADT				0.856	0.381	0.761	0.514	0.594
COST/VEHICLE MILE-FUTURE ADT					0.544	0.801	0.635	0.711
DELAY SAVINGS RATIO						0.736	0.800	0.914
TEXAS PRIORITY FORMULA							0.806	0.916
HEEM-II								0.939

*All coefficients are statistically significant at the one percent level.

Table 15. Benefits as Percent of Modified HEEM-II Benefits and Rank Correlation Coefficients, of the Listed Technique with Modified HEEM-II.

Ranking Technique	Benefits as Percent of HEEM-II Benefits*	Rank Correlation Coefficient of the Listed Technique with HEEM-II
Texas Sufficiency Rating (S)	61.7 %	.467
Present Cost Index (C)	74.3	.459
Future Cost Index (F)	81.4	.729
Cost/Vehicle Mile, Present ADT (V)	61.5	.514
Cost/Vehicle Mile, Future ADT (M)	70.6	.635
Delay Savings Ratio (D)	92.6	.800
Texas Priority Formula (P)	87.2	.806
Modified HEEM-II (H)	100.0	1.000
Ranking Formula (R)	96.1	.939
DHT Selection	63.9	Not Available
Random Selection (N)	40.7	.000

*Calculated at the 10-Year Budget Level of $5.742 Billion.

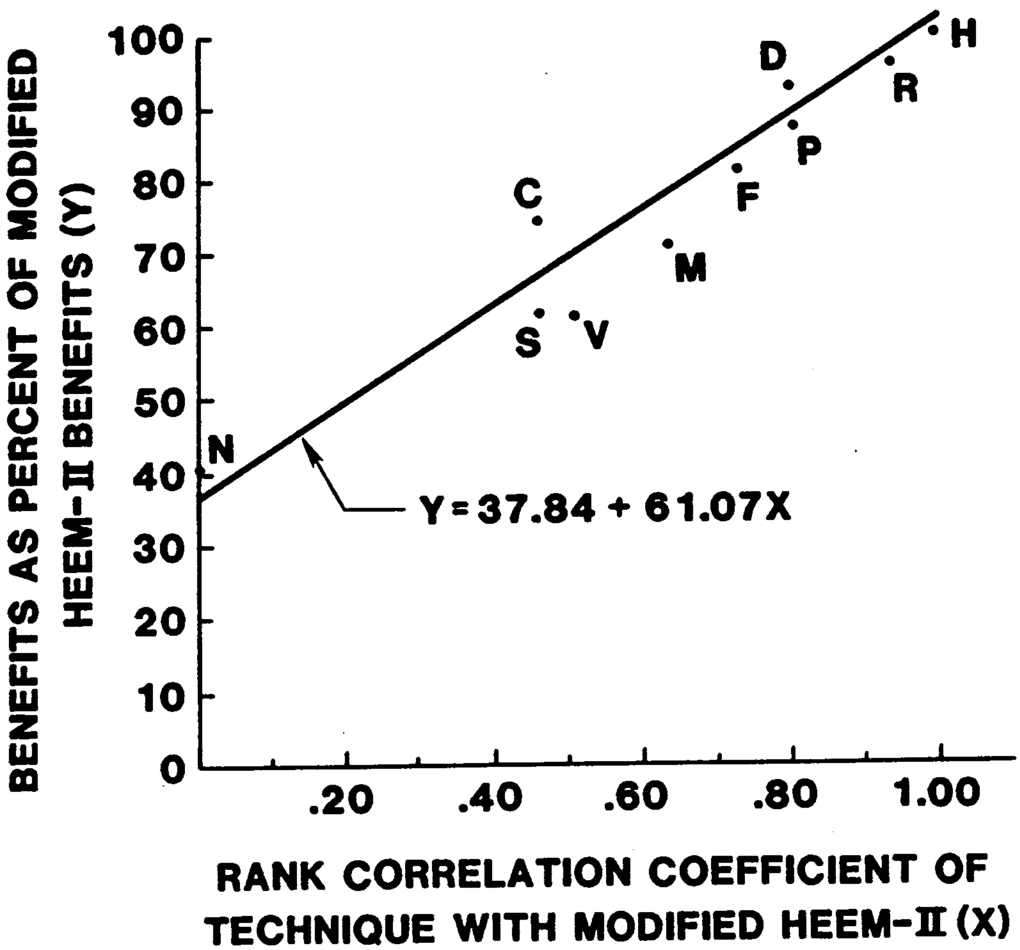


Figure 5. Relationship Between Rank Correlation Coefficients and Benefits as a Percent of Modified HEEM-II Benefits, for Different Techniques.

The Texas Sufficiency Rating technique's correlation coefficients from Table 14 are relatively low with respect to most other techniques, the highest being with the Texas Priority Formula, which is based partially on the Sufficiency Rating. The next highest coefficients are those relative to the Present Cost Index (0.662) and the Ranking Formula (0.583), which is based partially on the Texas Priority Formula.

The Present Cost Index is most closely correlated with the Sufficiency Rating (0.662), with most of its other correlation coefficients ranging from 0.459 to 0.530, the exceptions being the two Cost/Vehicle Mile techniques at 0.168 and 0.117.

The Future Cost Index has relatively high correlation coefficients (0.713 to 0.816) with respect to most techniques, the exceptions being the Sufficiency Rating (0.480), the Present Cost Index (0.510), and the Cost/Vehicle Mile, Present ADT (0.565).

The Cost/Vehicle Mile, Present ADT is most highly correlated with the Cost/Vehicle Mile, Future ADT (0.856) and with the Priority Formula (0.761).

The Cost/Vehicle Mile, Future ADT is highly correlated not only with the Cost/Vehicle Mile, Present ADT (0.856) but also with the Priority Formula (0.801), the Future Cost Index (0.792), the Ranking Formula (0.711), and HEEM-II (0.635).

The Delay Savings Ratio is highly correlated with the Ranking Formula (0.914), HEEM-II (0.800), the Priority Formula (0.736), and the Future Cost Index (0.713).

The Texas Priority Formula has very high correlation coefficients ranging from 0.673 to 0.916 with all techniques except for one, the Present Cost Index (0.498). Even with the Present Cost Index, however, the Priority Formula's correlation coefficient is about as high as the other techniques' correlation coefficients with the Present Cost Index, the lone exception being the Sufficiency Rating which has a correlation coefficient of 0.662 with respect to the Present Cost Index.

HEEM-II is most highly correlated with the Ranking Formula (0.939) and also highly correlated with the Priority Formula (0.806), the Delay Savings Ratio (0.800) and, to a lesser extent, with the Future Cost Index (0.729) and the Cost/Vehicle Mile, Future ADT (.635).

Being a technique that is based on the rankings of three other techniques, the Ranking Formula might be expected to be highly correlated with other techniques and such is the case. It is highly correlated with the three techniques on which it is based--HEEM-II (0.939), the Priority Formula (0.916), and the Delay Savings Ratio (0.914). It is also highly related to the Future Cost Index (0.816) and the Cost/Vehicle Mile, Future ADT (0.711).

Some characteristics of the rank correlation coefficients for each technique are summarized in Table 16. The first column shows the low and high coefficients and the second column shows the average coefficient for each technique with respect to all other techniques. The Priority Formula and the Ranking Formula have the highest average coefficients with respect to all other techniques at 0.751 and 0.750, respectively, followed by the Future Cost Index (.678), HEEM-II (.669), the Delay Savings Ratio (.635), and the Cost per Vehicle Mile, Future ADT (.593). Therefore, if the goal is to choose a consensus technique, the Priority Formula or Ranking Formula probably is the best choice based on this analysis.

Comparison of DHT Rankings with Rankings from Other Techniques at Selected Budget Levels

The DHT project selection procedure identifies projects for a One-Year Program (actually a 14-month list with supplemental projects), a Four-Year Program (years 2-5), and a Five-Year Program (Years 6-10). These three programs make up the ten-year planned construction list. All other projects in the twenty-year list are referred to here as the remainder. Since projects are not currently ranked from best to worst for all 1,942 added capacity projects, it is not possible to calculate Spearman's rank correlation coefficients between the DHT ranking and other rankings. It is possible, however, to develop a contingency table showing a cross-classification of the number of projects as ranked by DHT versus other techniques. Table 17 is such a table for DHT rankings and the Modified HEEM-II rankings. For the ten-year budget, the actual DHT selection included 623 projects with 95 projects in Year One, 258 in Years 2-5, and 270 in Years 6-10. For the same budget, HEEM-II selected a total of 554 projects with 116 in Year One, 220 in Years 2-5, and 218 in Years 6-10. The first column in Table 17 shows how DHT's one-year program was ranked by HEEM-II. Of the 95 projects, HEEM-II places 22 in Year One, 21 in Years 2-5, 18 in Years 6-10, and 34 projects are in the remainder (i.e., not chosen in the ten-year plan).

Chi-square values can be used to test whether the groupings by DHT and by HEEM-II are independent or whether they are related. "Expected values"

Table 16. Characteristics of Rank Correlation Coefficients, by Technique.

Ranking Technique	Rank Correlation Coefficients	
	Low - High	Average
Texas Sufficiency Rating (S)	.285 - .673	.498
Present Cost Index (C)	.117 - .662	.432
Future Cost Index (F)	.480 - .820	.678
Cost/Vehicle Mile, Present ADT (V)	.168 - .856	.525
Cost/Vehicle Mile, Future ADT (M)	.117 - .856	.593
Delay Savings Ratio (D)	.381 - .914	.635
Texas Priority Formula (P)	.498 - .916	.751
Modified HEEM-II (H)	.459 - .939	.669
Ranking Formula (R)	.530 - .939	.750

Table 17. Cross Tabluation of Actual and Expected Numbers of Projects Selected at Different Budget Levels by DHT and by Modified HEEM-II.

Projects Selected by Modified HEEM-II	Projects Selected by DHT for Years Covered in Budgets and for Remainder				
	One Year Program	Years 2 - 5 Program	Years 6 - 10 Program	Remainder	Total
Year One	22 (5.7)	26 (15.4)	17 (16.1)	51 (78.8)	116
Years 2 - 5	21 (10.8)	54 (29.2)	59 (30.6)	86 (149.4)	220
Years 6 - 10	18 (10.7)	44 (29.0)	57 (30.3)	99 (148.1)	218
Remainder	34 (67.9)	134 (184.4)	137 (193.0)	1,083 (942.7)	1,388
Total	95	258	270	1,319	1,942

*The "expected" values are obtained by multiplying the sum for a row by the sum for a column, divided by the grand total. For example, the 5.7 in the upper left corner is calculated by multiplying 116 by 95 and dividing by 1,942. These are the values that would be expected if the two ways of ranking projects were independent of each other.

Note: See Appendix A for other techniques.

for each cell in the table are calculated by multiplying the column total by the appropriate row total and dividing by the total number of projects--1,942. These expected values are the values that would be expected if the two ways of classifying projects were independent. The expected values are shown in the table in parentheses. The Chi-square value that is used for testing whether the two classifications are independent is calculated with the following formula:

$$\chi^2 = \Sigma \frac{(O-E)^2}{E}$$

where

χ^2 = the calculated Chi-square value

O = the actual or observed value in a specific cell in the table

E = the corresponding expected value in a specific cell in the table

Σ = indicates that a summation is made over all cells in the table

The calculated Chi-square has degrees of freedom (d.f.) equal to (r-1)(c-1) where r is the number of rows and c is the number of columns. In this case, the degrees of freedom equals (4-1)(4-1) or 9. If the calculated Chi-square value is greater than a table value for Chi-square, taken at the one percent signficance level, with 9 degrees of freedom, we conclude that the two classifications are not independent. In the case shown in Table 17, the calculated Chi-square is 268.6 and the table Chi-square is 21.7 so we conclude that the two classifications are not independent. Such Chi-square values were calculated for project selections by all nine ranking techniques as compared to the projects selected by DHT. These Chi-square values are shown in Table 18, which also shows the total number of projects selected in the ten-year plan by each technique and the number and percent of these projects that are also included in the ten-year plan selected by DHT. All of the Chi-square values are statistically significant indicating that all of the techniques select projects that are significantly related (statistically) to the DHT selections. Also, the larger Chi-square values are associated with greater percentages of the techniques' projects being in the DHT selection. The techniques for which the highest percentages of their choices are also chosen by DHT are the Present Cost Index (64.0%), the Ranking Formula (59.1%), the Delay Savings Ratio (57.6%), and Modified HEEM-II (57.4%). The

Table 18. Number of Projects Selected in Ten-Year Program by Different Techniques That Are Also Selected in DHT's Ten-Year Program, and Chi-Square Values for Techniques

Technique	(1) Number of Projects Selected in Ten-Year Program, by Listed Technique	(2) Number of Projects in Column (1) Also Selected by DHT in Ten-Year Program	(3) Column (2) as Percent of Column (1)	(4) Chi-Square Value for DHT Versus Listed Technique
$/Veh.Mi., Fut. ADT, M	634	241	38.0%	41.4
$/Veh.Mi., Pres. ADT, V	659	258	39.2	49.4
Sufficiency Rating, S	232	100	43.1	62.2
Future Cost Index, F	544	254	46.7	89.2
Priority Formula, P	446	226	50.7	133.0
Delay Savings Ratio, D	441	254	57.6	207.7
Ranking Formula, R	445	269	59.1	247.7
Modified HEEM-II, H	554	318	57.4	268.6
Present Cost Index, C	422	270	64.0	320.4

largest absolute number of DHT projects that are chosen by a technique are 318 projects chosen by Modified HEEM-II, followed by the Present Cost Index (270 projects), and the Cost per Vehicle Mile Traveled, Present ADT (258 projects). It is concluded that the Chi-square values are a good indicator of the percent of a technique's projects that are also chosen by DHT. The absolute number chosen depends partially on the total number chosen by the technique. Modified HEEM-II has the largest absolute number that match the DHT selections partially because it chooses a fairly large total number of projects (554 as compared to DHT's 623) and because a relatively large percentage of those chosen by HEEM-II also are selected by DHT (57.4%).

Analysis of Location and Size of Projects Selected by Deciles of Cost

To further investigate the characteristics of projects being ranked highest by each technique, the rankings for each technique were divided into ten groups (deciles) of roughly equal cost. To determine the projects in the first decile for a specific technique, the procedure used entailed going down the ranked list of projects until the next (marginal) project would make cumulative cost exceed one-tenth of the total cost of all projects. The second decile includes that marginal project plus all other projects down the list until the next project would exceed two-tenths of the total cost of all projects, and so forth. There are some small differences between the costs of each decile because of projects not adding precisely to one-tenth. Also, in the case of sufficiency ratings, there are some project ties in the ranking. All of the ties are put in the same decile so there is more irregularity in the decile costs for sufficiency ratings than for the other techniques.

Within each decile, for each ranking technique, several characteristics are evaluated. The characteristics of all 1,942 added capacity projects are summarized in Table 19. Less than one-third of all projects are in urban areas but these projects represent almost 50 percent of all project cost. The urban/rural fringe area projects represent 20.7 percent of all projects and only 13.8 percent of all cost. Rural projects represent 48.1 percent of all projects but only 36.5 percent of all cost.

Table 19. Characteristics of 1,942 Added Capacity Projects Considered as Possibilities for Future Consturction

Characteristic	Type of Area			
	Urban	Urban/Rural	Rural	Total
Number of Projects	605	402	935	1,942
Percent of All Projects	31.2%	20.7%	48.1%	100.0%
Cost of Projects	$10,542 Million	$2,934 Million	$7,752 Million	$21,228 Million
Percent of All Cost	49.7%	13.8%	36.5%	100.0%
Average Cost per Project	$17.4 Million	$7.3 Million	$8.3 Million	$10.9 Million

Tables 20 through 22 show the number of projects selected by each technique by deciles of total cost for, respectively, urban areas, urban/rural fringe areas, and rural areas. Tables 23 through 25 show the costs of these projects by decile. Most of the techniques tend to favor urban projects over rural projects as can be seen by comparing the numbers in each cell with the overall table average. The Sufficiency Rating tends to select large urban projects in the top deciles but distributes urban/rual fringe projects more evenly over deciles. Large urban projects tend to be ranked high because they have large traffic volumes and thus large sufficiency ratings and the Sufficiency Rating does not adjust this for large costs. This effect carries over somewhat into the Priority Formula and from there to the Ranking Formula. The techniques that tend to give more uniform distribution across deciles are the Modified HEEM-II and Future Cost Index techniques. The Delay Savings Ratio, the Priority Formula, Modified HEEM-II, and the Ranking Formula all tend to favor urban/rural fringe area projects much more than do the other techniques.

Tables 26 and 27 show total numbers of projects and the corresponding project costs summed over the first three deciles in Tables 20 through 25. Tables 28 and 29 show this same information on a percentage basis. These top three deciles cover a total project cost of about $6.368 billion, or slightly more than it is anticipated will be available for these types of projects in the next ten years, so these three deciles cover the projects that are of most interest in developing a ten-year plan.

The techniques that allocate the highest percent of total cost to urban projects, in the top three deciles, are the Sufficiency Rating (73.1%), the Priority Formula (63.9%), and the Cost per Vehicle Mile Traveled, Present ADT (63.8%). Techniques allocating the highest percent of total cost to rural in the top three deciles are the Future Cost Index (34.2%), the Cost per Vehicle Mile Traveled, Future ADT (29.4%), and Modified HEEM-II (28.6%). The last four techniques listed in Table 29 show a considerably higher percentage for urban/rural fringe projects than do the first five listed techniques. The two Cost per Vehicle Mile Traveled techniques give especially low percentages to the urban/rural category.

The technique that distributes funds most like the division for all 1,942 projects, shown as the bottom row in Table 29, is the Future Cost Index. Modified HEEM-II is fairly close to the universe distribution for

Table 20. Number of Urban Projects Selected by Each Technique by Decile of Total Cost

Technique	Decile of Total Cost										Total
	1	2	3	4	5	6	7	8	9	10	
Sufficiency Rating (S)	45	71	55	43	57	58	53	94	83	46	605
Present Cost Index (C)	81	56	48	41	45	36	35	47	44	172	605
Future Cost Index (F)	111	79	47	58	62	60	39	29	44	76	605
Cost/Vehicle Mile, Present ADT (V)	159	96	80	62	61	43	28	17	24	35	605
Cost/Vehicle Mile, Future ADT (M)	153	107	64	53	51	55	32	29	24	37	605
Delay Savings Ratio (D)	104	44	54	56	72	82	75	40	44	34	605
Priority Formula (P)	96	92	64	71	60	52	47	46	26	51	605
Modified HEEM-II (H)	93	60	58	56	65	66	60	42	71	34	605
Ranking Formula (R)	97	69	58	68	71	61	40	56	51	34	605
Average	104	75	59	56	60	57	45	44	46	58	60.5

Table 21. Number of Urban/Rural Fringe Projects Selected by Each Technique by Decile of Total Cost

Technique	Decile of Total Cost										Total
	1	2	3	4	5	6	7	8	9	10	
Sufficiency Rating (S)	14	15	25	24	16	25	39	51	76	117	402
Present Cost Index (C)	26	26	25	39	15	25	29	34	52	131	402
Future Cost Index (F)	38	36	41	34	36	23	20	25	33	116	402
Cost/Vehicle Mile, Present ADT (V)	33	47	59	46	43	40	36	36	33	29	402
Cost/Vehicle Mile, Future ADT (M)	40	45	52	41	46	41	312	33	31	42	402
Delay Savings Ratio (D)	78	40	23	40	32	65	67	36	15	6	402
Priority Formula (P)	47	38	35	35	39	29	33	40	37	69	402
Modified HEEM-II (H)	73	49	39	37	31	44	35	28	47	19	402
Ranking Formula (R)	64	54	27	43	38	38	21	50	34	33	402
Average	46	39	36	38	33	37	35	37	40	62	40.2

Table 22. Number of Rural Projects Selected by Each Technique by Decile of Total Cost

Technique	Decile of Total Cost										Total
	1	2	3	4	5	6	7	8	9	10	
Sufficiency Rating (S)	4	9	29	39	74	86	146	139	193	216	935
Present Cost Index (C)	51	84	60	63	60	80	100	164	152	121	935
Future Cost Index (F)	82	77	77	80	85	101	82	70	105	176	935
Cost/Vehicle Mile, Present ADT (V)	48	69	127	91	134	121	91	59	77	118	935
Cost/Vehicle Mile, Future ADT (M)	75	79	83	106	111	107	106	118	66	84	935
Delay Savings Ratio (D)	68	38	21	38	53	70	200	177	138	132	935
Priority Formula (P)	31	35	43	88	79	120	115	121	133	170	935
Modified HEEM-II (H)	57	73	90	81	107	127	88	76	121	115	935
Ranking Formula (R)	39	43	32	91	108	109	91	157	106	159	935
Average	51	56	62	75	90	102	113	120	122	143	93.5

Table 23. Total Cost ($ Millions) of Urban Projects Selected by Each Technique by Decile of Total Cost

Technique	Decile of Total Cost										Total
	1	2	3	4	5	6	7	8	9	10	
Sufficiency Rating (S)	$1,726	$1,670	$1,258	$1,312	$1,263	$1,345	$ 699	$ 659	$ 496	$ 114	$10,542
Present Cost Index (C)	1,440	1,012	1,125	1,105	1,287	962	1,222	487	637	1,263	10,542
Future Cost Index (F)	1,241	1,112	975	864	1,351	1,065	1,098	1,289	1,035	512	10,542
Cost/Vehicle Mile, Present ADT (V)	1,730	1,449	833	1,263	933	796	729	1,092	858	859	10,542
Cost/Vehicle Mile, Future ADT (M)	1,496	1,330	1,077	892	833	947	923	868	1,113	1,061	10,542
Delay Savings Ratio (D)	947	943	1,602	1,246	1,383	1,327	675	484	908	1,027	10,542
Priority Formula (P)	1,249	1,338	1,382	1,220	1,228	968	1,134	792	671	559	10,542
Modified HEEM-II (H)	972	870	1,083	1,147	841	694	1,277	1,316	1,080	1,261	10,542
Ranking Formula (R)	1,112	1,078	1,584	884	1,157	957	1,263	597	771	1,138	10,542
Average	1,324	1,200	1,213	1,204	1,142	1,007	1,002	842	841	866	1,054.2

Table 24. Total Cost ($ Millions) of Urban/Rural Fringe Projects Selected by Each Technique by Decile of Total Cost

Technique	Decile of Total Cost										Total
	1	2	3	4	5	6	7	8	9	10	
Sufficiency Rating (S)	$ 257	$ 373	$ 403	$ 425	$ 83	$ 172	$ 342	$ 315	$ 206	$ 358	$ 2,934
Present Cost Index (C)	212	245	558	455	326	227	255	224	177	255	2,934
Future Cost Index (F)	159	276	423	395	374	243	216	242	256	351	2,934
Cost/Vehicle Mile, Present ADT (V)	60	219	299	189	183	298	475	556	343	310	2,934
Cost/Vehicle Mile, Future ADT (M)	93	244	256	294	369	386	289	283	327	395	2,934
Delay Savings Ratio (D)	608	749	270	375	234	285	170	189	44	11	2,934
Priority Formula (P)	538	540	294	284	295	124	182	253	150	275	2,934
Modified HEEM-II (H)	589	671	338	359	235	208	183	94	210	45	2,934
Ranking Formula (R)	624	651	304	365	225	243	107	172	92	152	2,934
Average	349	441	349	349	258	243	247	259	201	239	293.4

Table 25. Total Cost ($ Millions) of rural Projects Selected by Each Technique by Decile of Total Cost

Technique	Decile of Total Cost										Total
	1	2	3	4	5	6	7	8	9	10	
Sufficiency Rating (S)	$ 107	$ 108	$ 463	$ 378	$ 674	$ 694	$1,085	$1,167	$1,426	$1,650	$ 7,752
Present Cost Index (C)	467	757	540	566	466	728	909	1,406	1,303	611	7,752
Future Cost Index (F)	721	703	749	748	519	789	846	574	826	1,277	7,752
Cost/Vehicle Mile, Present ADT (V)	290	497	913	746	999	1,036	837	547	934	953	7,752
Cost/Vehicle Mile, Future ADT (M)	532	550	789	921	923	789	931	967	673	678	7,752
Delay Savings Ratio (D)	547	451	243	460	546	510	1,289	1,452	1,168	1,087	7,752
Priority Formula (P)	330	251	288	733	631	1,027	829	1,072	1,300	1,291	7,752
Modified HEEM-II (H)	517	612	679	642	1,031	1,204	707	677	864	819	7,752
Ranking Formula (R)	366	403	242	796	801	924	780	1,343	943	1,155	7,752
Average	431	481	545	666	732	856	913	1,023	1,049	1,058	775.2

Table 26. Numbers of Projects Chosen in First Three Deciles by Type of Areas, by Technique

Technique	Number of Projects Chosen in Top Three Deciles by Type of Area, by Technique			
	Urban	Urban/Rural	Rural	Total
Sufficiency Rating (S)	171	54	42	267
Present Cost Index (C)	185	77	195	457
Future Cost Index (F)	237	115	236	588
Cost/Vehicle Mile, Present ADT (V)	335	139	244	718
Cost/Vehicle Mile, Future ADT (M)	324	137	237	698
Delay Savings Ratio (D)	202	141	127	470
Priority Formula (P)	252	120	109	481
Modified HEEM-II (H)	211	161	220	592
Ranking Formula (R)	224	145	114	483
Average	238	121	169	528

Table 27. Cost of Projects Chosen in First Three Deciles by Type of Area by Technique, in Millions of Dollars

Technique	Cost ($ Millions) of Projects Chosen in Top Three Deciles by Type of Area			
	Urban	Urban/Rural	Rural	Total
Sufficiency Rating (S)	$ 4,654	$ 1,033	$ 678	$ 6,365
Present Cost Index (C)	3,577	1,015	1,764	6,356
Future Cost Index (F)	3,328	858	2,173	6,359
Cost/Vehicle Mile, Present ADT (V)	4,012	578	1,700	6,290
Cost/Vehicle Mile, Future ADT (M)	3,903	593	1,871	6,367
Delay Savings Ratio (D)	3,492	1,627	1,241	6,360
Priority Formula (P)	3,969	1,372	869	6,210
Modified HEEM-II (H)	2,925	1,598	1,808	6,331
Ranking Formula (R)	3,774	1,579	1,011	6,364
Average	3,737	1,139	1,457	6,334

Table 28. Percentage Distribution of Number of Projects in Top Three Deciles by Type of Area, by Technique

Technique	Percentage Distribution of Number of Projects in Top Three Deciles by Type of Area			
	Urban	Urban/Rural	Rural	Total
Sufficiency Rating (S)	64.0%	20.2%	15.7%	99.9%
Present Cost Index (C)	40.5	16.8	42.7	100.0
Future Cost Index (F)	40.3	19.6	40.1	100.0
Cost/Vehicle Mile, Present ADT (V)	46.7	19.4	34.0	100.1
Cost/Vehicle Mile, Future ADT (M)	46.4	19.6	34.0	100.0
Delay Savings Ratio (D)	43.0	30.0	27.0	100.0
Priority Formula (P)	52.4	24.9	22.7	100.0
Modified HEEM-II (H)	35.6	27.2	37.2	100.0
Ranking Formula (R)	46.4	30.0	23.6	100.0
Average	45.1	22.9	32.0	100.0
Average All Deciles	31.2	20.7	48.1	100.0

Table 29. Percentage Distribution of Cost of Projcts in in Top Three Deciles by Type of Area, by Technique

Technique	Percentage Distribution of Cost of Projcts in Top Three Deciles by Type of Area			
	Urban	Urban/Rural	Rural	Total
Sufficiency Rating (S)	73.1%	16.2%	10.7%	100.0%
Present Cost Index (C)	56.3	16.0	27.8	100.1
Future Cost Index (F)	52.3	13.5	34.2	100.0
Cost/Vehicle Mile, Present ADT (V)	63.8	9.2	27.0	100.0
Cost/Vehicle Mile, Future ADT (M)	61.3	9.3	29.4	100.0
Delay Savings Ratio (D)	54.9	25.6	19.5	100.0
Priority Formula (P)	63.9	22.1	14.0	100.0
Modified HEEM-II (H)	46.2	25.2	28.6	100.0
Ranking Formula (R)	59.3	24.8	15.9	100.0
Average	59.0	18.0	23.0	100.0
Average All Deciles	49.7	13.8	36.5	100.0

urban but tends to favor urban/rural over rural in the top three deciles. The Present Cost Index also matches the universe quite well with slightly more emphasis on urban and urban/rural as opposed to rural. The two Cost per Vehicle Mile Traveled techniques favor urban over the other two categories. The Delay Savings Ratio, the Priority Formula, and the Ranking Formula all favor urban/rural and urban over the rural, having the lowest percentage of rural of all techniques except the Sufficiency Rating.

Three sets of figures in Appendix B show the detailed comparisons by deciles. Figures B1 through B9 show project costs by type of area for each decile by technique. Figures B10 through B18 show the number of projects selected in each area for each decile, by technique. Figures B19 through B27 show the average cost per project in each area for each decile, by technique.

CHAPTER V. SUMMARY AND CONCLUSIONS

This report presents a discussion of selected techniques that can be used to rank major highway construction projects. Emphasis is placed on techniques that estimate the increase in motorist benefits that can be obtained for a limited construction budget. Emphasis is placed on techniques for evaluating projects that provide increases in highway capacity by increasing the number of lanes and/or by providing medial or marginal access control. Techniques that can be used for ranking upgrade-to-standards and new location projects also are discussed.

Advisory Committee Recommendations

A study advisory committee provided recommendations on factors that should be considered in ranking projects and the relative weights that should be placed on these factors. In general, it is concluded that the factors currently included in the Texas Sufficiency Rating schedules are superior to those typically used elsewhere because they focus on the specific factors that should be considered and these factors are different for added-capacity and upgrade-to-standards projects. The major factors that the advisory committee would like to see added to current sufficiency ratings are factors dealing explicitly with accident experience, pavement condition or drainage problems, passing opportunities, and district priority. However, no attempt has been made in this research to add additional factors to the currently used sufficiency ratings.

A sensitivity analysis was made of the factor weights in the current sufficiency rating for added capacity projects as compared to the weights suggested by committee members for those same factors. It was concluded that the change in weights would make little difference in project rankings. A sensitivity analysis also was performed to determine whether changing from discrete sub-categories to continuous functions would affect rankings obtained by sufficiency ratings. It was concluded that there would be little change in the sufficiency rating rankings but there would be a significant change in rankings derived by the Texas Priority Formula, a technique that is based on the change in the Texas Sufficiency Ratings.

Comparison of Rankings for Added-Capacity Projects

Nine different techniques are presented as possibilities for ranking added-capacity projects:

1. Texas Sufficiency Rating
2. Texas Priority Formula (based on change in Sufficiency Rating)
3. Present Cost Index (based on reduction in current congestion)
4. Future Cost Index (based on reduction in future congestion)
5. Cost per Vehicle Mile Traveled, using Present ADT
6. Cost per Vehicle Mile Traveled, using Future ADT
7. Delay Savings Ratio (based on reduction in delay)
8. Modified HEEM-II (based on ratio of benefits to costs)
9. Ranking Formula (based on weighted average of rankings given by Nos. 2, 7, and 8 in list)

Each of these techniques was used to rank 1,942 major added-capacity projects with an expected cost of $21.1 billion. These projects include most of the major added-capacity improvements that are currently expected to be needed in the next twenty years. The list does not include interchanges, rail/highway grade separations, and some second stage projects, mostly in major urban areas, if the first stage is already included in the list.

The rankings were compared in several ways. First, the motorist benefits obtained from the rankings, as estimated by the modified HEEM-II program, were compared at selected budget levels, including the level expected to be available for the next ten years representing initial project costs of $5.742 billion. At this budget level, the two techniques that showed the least improvement over random selection were the Cost per Vehicle Mile Traveled, using Present Average Daily Traffic and the Texas Sufficiency Rating, providing 51 percent and 51.5 prcent more benefits than would random selection. The current department selection for this budget level, which is partially based on these two techniques, was better than either of these techniques with estimated benefits that are 56.8 percent greater than random selection. The best techniques gave considerably more benefits than the current department selection, but it again should be emphasized, as discussed on page 41, that the department selection process had constraints and considered objectives that were not considered when ranking using the nine techniques. For example, the department considered scheduling restrictions and omitted some projects for environmental or other reasons. In addition, the department used a system concept in project planning, as discussed on page 41.

The modified HEEM-II program provides estimated benefits that are 145.6 percent greater than those provided by random selection at a budget level of $5.742 billion, representing an improvement of $22.7 billion over the Texas Sufficiency Rating technique. This is followed by the Ranking Formula (136.1 percent improvement over random selection), the Delay Savings Ratio (127.4 percent), the Texas Priority Formula (114.1 percent), and the Future Cost Index (100.0 percent). This comparison indicates that a substantial increase in benefits may be possible through use of improved ranking techniques if the estimation of benefits is reasonably correct. It should be emphasized that all references to benefits represent dollar savings in future benefits as estimated by Modified HEEM-II, as opposed to savings in expenditure of tax dollars.

Rankings given by the different techniques also were compared using rank correlation coefficients. A rank correlation coefficient ranges from -1.0 for an exactly inverse relationship between the rankings of two techniques to +1.0 for a perfect match between two rankings. A rank correlation coefficient of 0.0 indicates the two rankings are totally unrelated. All of the pairs of rankings for the nine techniques were positively related and the relationship was statistically significant. The two techniques that showed the highest correlation with all of the other techniques were the Texas Priority Formula and the Ranking Formula indicating that these are good "consensus" techniques. Other techniques that tend to have high average rank correlation coefficients are the Future Cost Index, Modified HEEM-II, and the Delay Savings Ratio.

Rankings were further compared by analyzing the types of projects (rural, rural/urban, and urban) and the average cost of projects by decile of cost. This analysis indicates that the Texas Sufficiency Rating technique tends to select large urban projects more than do the other techniques. This selection bias toward large urban projects results from the high sufficiency rating on facilities with large traffic volumes and high levels of congestion. The Sufficiency Rating, however, does not indicate how much this congestion can be reduced per dollar of cost. The techniques that tend to give a more uniform distribution of project costs to each type of area are the Future Cost Index and Modified HEEM-II. The Future Cost Index's projects chosen in the top three deciles divide funds among urban, urban/ rural fringe, and rural areas more like the universe of all 1,942 project than does any other technique. Next most similar to the universe distribution is the Modified HEEM-II ranking. The Modified HEEM-II distribution of costs among area types is fairly close to the universe distribution for urban but tends to slightly favor urban/rural fringe projects over rural in the top three deciles.

The rankings by each technique also were compared to the latest DHT selections in their ten year plan for these same 1,942 added capacity projects. DHT personnel selected 623 projects in their ten-year plan. The Modified HEEM-II technique selected 554 projects in the ten-year plan, 318 of which were also selected in the DHT plan, which is higher than that for any other technique. The next highest number of DHT projects were selected by the Present Cost Index (270 projects) and the Ranking Formula (269 projects).

Three other criteria that are important in selecting a ranking technique are operational efficiency, ease of understanding the technique, and susceptibility of the technique to errors because of inaccurate input data. All of the techniques are operationally efficient and use the same general data base at this time. The techniques that use forecasted ADT probably are more susceptible to errors in input data than are the other techniques, so a considerable effort should be made to develop good traffic forecasts, if one of these techniques is used. Also, it may be desirable to perform a sensitivity analysis of ADT forecasts.

Ease of understanding is a very desirable characteristic for a ranking technique. Probably the most easily understandable techniques are the Sufficiency Rating, benefit-cost ratios (Modified HEEM-II and Delay Savings), and the cost per vehicle miles traveled techniques.

Status of Ranking Techniques for Other Types of Projects

A preliminary analysis was made of the status of different evaluation techniques that are available or could be made available with little change in existing computer programs for upgrade-to-standards and new location projects. The status of these techniques is summarized in Tables 30, 31, and 32. Most of these techniques can be used with only minor changes in existing computer programs, but additional data are needed, especially for the proposed improvements.

The only types of new location projects that would be difficult to evaluate with existing techniques are new loop highways where there are several major intersecting highways and other new circumferential routes where there is no well defined travel corridor. For these highway types, a network travel demand analysis, together with benefit-cost anlaysis, appears to be a promising approach.

Conclusions and Recommendations

The Modified HEEM-II technique rated as one of the better techniques by all the criteria used to compare techniques. HEEM-II's ranking is estimated to provide the most benefits of any technique. At the ten-year budget level of $5.742 billion, the Modified HEEM-II technique is expected to provide over $22 billion more benefits than the Sufficiency Rating technique or the Cost per Vehicle Mile, Present ADT, and more than $21 billion more than the latest DHT selection. It is not very surprising that Modified HEEM-II did better than the other techniques since benefits were calculated using the Modified HEEM-II program. Nevertheless, the magnitude of the difference in benefits between techniques is substantial and, at a minimum, is deserving of further study. If the benefit measurement is at least roughly correct, then a substantial increase in total benefits will result from using Modified HEEM-II.

The Modified HEEM-II program also rated high in being a fairly good consensus technique as did the Future Cost Index. On this basis, however, the best techniques were the Texas Priority Formula and the Texas Ranking Formula, both of which might be expected to be highly correlated with other techniques since they are partially based on other techniques.

Based on matching current DHT selections, Modified HEEM-II rated first, choosing 318 projects out of 623 projects in the ten-year plan. The Future Cost Index and Modified HEEM-II both distributed projects among urban, urban-rural, and rural areas more like the universe of all projects than did other techniques.

Table 30. Status of Different Evaluation Techniques for Upgrade-to-Standards Projects.

Evaluation Technique	Status
Sufficiency Rating	Currently operational
Priority Formula	Formula available, additional data needed for proposed improvements
HEEM-II	Minor modifications needed in program but data collection would be required
Cost per Vehicle-Mile Traveled, Current or Future ADT	Currently operational, but not very good for this type of project
Ranking Formula	Easy to define and use, if other techniques are operational

Table 31. Status of Different Evaluation Techniques for Bypass Projects with One Major Route Through City

Evaluation Technique	Status
Sufficiency Rating	New schedule could be developed, based on Advisory Committee recommendations, for existing route, but limitations to usefulness
Priority Formula	Proposed formula presented in this report but needs testing in pilot study
Delay Savings Ratio	Current program can be used but need additional data
HEEM-II	Current program needs minor modifications and need additional data
Ranking Formula	Easy to define and use, if other techniques are operational

Table 32. Status of Evaluation Techniques for Other New Location Projects.

Type Project and Evaluation Technique	Status of Evaluation Technique
Major Radial Highways in Urban Corridors	
a. Delay Savings Ratio	Program operational, but additional data needed
b. HEEM-II	Program operational, but additional data needed
Major New Rural Highways in Defined Travel Corridor	
a. Delay Savings Ratio	Program operational, but additional data needed
b. HEEM-II	Program operational, but additional data needed.
New Circumferential Routes in Urban Areas, No Well Defined Travel Corridor	Need network analysis supplemented by special benefit-cost study

Next to Modified HEEM-II, the Ranking Formula probably is the best technique, based on the comparisons made in this study. Consideration might also be given to variations of this Ranking Formula technique. Possibilities that might be considered include adding the Future Cost Index to make the Ranking Formula depend on four techniques instead of three. Another possibility would be to substitute the Future Cost Index for the Delay Savings Ratio in the Ranking Formula, since the Future Cost Index consistently ranked as one of the better techniques.

For projects other than added-capacity projects, several ranking techniques are presented but no comparisons of rankings are made because additional data are needed. It is recommended that such data be compiled and that these ranking techniques be compared as was done for added-capacity projects.

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APPENDIX A

Tables Comparing DHT Selections With Those By Different Techniques

(Refer to Chapter IV for discussion)

Table No.	Technique
A1	Sufficiency Rating
A2	Present Cost Index
A3	Future Cost Index
A4	Cost/Vehicle Mile, Present ADT
A5	Cost/Vehicle Mile, Future ADT
A6	Priority Formula
A7	Delay Savings Ratio
A8	Ranking Formula
(17, Chapter IV)	Modified HEEM-II

Table A1. Cross Tabulation of Actual and Expected Numbers of Projects Selected at Different Budget Levels by DHT and by Sufficiency Rating Technique

Projects Selected Selected by Sufficiency Rating	Projects Selected by DHT for Years Covered in Budgets and for Remainder				
	One Year Program	Years 2 - 5 Program	Years 6 - 10 Program	Remainder	Total
Year One	4 (1.2)	4 (3.5)	2 (3.5)	15 (17.0)	25
Years 2 - 5	9 (4.5)	27 (12.1)	4 (12.7)	51 (61.8)	91
Years 6 - 10	15 (5.7)	20 (15.4)	15 (16.1)	66 (78.8)	116
Remainder	67 (83.7)	207 (227.2)	249 (237.7)	1,187 (1,164.4)	1,710
Total	95	258	270	1,319	1,942

$\chi^2 = 63.19$

Table A2. Cross Tabulation of Actual and Expected Numbers of Projects Selected at Different Budget Levels by DHT and by Present Cost Index Technique

Projects Selected Selected by Present Cost Index	Projects Selected by DHT for Years Covered in Budgets and for Remainder				
	One Year Program	Years 2 - 5 Program	Years 6 - 10 Program	Remainder	Total
Year One	3 (3.3)	10 (8.9)	9 (9.3)	45 (45.5)	67
Years 2 - 5	21 (9.8)	76 (26.7)	41 (28.0)	63 (136.5)	201
Years 6 - 10	21 (7.5)	40 (20.5)	49 (21.4)	44 (104.6)	154
Remainder	50 (74.4)	132 (201.9)	171 (211.3)	1,167 (1,032.4)	1,520
Total	95	258	270	1,319	1,942

$\chi^2 = 320.39$

Table A3. Cross Tabulation of Actual and Expected Numbers of Projects Selected at Different Budget Levels by DHT and by Future Cost Index Technique

Projects Selected Selected by Future Cost Index	Projects Selected by DHT for Years Covered in Budgets and for Remainder				
	One Year Program	Years 2 - 5 Program	Years 6 - 10 Program	Remainder	Total
Year One	10 (4.9)	15 (13.4)	12 (14.0)	64 (68.6)	101
Years 2 - 5	17 (12.3)	52 (33.4)	46 (34.9)	136 (170.5)	251
Years 6 - 10	16 (9.4)	41 (25.5)	45 (26.7)	90 (130.4)	192
Remainder	52 (68.4)	150 (185.7)	167 (194.4)	1,029 (949.5)	1,398
Total	95	258	270	1,319	1,942

$\chi^2 = 89.17$

Table A4. Cross Tabulation of Actual and Expected Numbers of Projects Selected at Different Budget Levels by DHT and by Cost per Vehicle Mile Traveled, Present ADT

Projects Selected Selected by Cost/ Vehicle Mile, Present ADT	Projects Selected by DHT for Years Covered in Budgets and for Remainder				
	One Year Program	Years 2 - 5 Program	Years 6 - 10 Program	Remainder	Total
Year One	1 (5.2)	9 (14.1)	14 (14.7)	82 (72.0)	106
Years 2 - 5	16 (12.9)	43 (34.9)	38 (36.6)	166 (178.6)	263
Years 6 - 10	21 (14.2)	60 (38.5)	56 (40.3)	153 (197.0)	290
Remainder	57 (62.8)	146 (170.5)	162 (178.4)	918 (871.4)	1,283
Total	95	258	270	1,319	1,942

$\chi^2 = 49.40$

Table A5. Cross Tabulation of Actual and Expected Numbers of Projects Selected at Different Budget Levels by DHT and by Cost per Vehicle Mile Traveled, Future ADT

Projects Selected Selected by Cost/ Vehicle Mile, Future ADT	Projects Selected by DHT for Years Covered in Budgets and for Remainder				
	One Year Program	Years 2 - 5 Program	Years 6 - 10 Program	Remainder	Total
Year One	4 (5.7)	11 (15.5)	12 (16.3)	90 (79.5)	117
Years 2 - 5	19 (14.1)	41 (38.4)	44 (40.2)	185 (196.3)	289
Years 6 - 10	15 (11.2)	51 (30.3)	44 (31.7)	118 (154.9)	228
Remainder	57 (64.0)	155 (173.8)	170 (181.9)	926 (888.4)	1,308
Total	95	258	270	1,319	1,942

$\chi^2 = 41.41$

Table A6. Cross Tabulation of Actual and Expected Numbers of Projects Selected at Different Budget Levels by DHT and by Priority Formula

Projects Selected Selected by Priority Formula	Projects Selected by DHT for Years Covered in Budgets and for Remainder				
	One Year Program	Years 2 - 5 Program	Years 6 - 10 Program	Remainder	Total
Year One	10 (3.7)	14 (10.1)	7 (10.6)	45 (51.6)	76
Years 2 - 5	25 (10.4)	45 (28.2)	39 (29.5)	103 (144.0)	212
Years 6 - 10	11 (7.7)	47 (21.0)	28 (22.0)	72 (107.3)	158
Remainder	49 (73.2)	152 (198.8)	196 (208.0)	1,099 (1,016.1)	1,496
Total	95	258	270	1,319	1,942

$\chi^2 = 132.96$

Table A7. Cross Tabulation of Actual and Expected Numbers of Projects Selected at Different Budget Levels by DHT and by Delay Savings Ratio

Projects Selected Selected by Delay Savings Ratio	Projects Selected by DHT for Years Covered in Budgets and for Remainder				
	One Year Program	Years 2 - 5 Program	Years 6 - 10 Program	Remainder	Total
Year One	24 (7.0)	38 (18.9)	23 (19.7)	57 (96.5)	142
Years 2 - 5	16 (8.9)	47 (24.2)	36 (25.3)	83 (123.6)	182
Years 6 - 10	9 (5.7)	27 (15.5)	34 (16.3)	47 (79.5)	117
Remainder	46 (73.4)	146 (199.4)	177 (208.7)	1,132 (1,019.5)	1,501
Total	95	258	270	1,319	1,942

$\chi^2 = 207.70$

Table A8. Cross Tabulation of Actual and Expected Numbers of Projects Selected at Different Budget Levels by DHT and by Ranking Formula

Projects Selected Selected by Ranking Formula	Projects Selected by DHT for Years Covered in Budgets and for Remainder				
	One Year Program	Years 2 - 5 Program	Years 6 - 10 Program	Remainder	Total
Year One	19 (4.9)	23 (13.3)	11 (13.9)	47 (67.9)	100
Years 2 - 5	23 (10.2)	60 (27.6)	46 (28.9)	79 (141.3)	208
Years 6 - 10	11 (7.2)	32 (19.5)	44 (20.4)	60 (99.8)	147
Remainder	42 (72.7)	143 (197.6)	169 (206.7)	1,133 (1,016.8)	1,487
Total	95	258	270	1,319	1,942

$X^2 = 247.74$

APPENDIX B

Figures Showing Project Cost, Numbers of Projects, and Average Cost Per Project by Deciles of Total Cost, for Each Technique

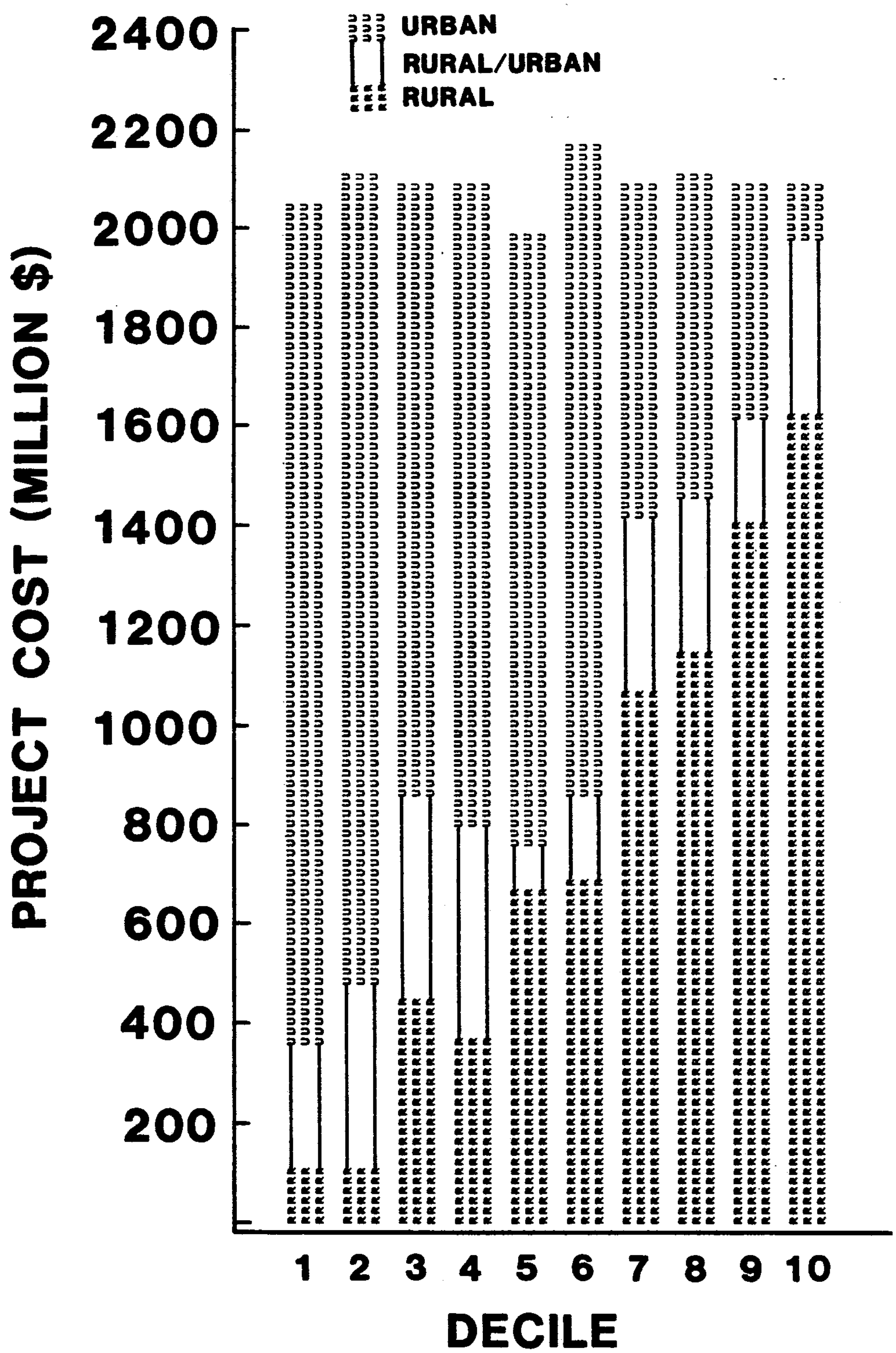

Figure B1. Distribution of Project Costs Among Urban, Urban/Rural, and Rural Areas by Deciles of Total Project Cost for Rankings by the Sufficiency Rating (S).

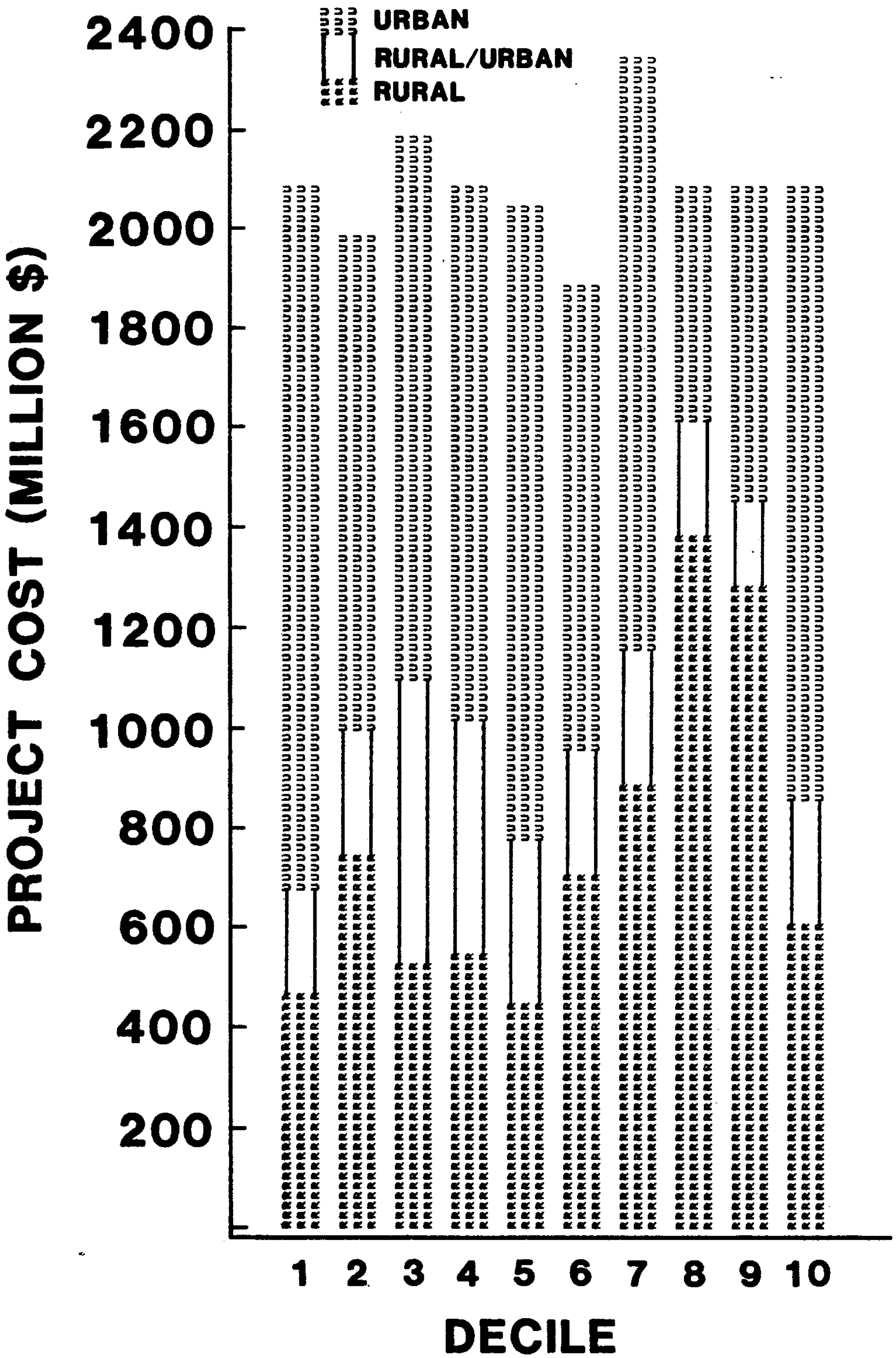

Figure B2. Distribution of Project Costs Among Urban, Urban/Rural, and Rural Areas by Deciles of Total Project Cost for Rankings by the Present Cost Index (C).

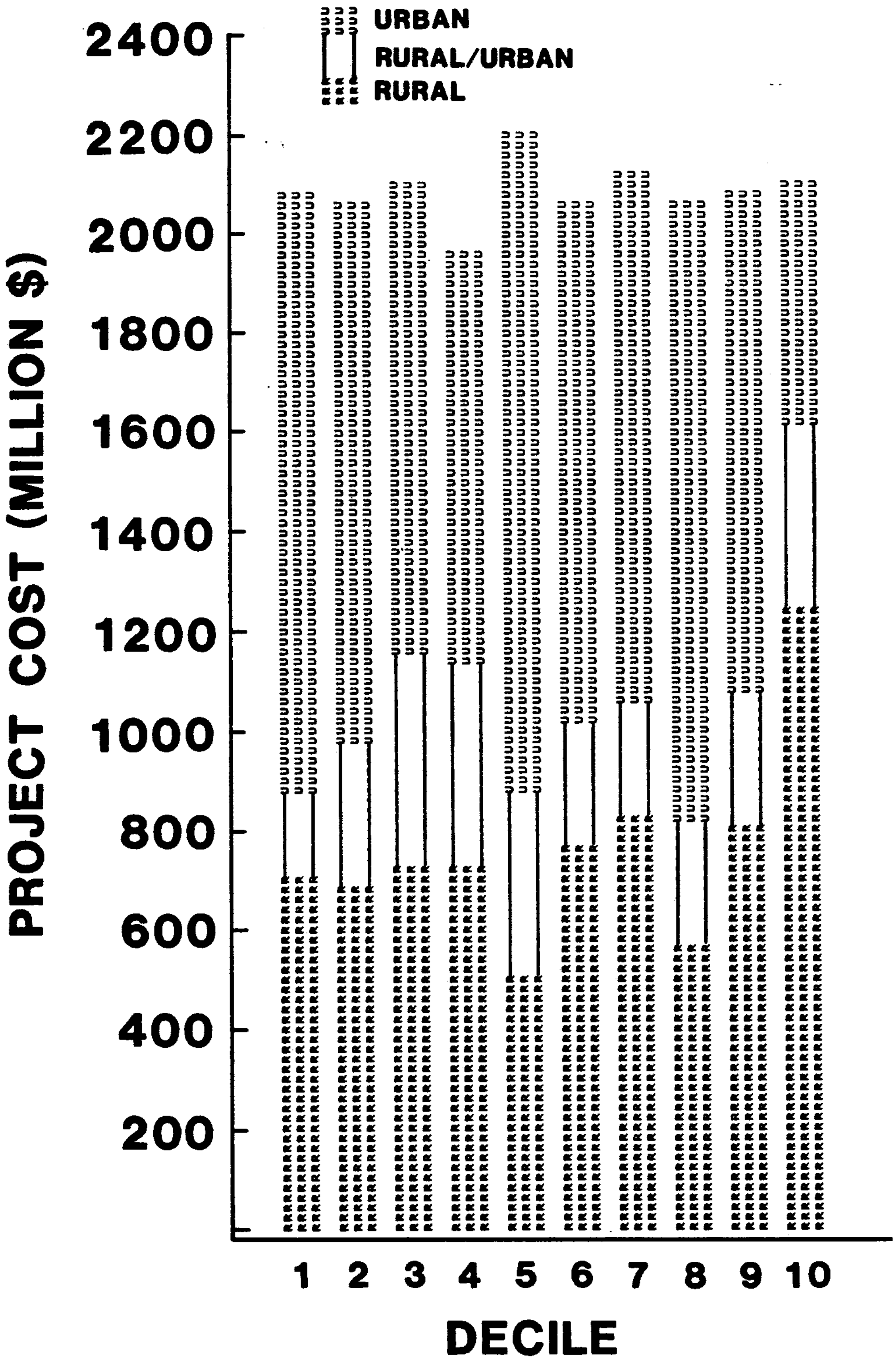

Figure B3. Distribution of Project Costs Among Urban, Urban/Rural, and Rural Areas by Deciles of Total Project Cost for Rankings by the Future Cost Index (F).

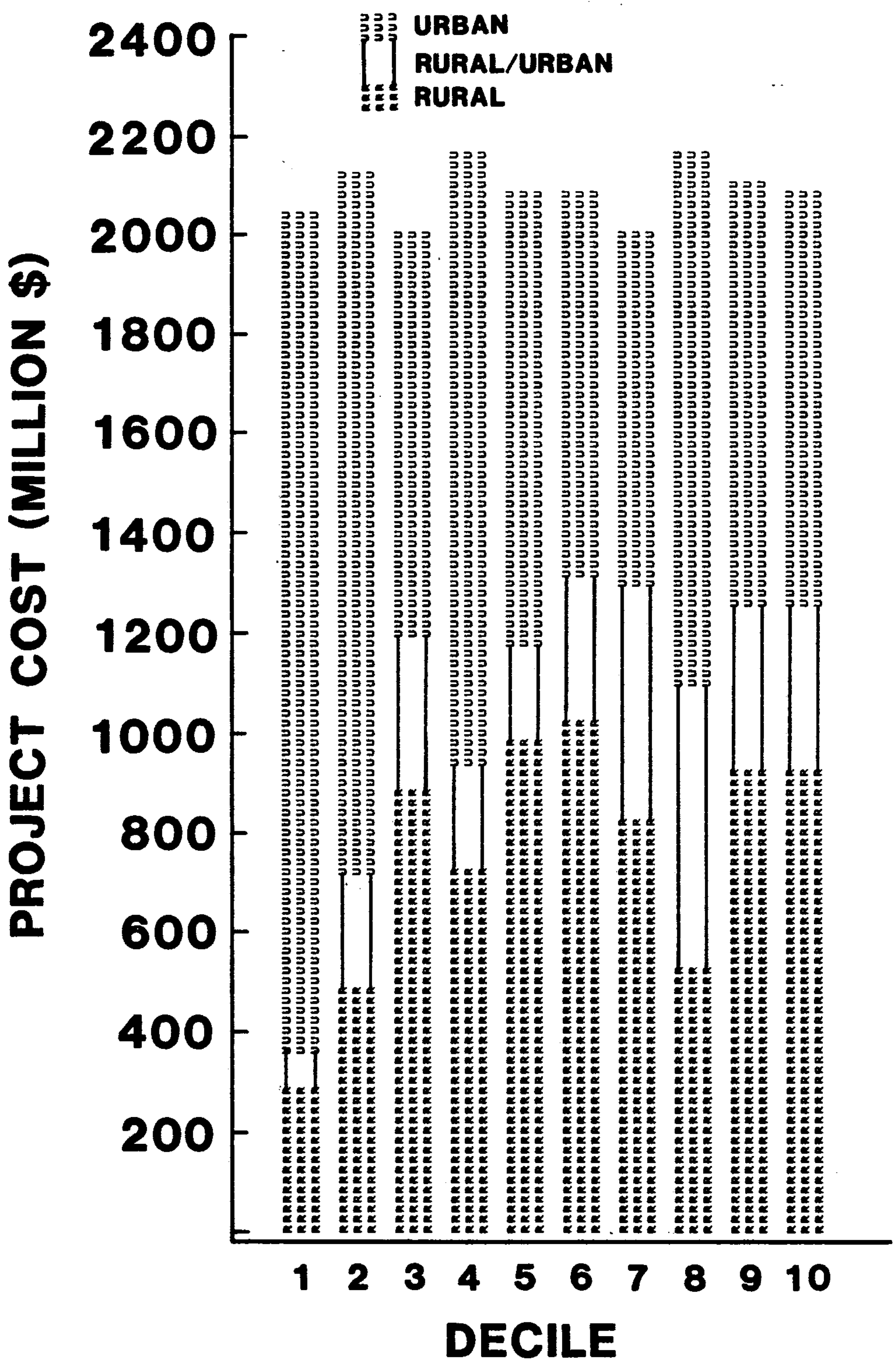

Figure B4. Distribution of Project Costs Among Urban, Urban/Rural, and Rural Areas by Deciles of Total Project Cost for Rankings by the Cost Per Vehicle Mile Traveled, Present ADT (V).

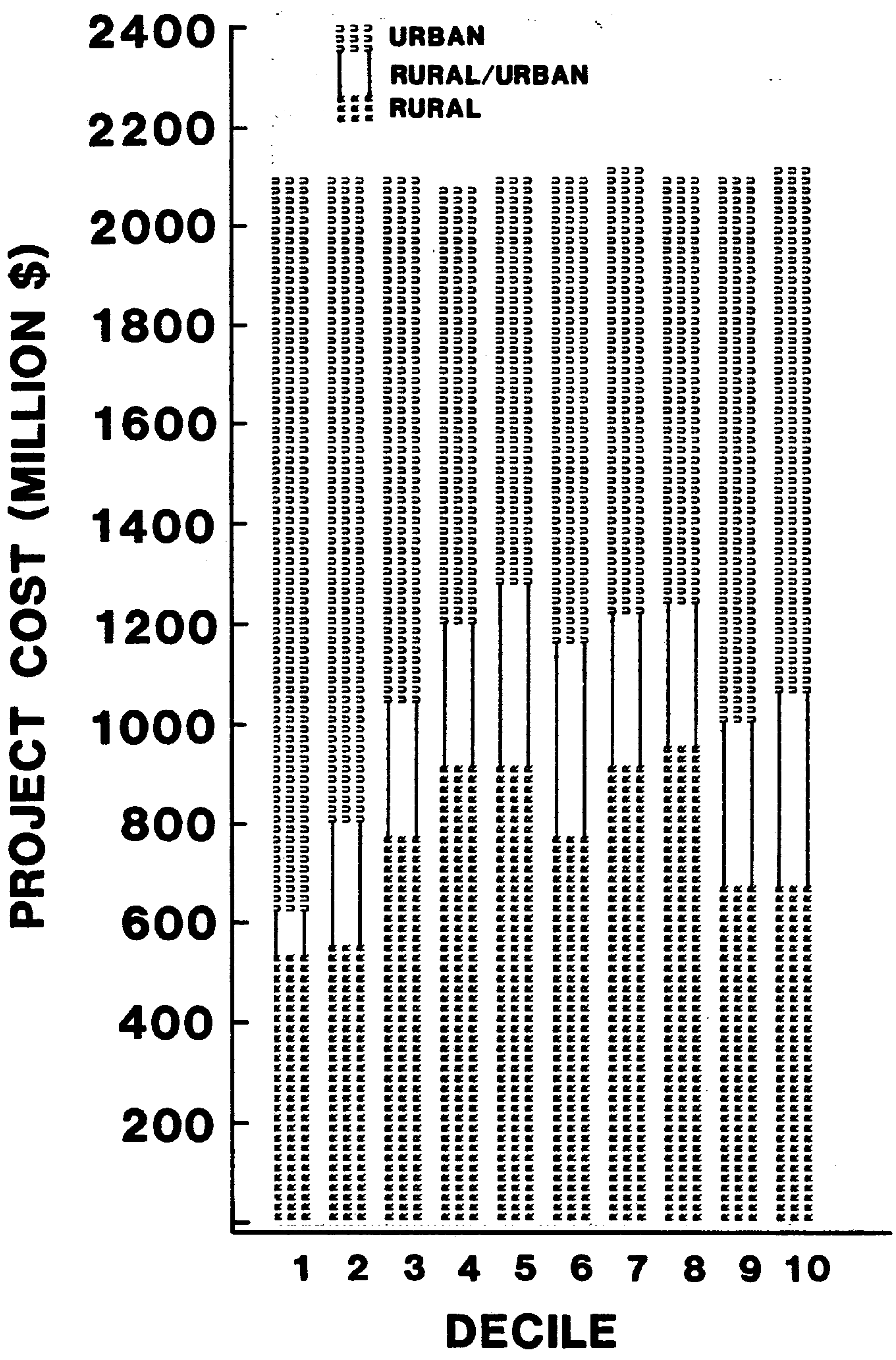

Figure B5. Distribution of Project Costs Among Urban, Urban/Rural, and Rural Areas by Deciles of Total Project Costs for Rankings by the Cost Per Vehicle Mile Traveled, Future ADT (M).

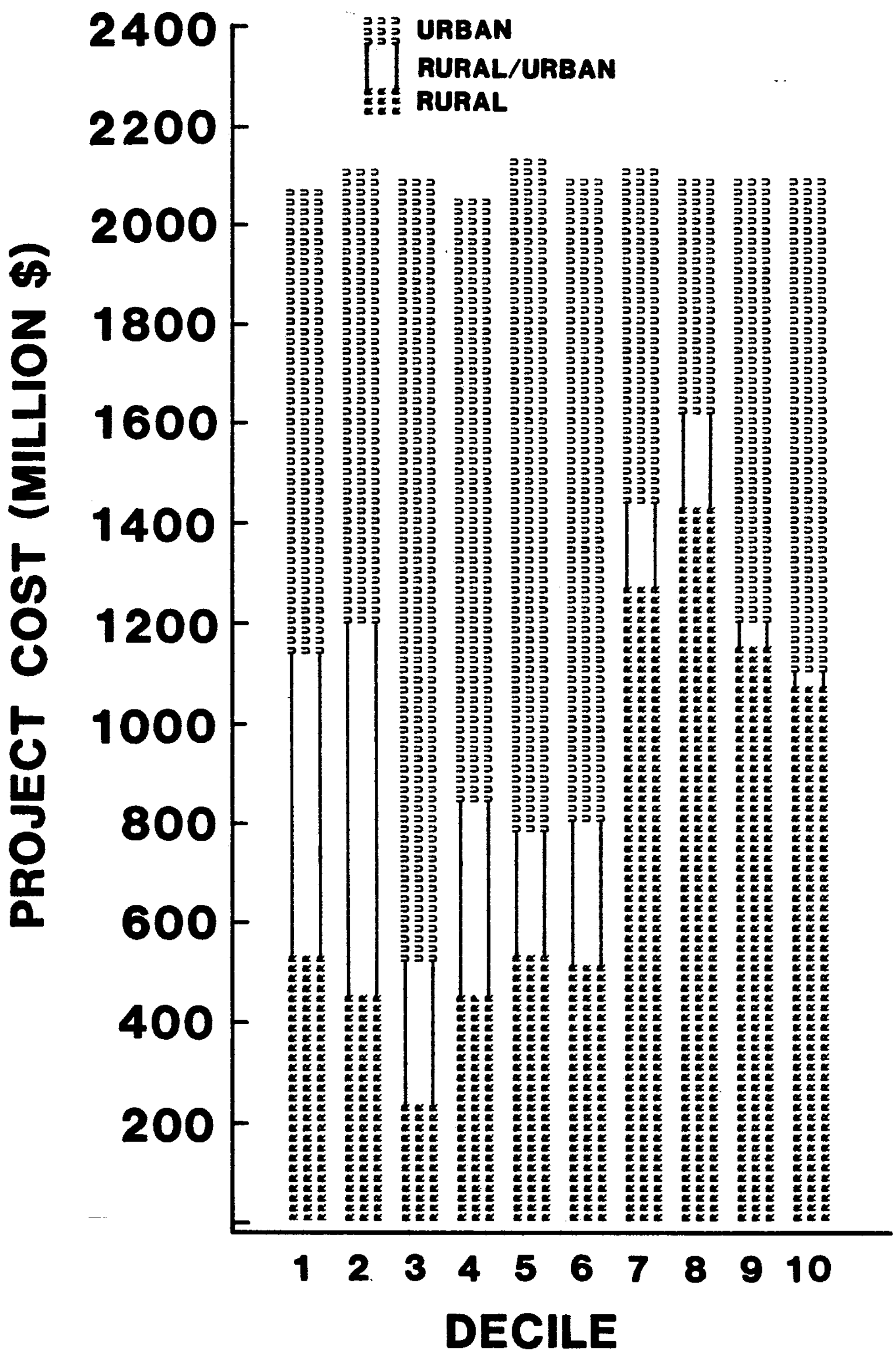

Figure B6. Distribution of Project Costs Among Urban, Urban/Rural, and Rural Areas by Deciles of Total Project Costs for Rankings by the Delay Savings Ratio (D).

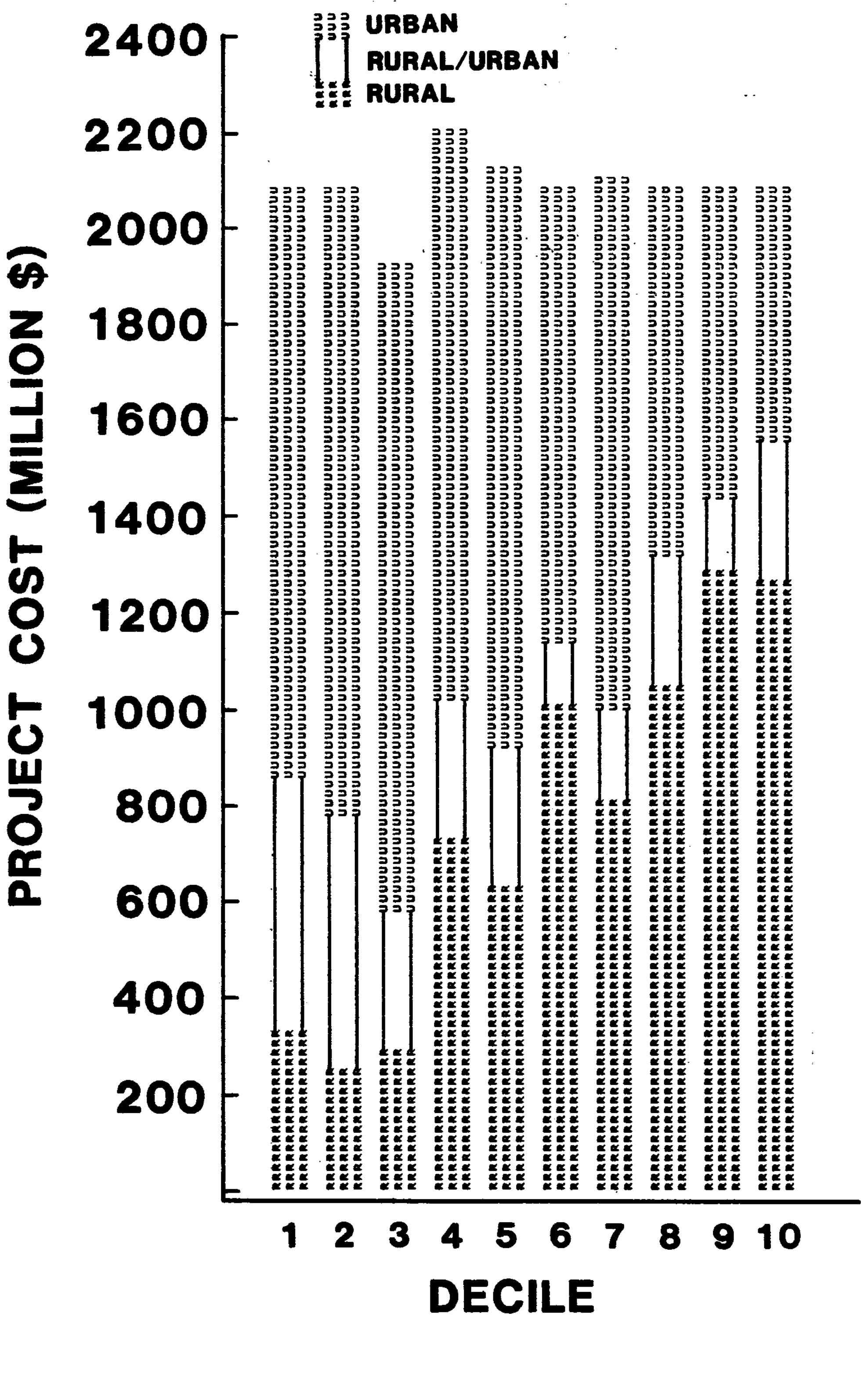

Figure B7. Distribution of Project Costs Among Urban, Urban/Rural, and Rural Areas by Deciles of Total Project Costs for Rankings by the Priority Formula (P).

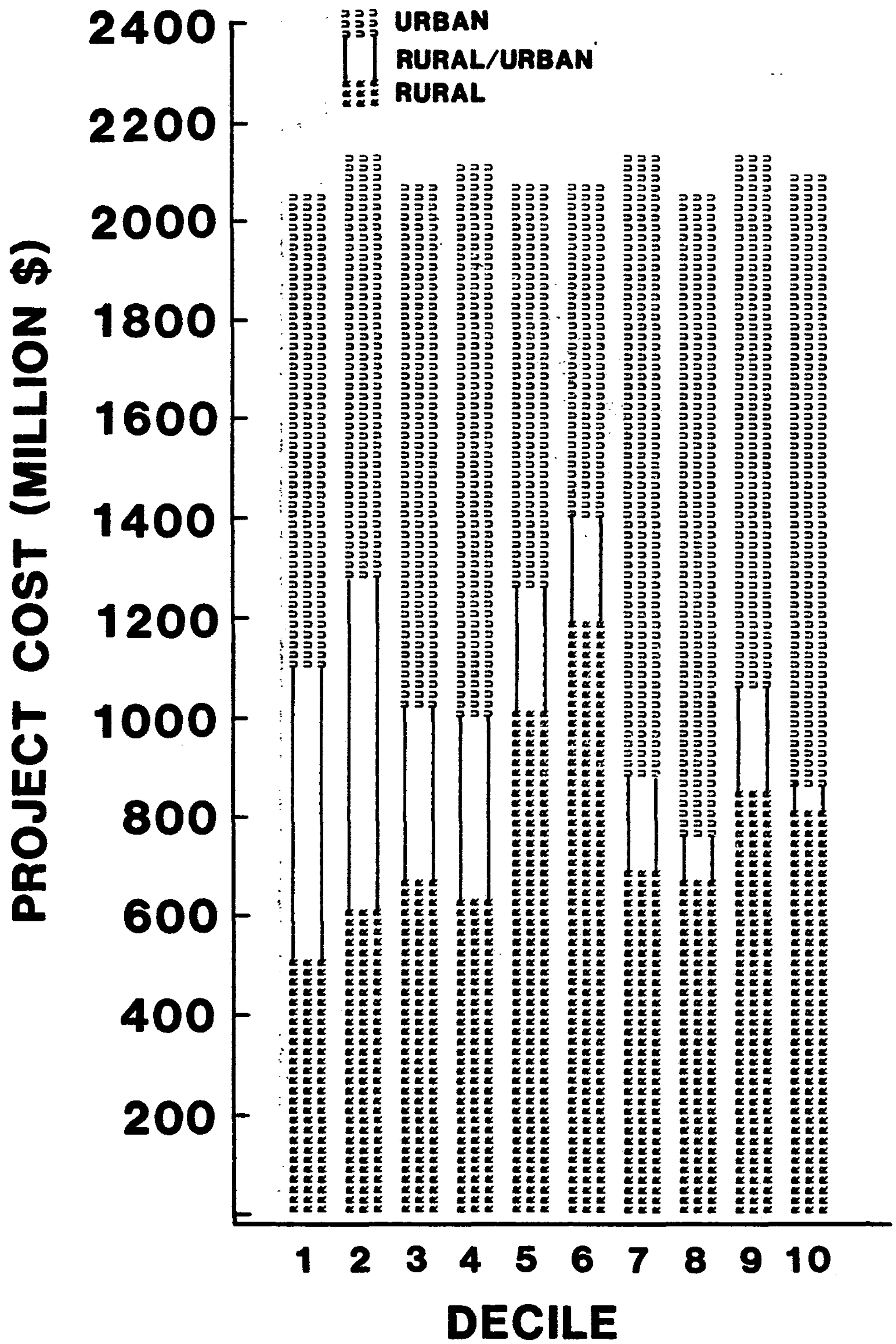

Figure B8. Distribution of Project Costs Among Urban, Urban/Rural, and Rural Areas by Deciles of Total Project Costs for Rankings by Modified HEEM-II (H).

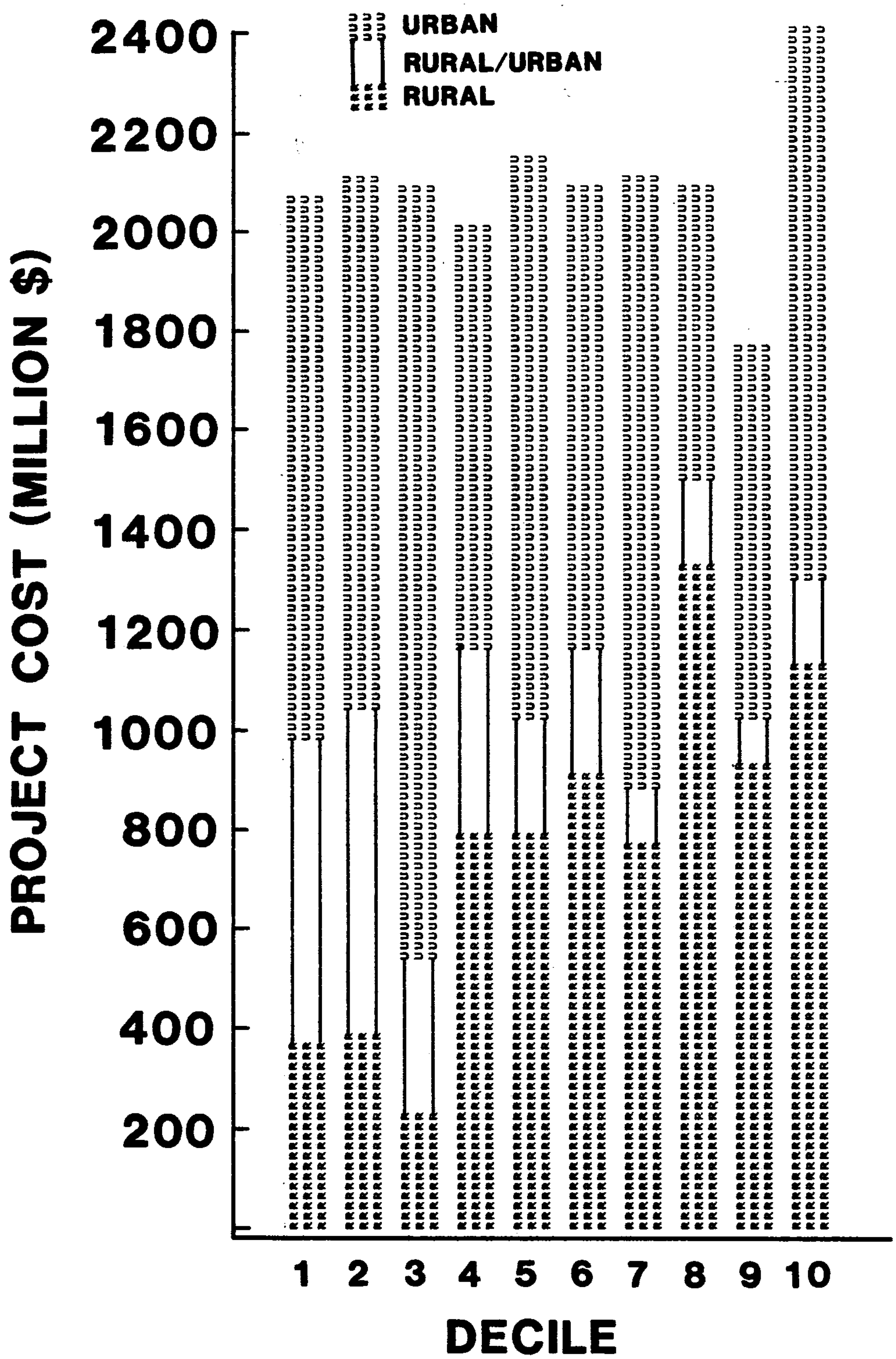

Figure B9. Distribution of Project Costs Among Urban, Urban/Rural, and Rural Areas by Deciles of Total Project Costs for Rankings by the Ranking Formula (R).

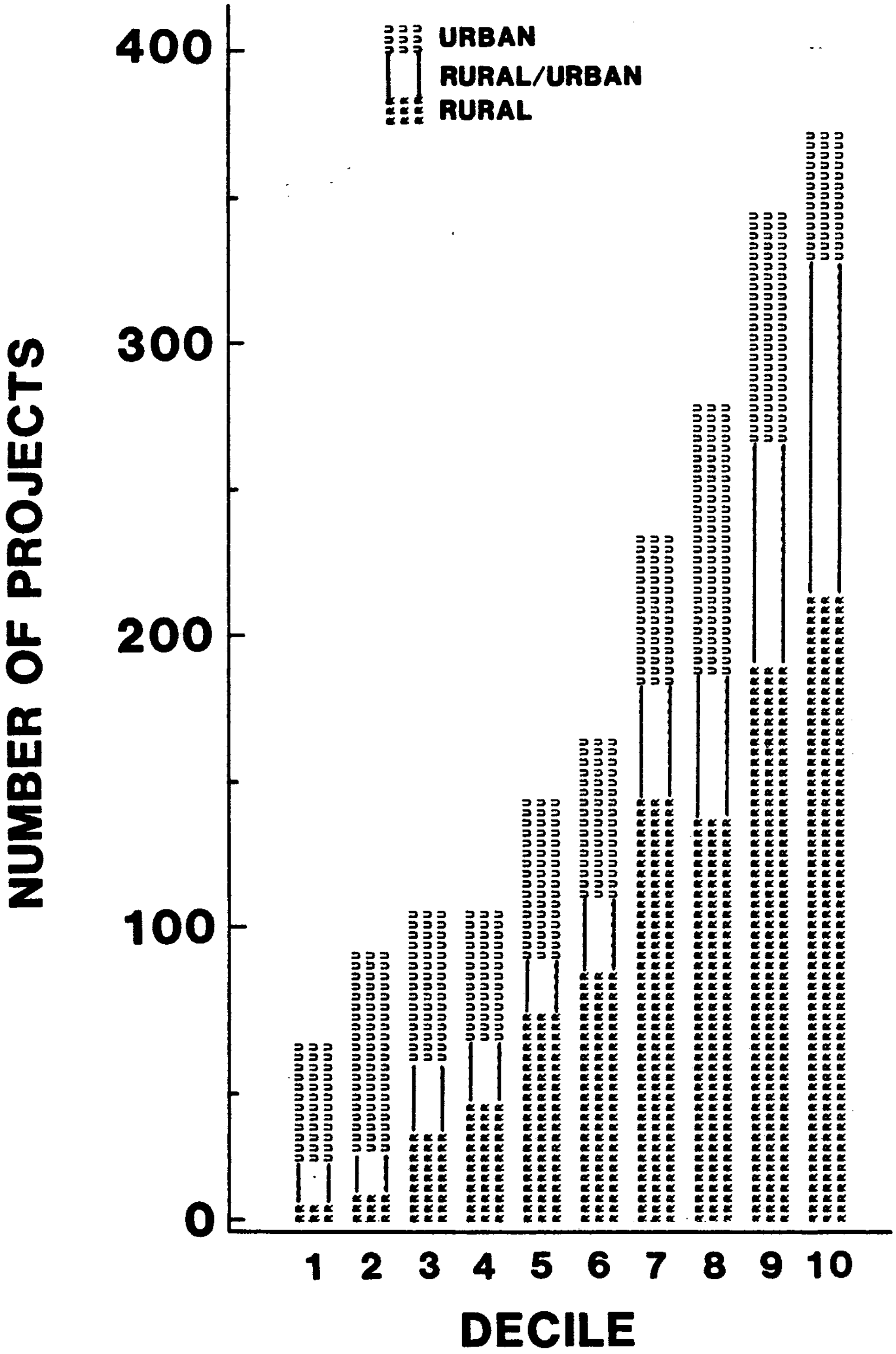

Figure B10. Distribution of Number of Projects Among Urban, Urban/Rural, and Rural Areas by Deciles of Total Project Cost for Rankings by the Sufficiency Rating (S).

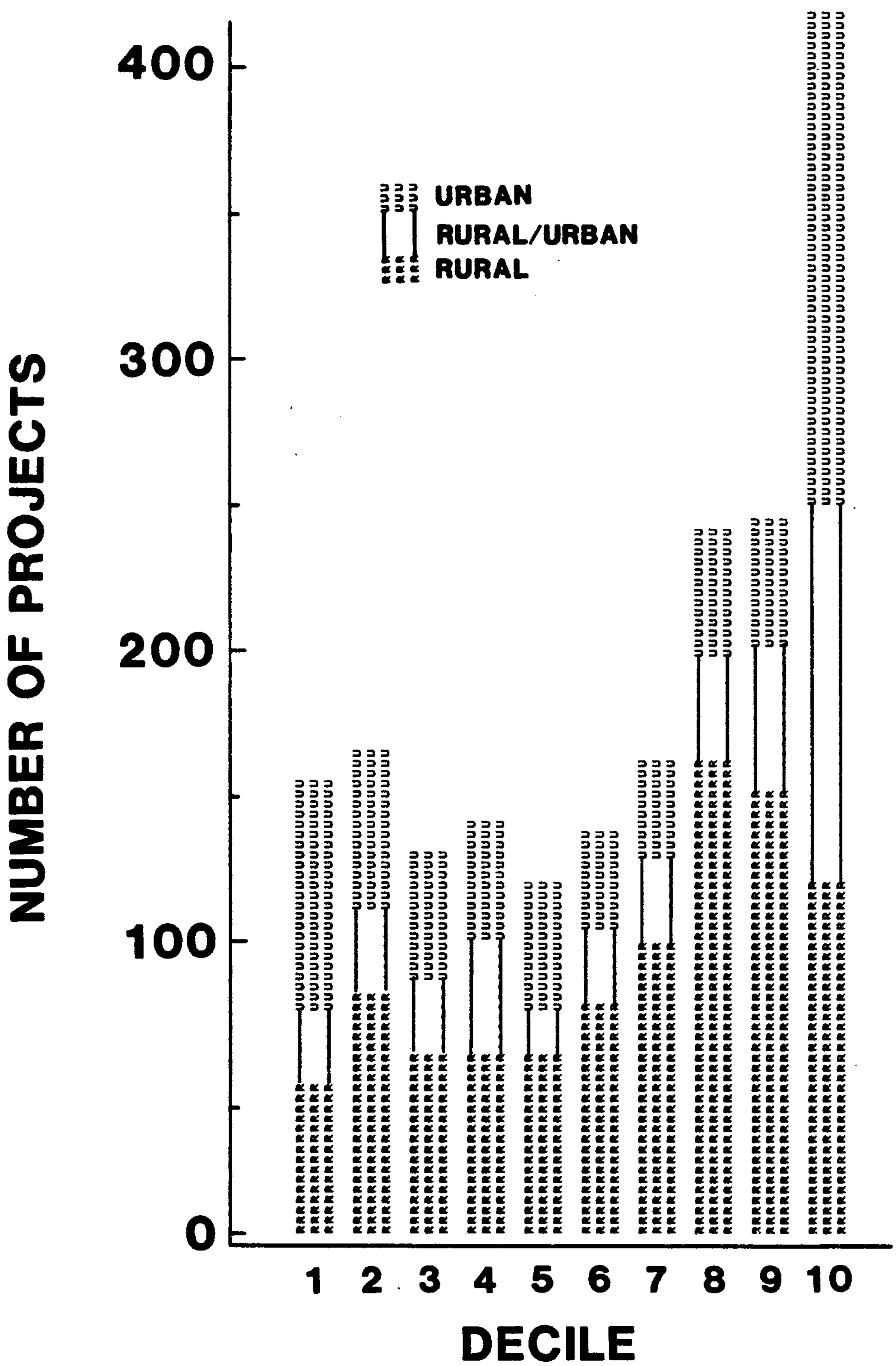

Figure B11. Distribution of Number of Projects Among Urban, Urban/Rural, and Rural Areas by Deciles of Total Project Cost for Rankings by the Present Cost Index (C).

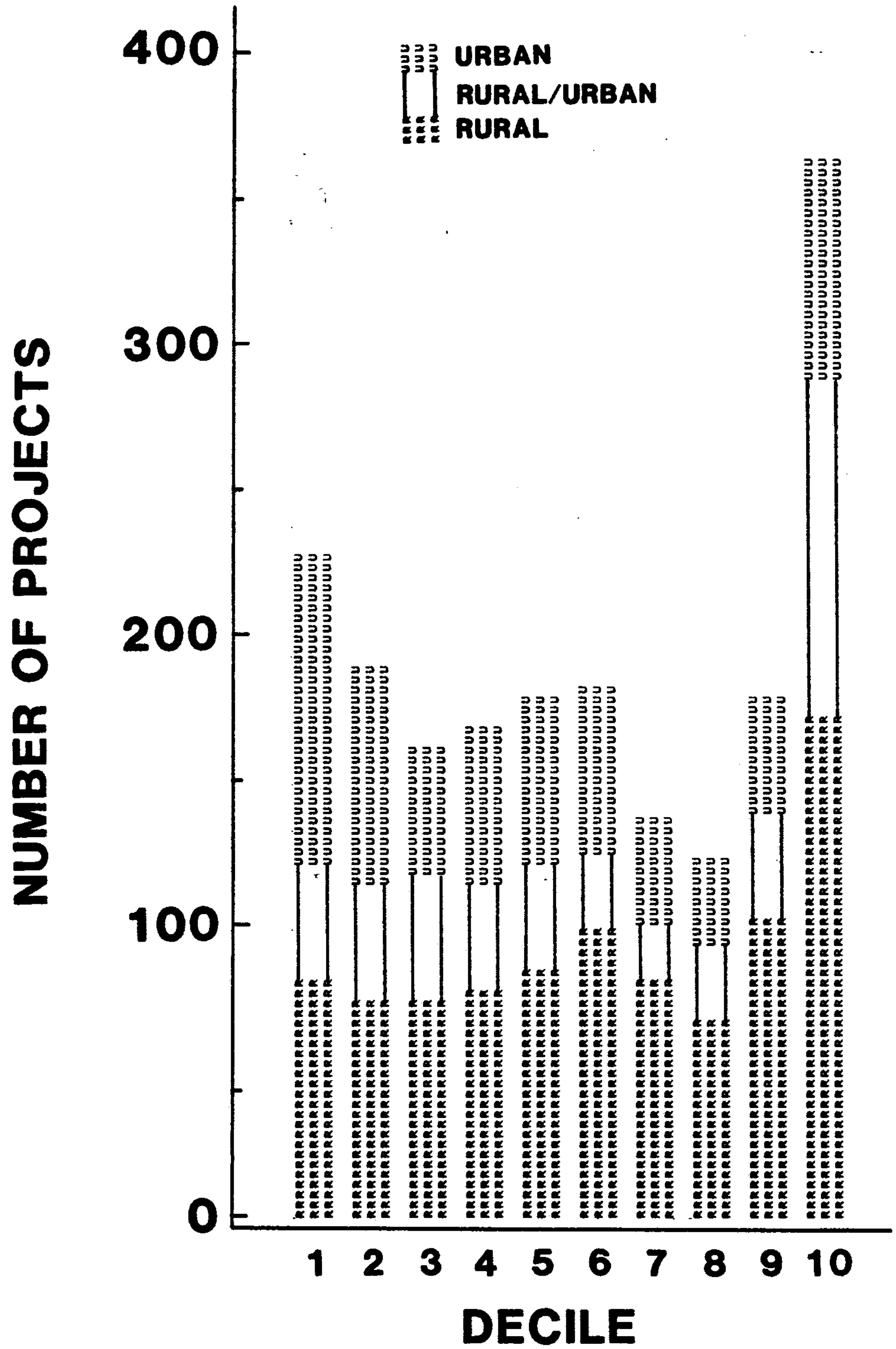

Figure B12. Distribution of Number of Projects Among Urban, Urban/Rural, and Rural Areas by Deciles of Total Project Cost for Rankings by the Future Cost Index (F).

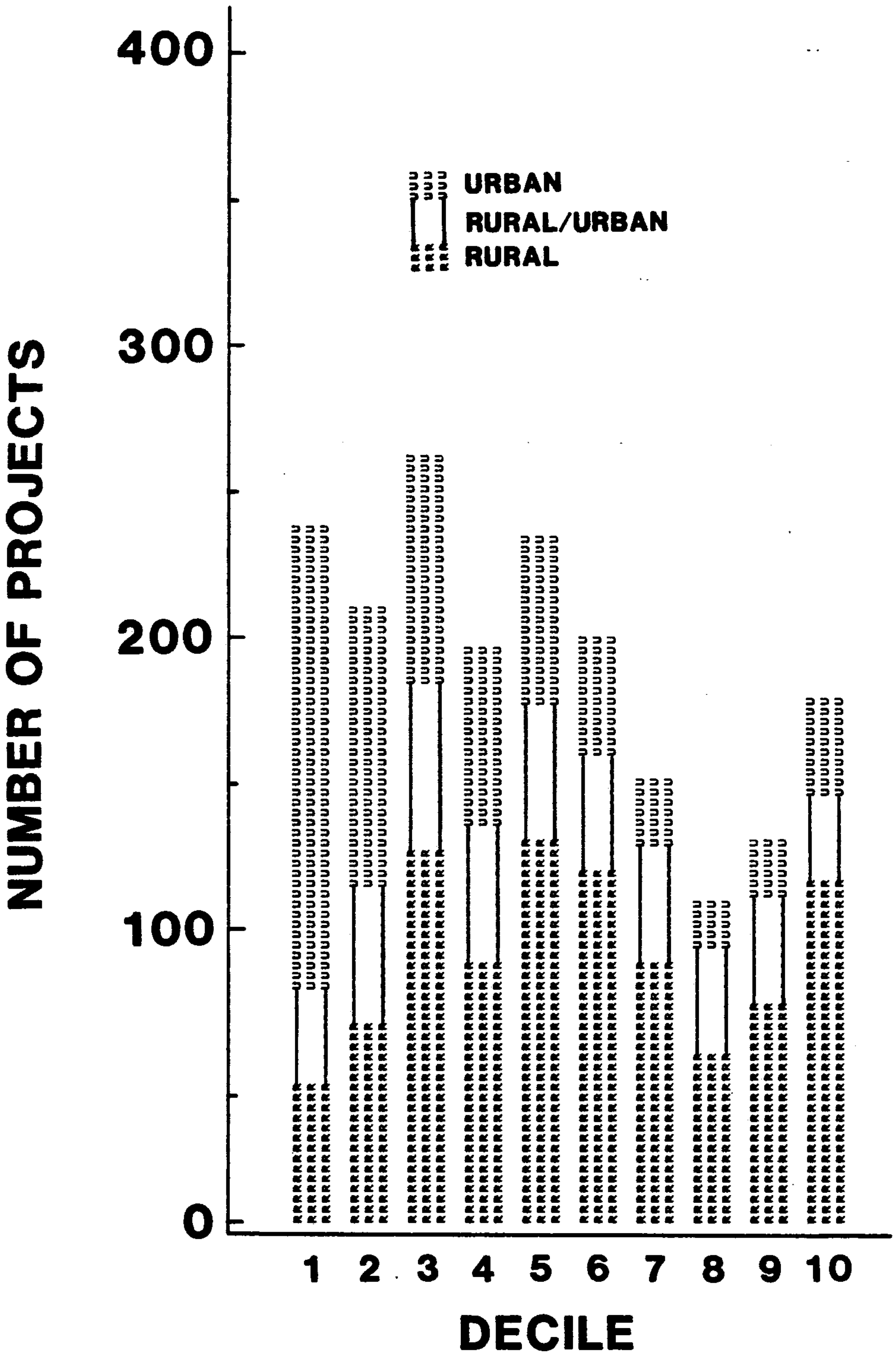

Figure B13. Distribution of Number of Projects Among Urban, Urban/Rural, and Rural Areas by Deciles of Total Project Cost for Rankings by the Cost Per Vehicle Mile Traveled, Present ADT (V).

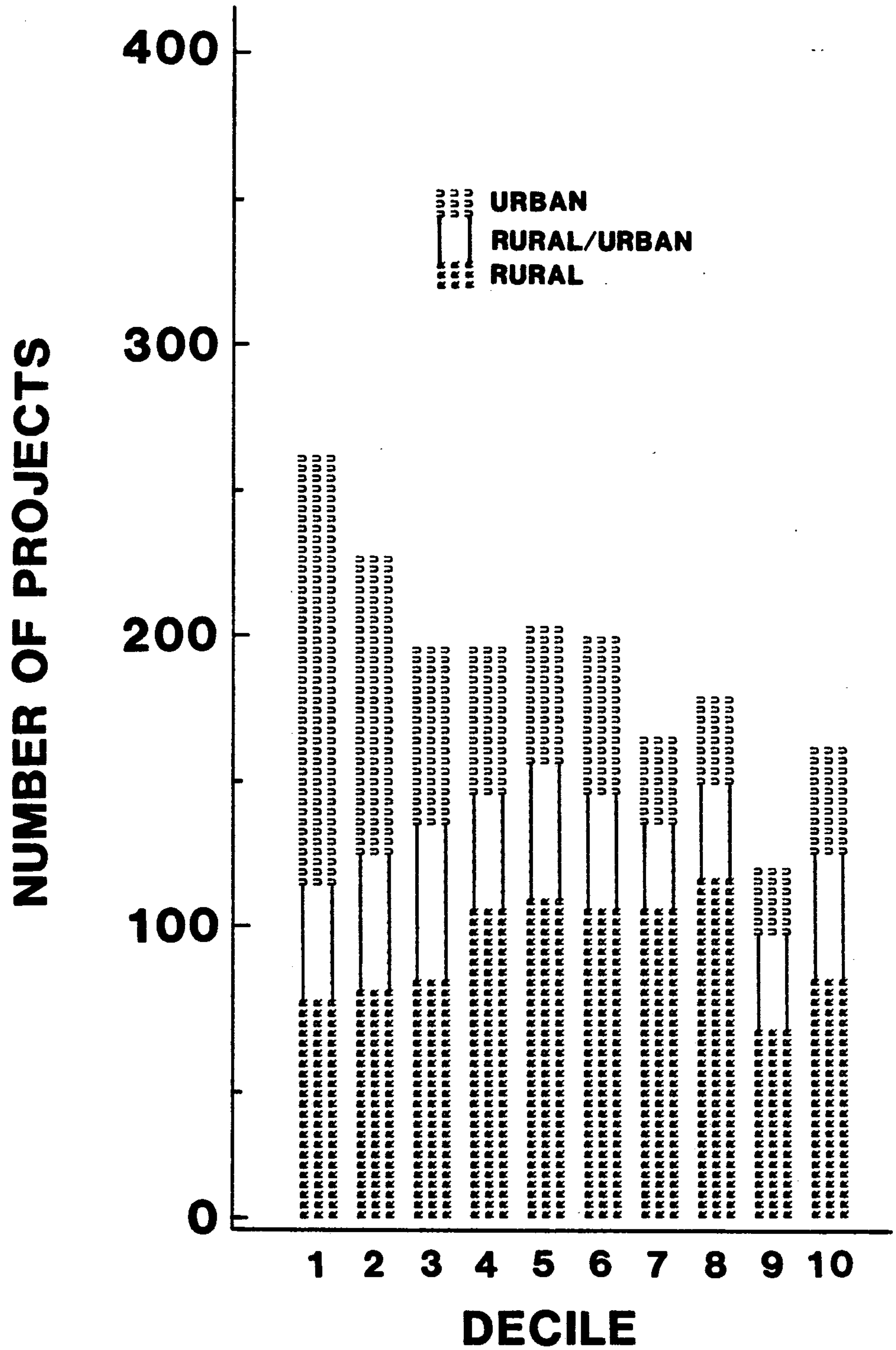

Figure B14. Distribution of Number of Projects Among Urban, Urban/Rural, and Rural Areas by Deciles of Total Project Cost for Rankings by the Cost Per Vehicle Mile Traveled, Future ADT (M).

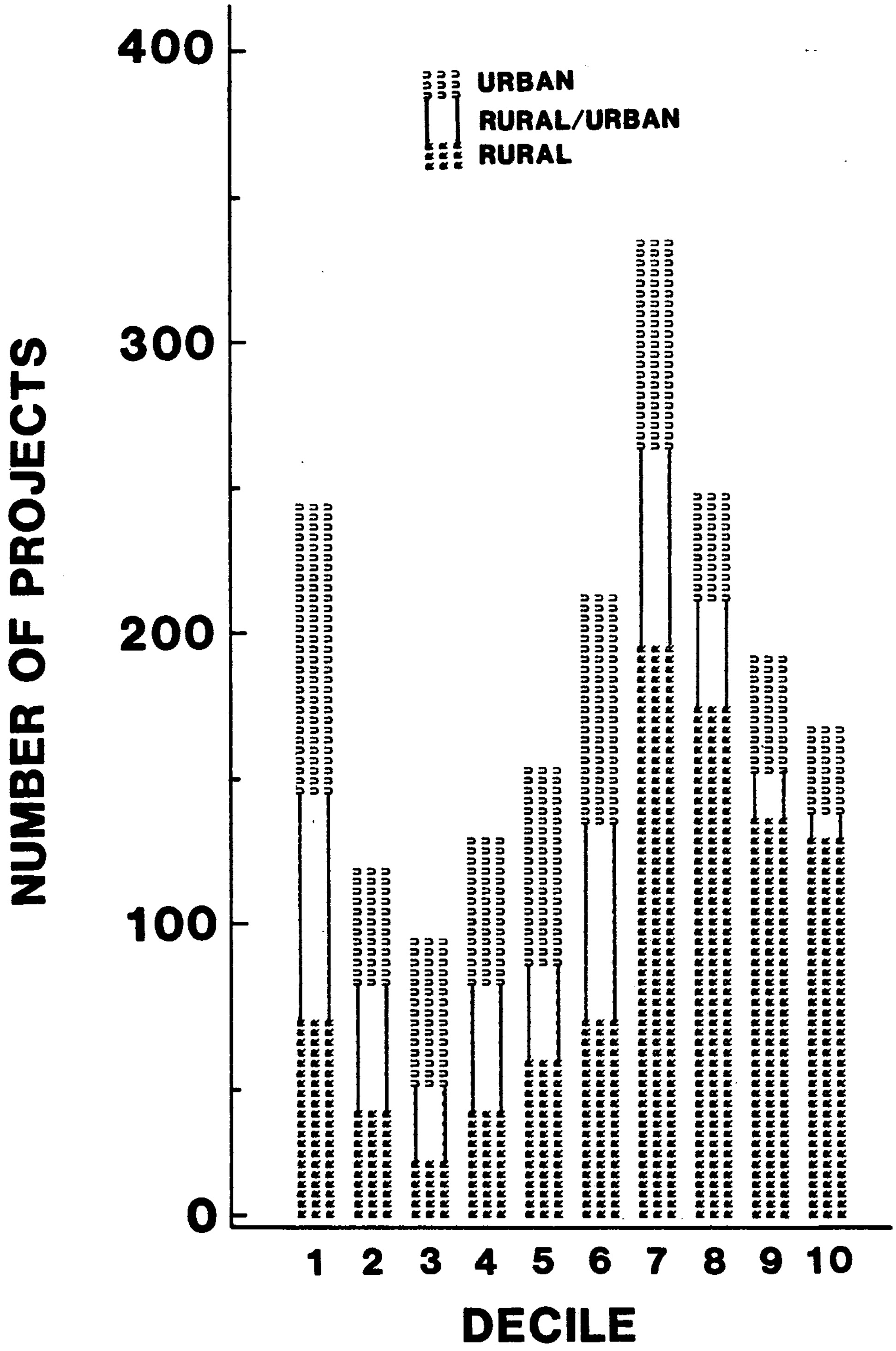

Figure B15. Distribution of Number of Projects Among Urban, Urban/Rural, and Rural Areas by Deciles of Total Project Cost for Rankings by the Delay Savings Ratio (D).

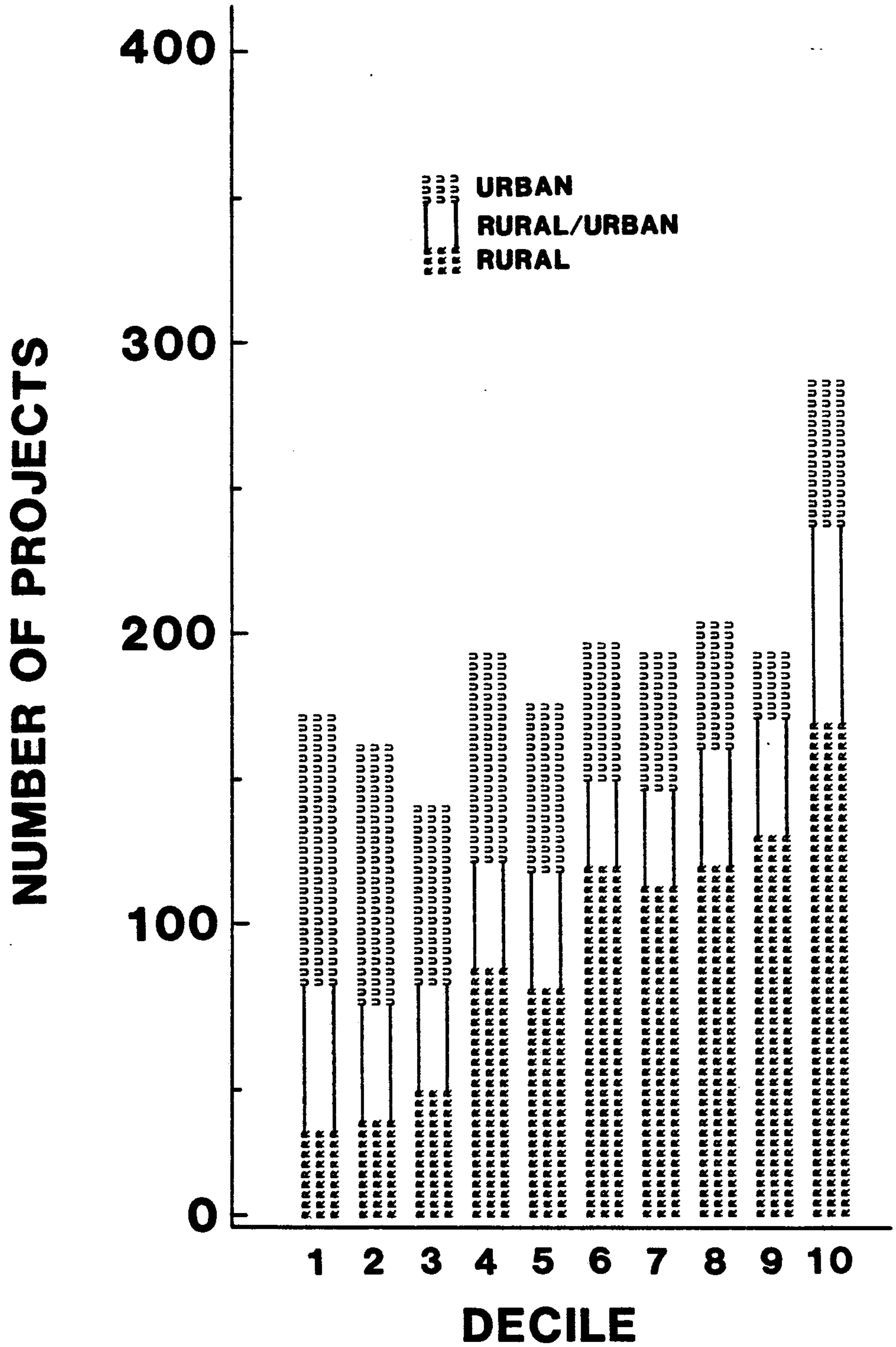

Figure B16. Distribution of Number of Projects Among Urban, Urban/Rural, and Rural Areas by Deciles of Total Project Cost for Rankings by the Priority Formula (P).

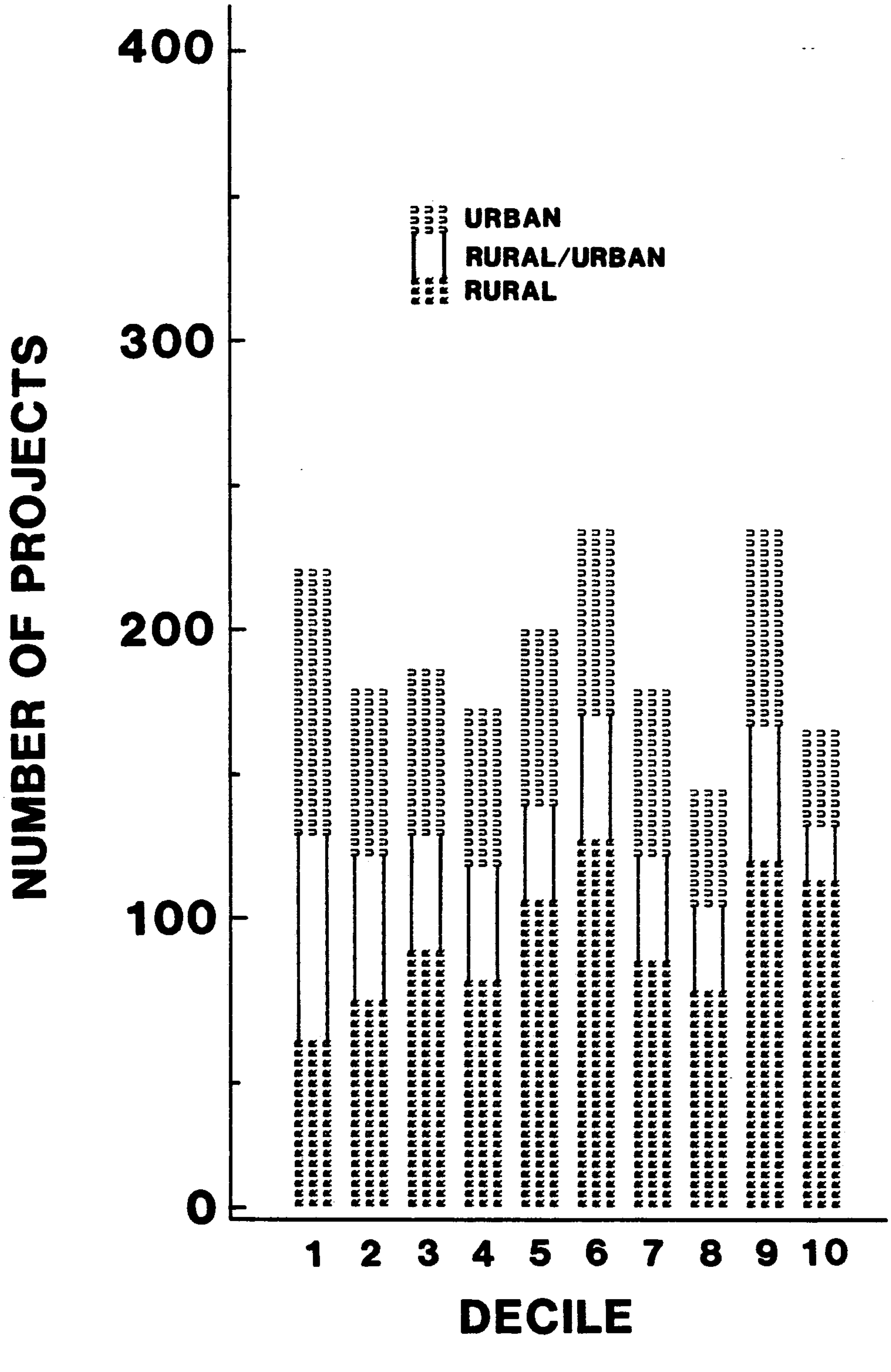

Figure B17. Distribution of Number of Projects Among Urban, Urban/Rural, and Rural Areas by Deciles of Total Project Cost for Rankings by Modified HEEM-II (H).

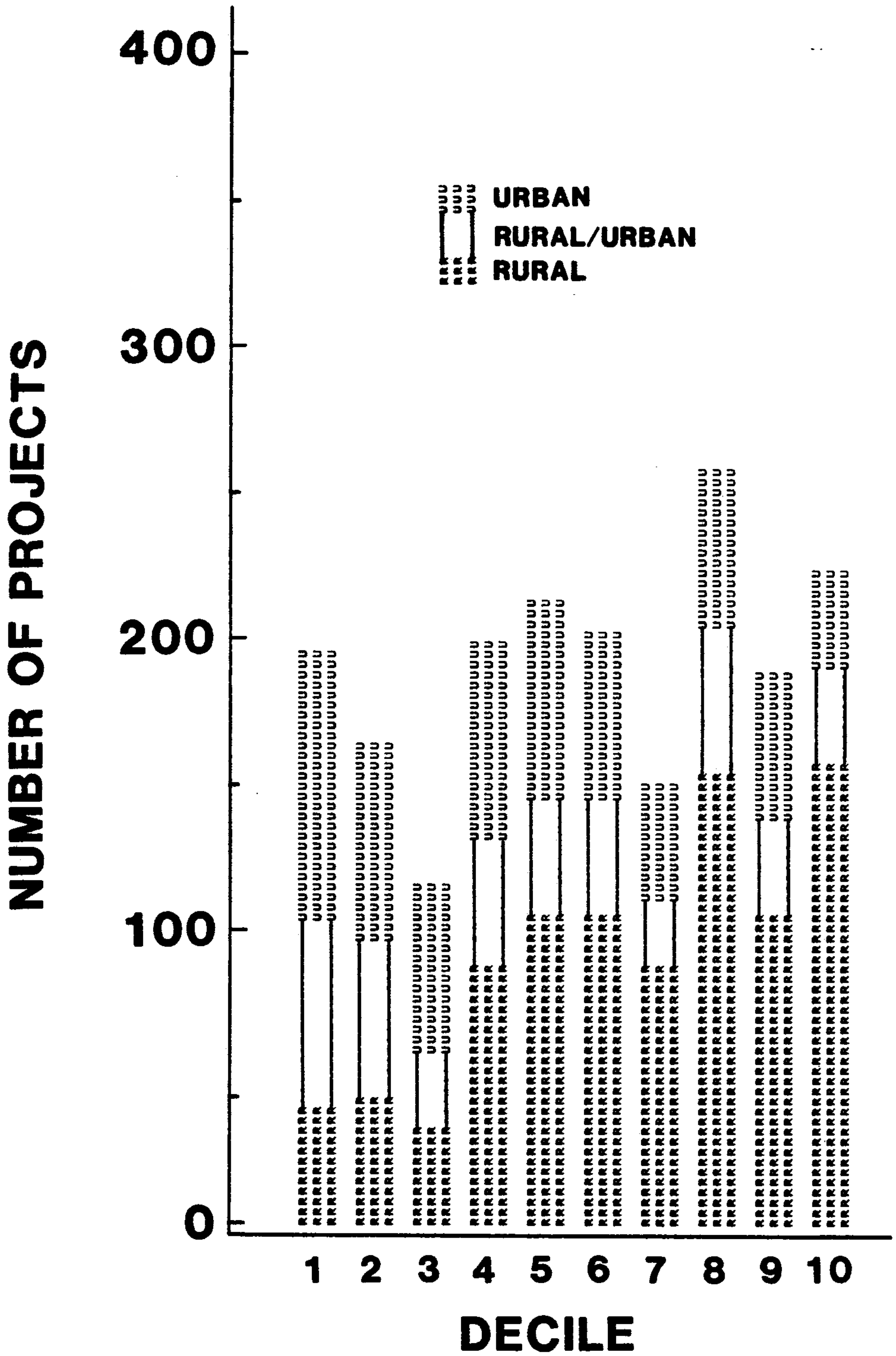

Figure B18. Distribution of Number of Projects Among Urban, Urban/Rural, and Rural Areas by Deciles of Total Project Cost for Rankings by the Ranking Formula (R).

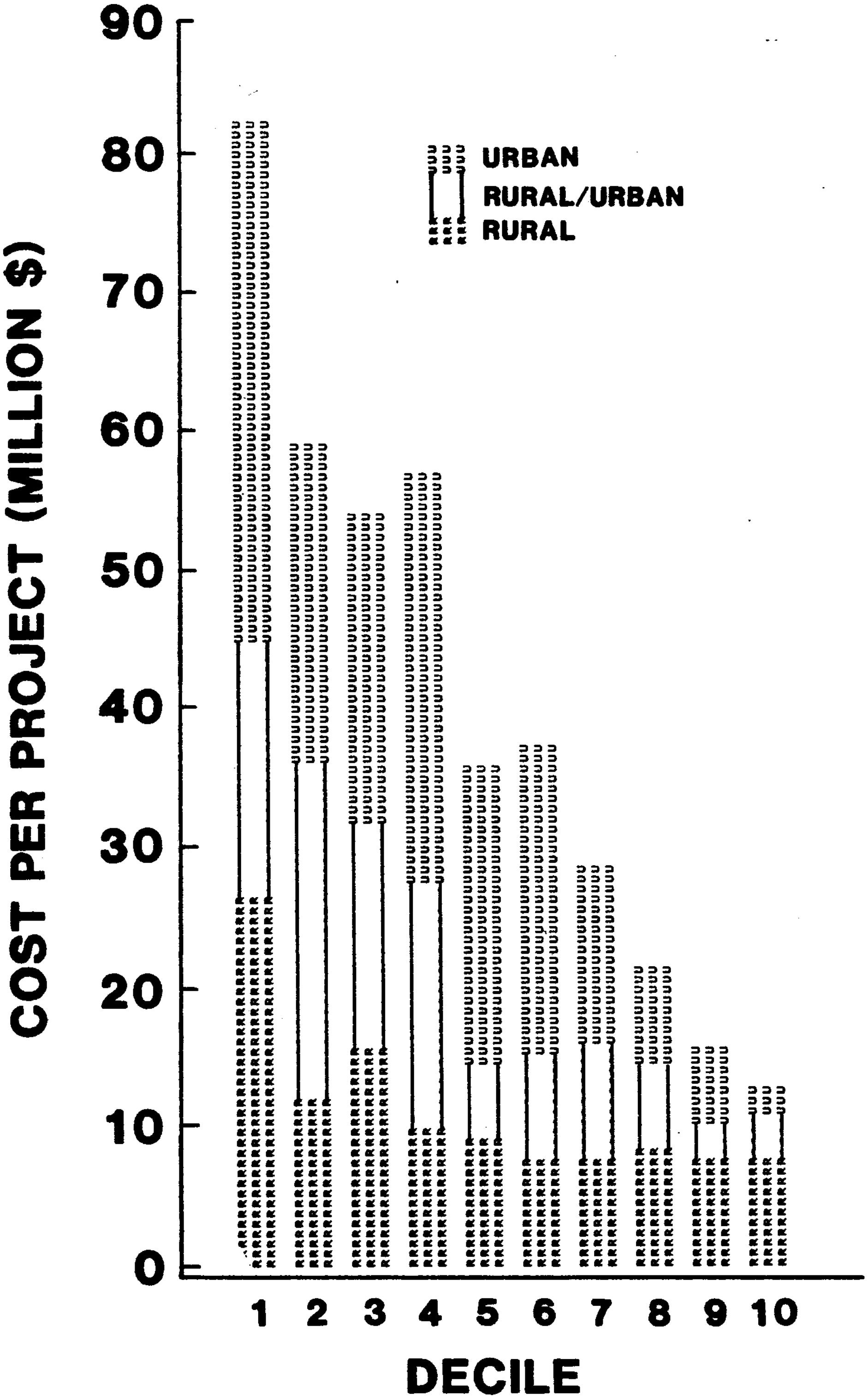

Figure B19. Average Cost Per Project for Urban, Urban/Rural, and Rural Areas, by Deciles of Total Project Cost for Rankings by the Sufficiency Rating (S).

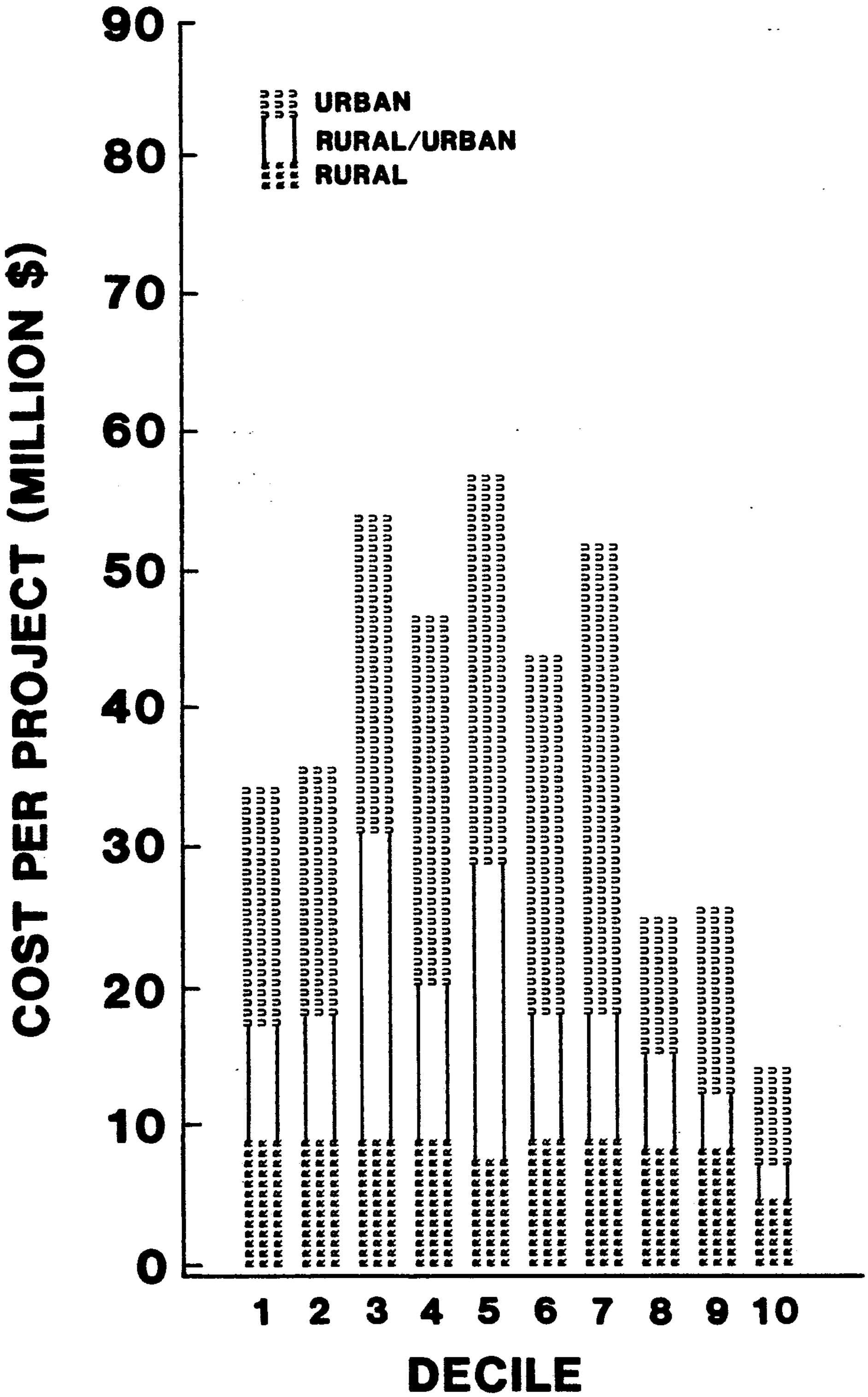

Figure B20. Average Cost Per Project for Urban, Urban/Rural, and Rural Areas, by Deciles of Total Project Cost for Rankings by the Present Cost Index (C).

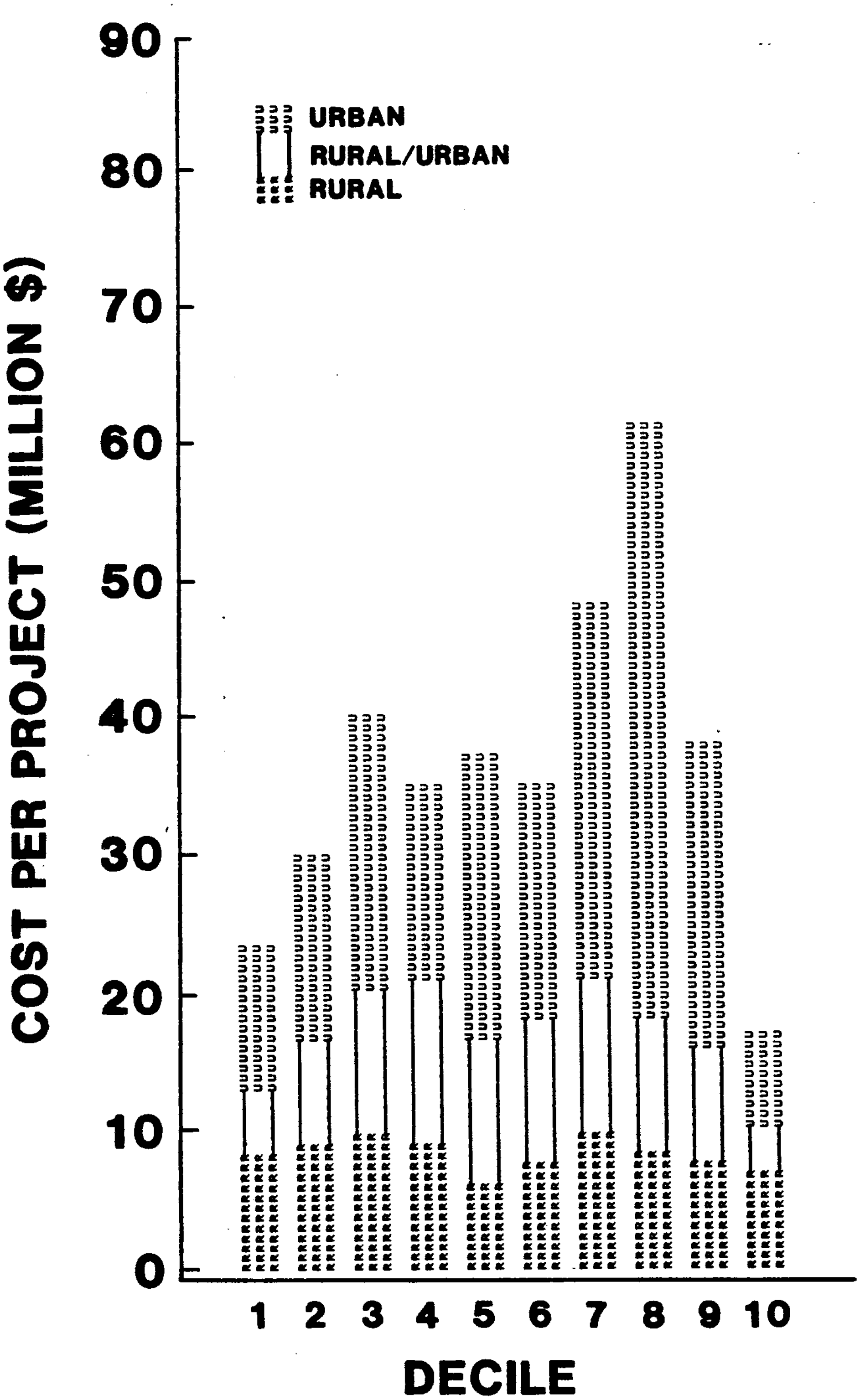

Figure B21. Average Cost Per Project for Urban, Urban/Rural, and Rural Areas, by Deciles of Total Project Cost for Rankings by the Future Cost Index (F).

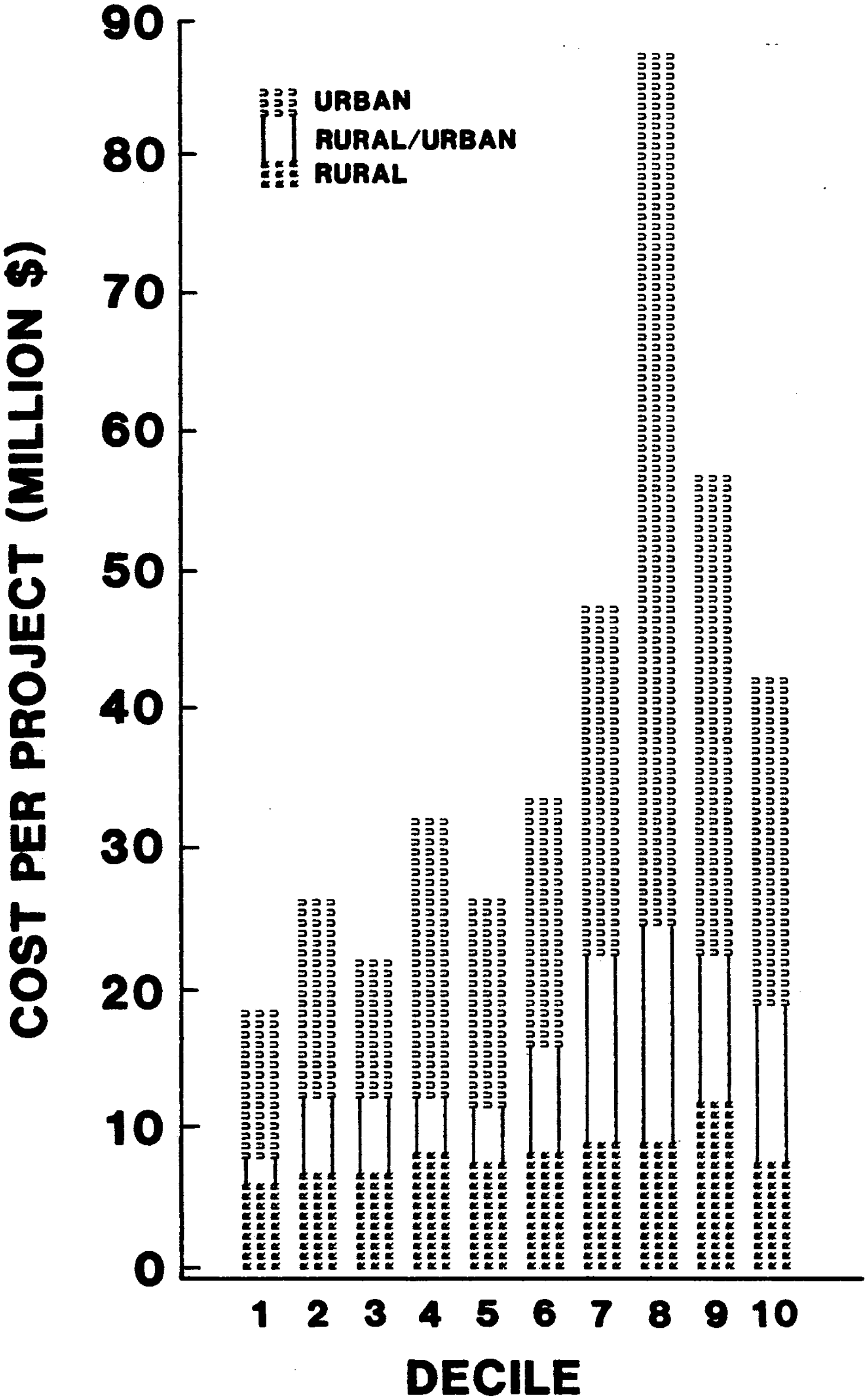

Figure B22. Average Cost Per Project for Urban, Urban/Rural, and Rural Areas, by Deciles of Total Project Cost for Rankings by Cost Per Vehicle Mile Traveled, Present ADT (V).

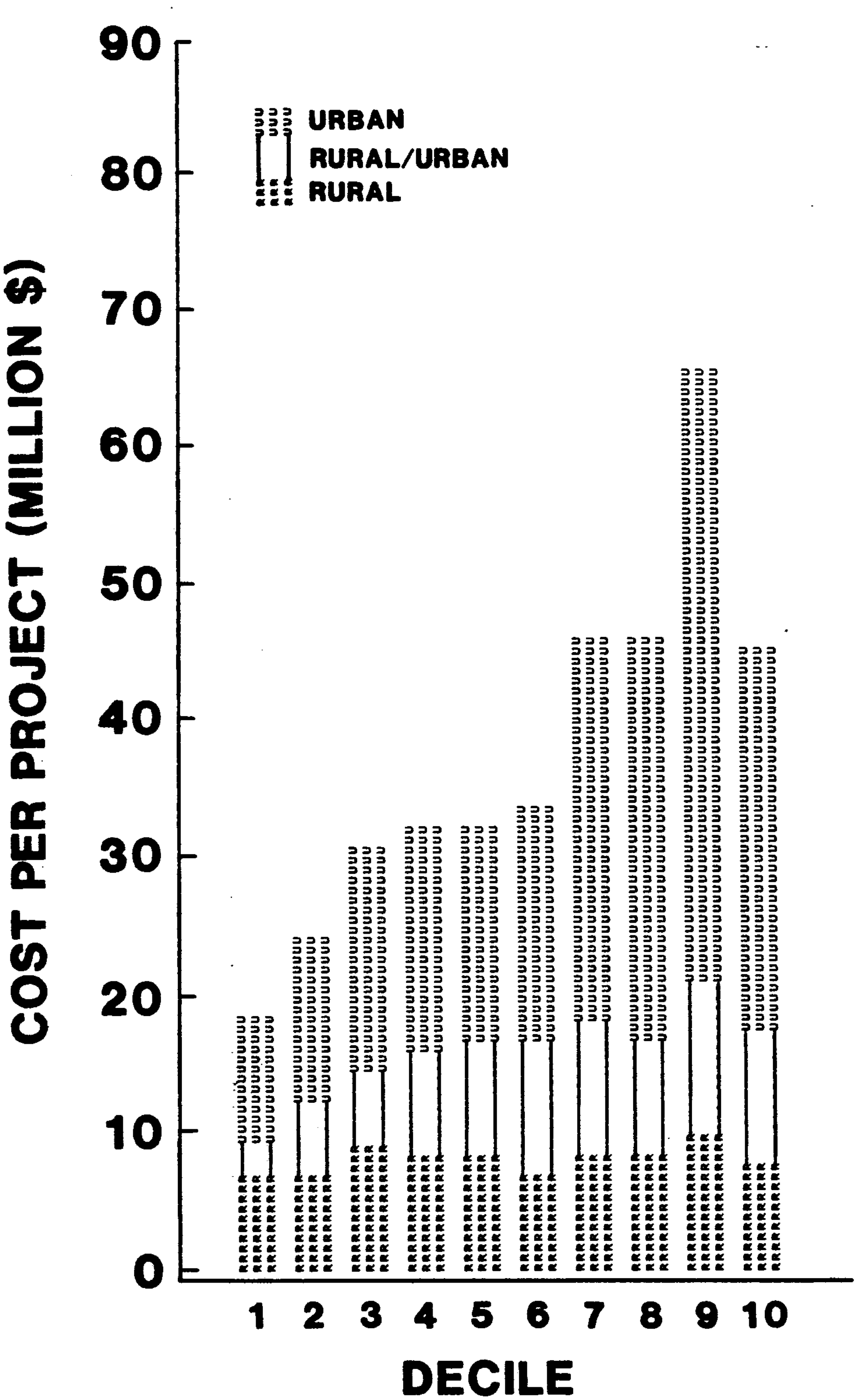

Figure B23. Average Cost Per Project for Urban, Urban/Rural, and Rural Areas, by Deciles of Total Project Cost for Rankings by the Cost Per Vehilce Mile Traveled, Future ADT (M).

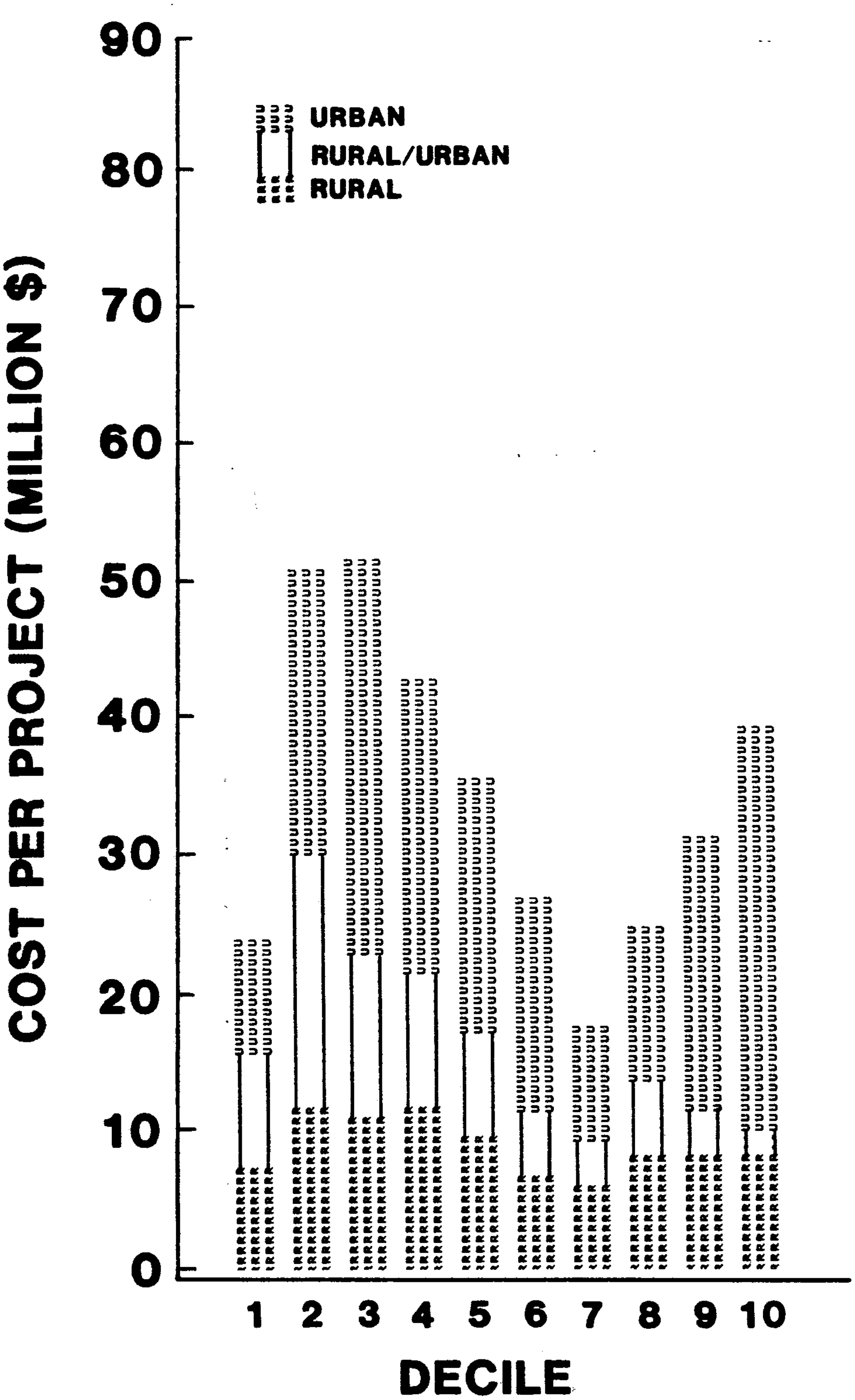

Figure B24. Average Cost Per Project for Urban, Urban/Rural, and Rural Areas, by Deciles of Total Project Cost for Rankings by the Delay Savings Ratio (D).

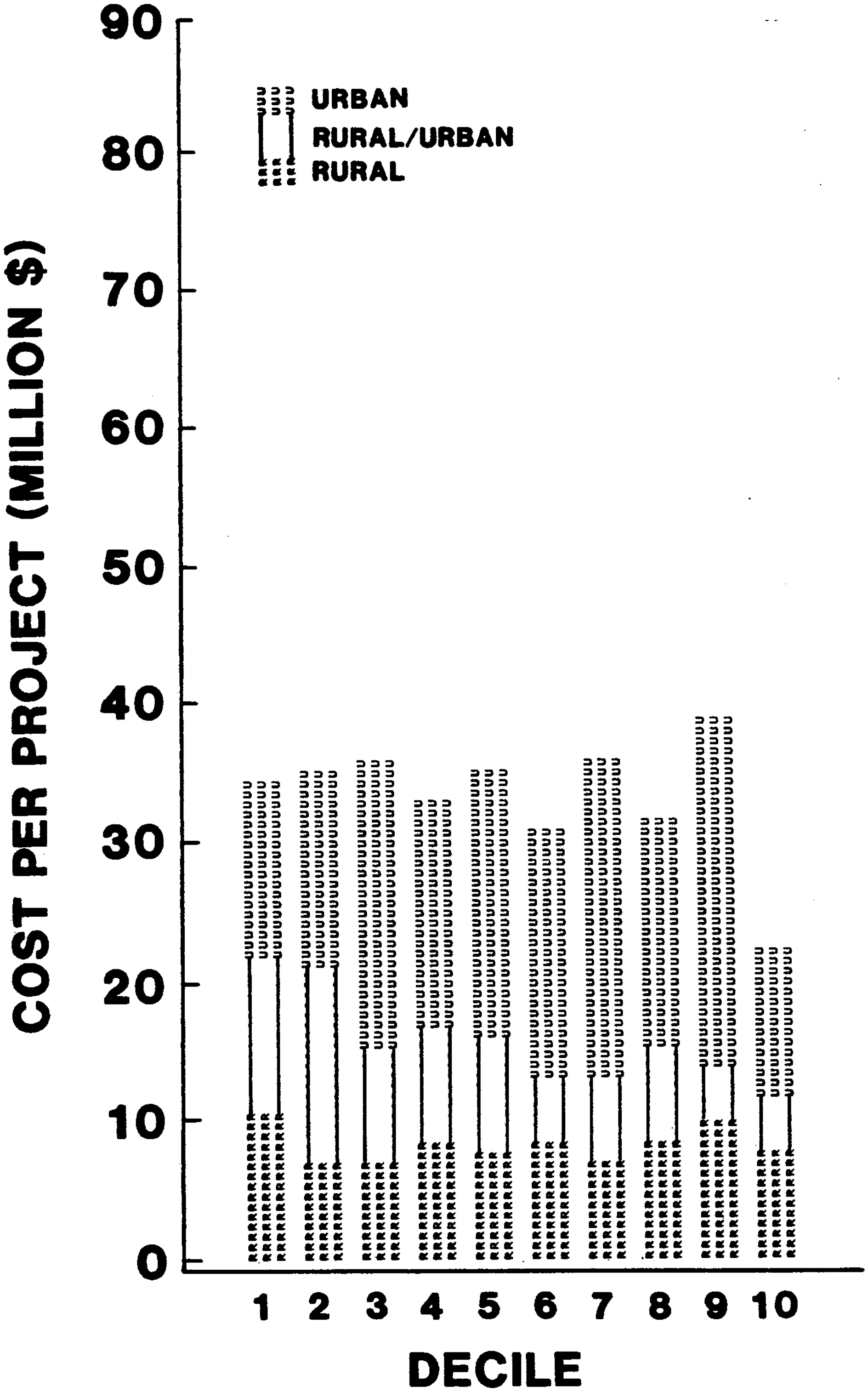

Figure B25. Average Cost Per Project for Urban, Urban/Rural, and Rural Areas, by Deciles of Total Project Cost for Rankings by the Priority Formula (P).

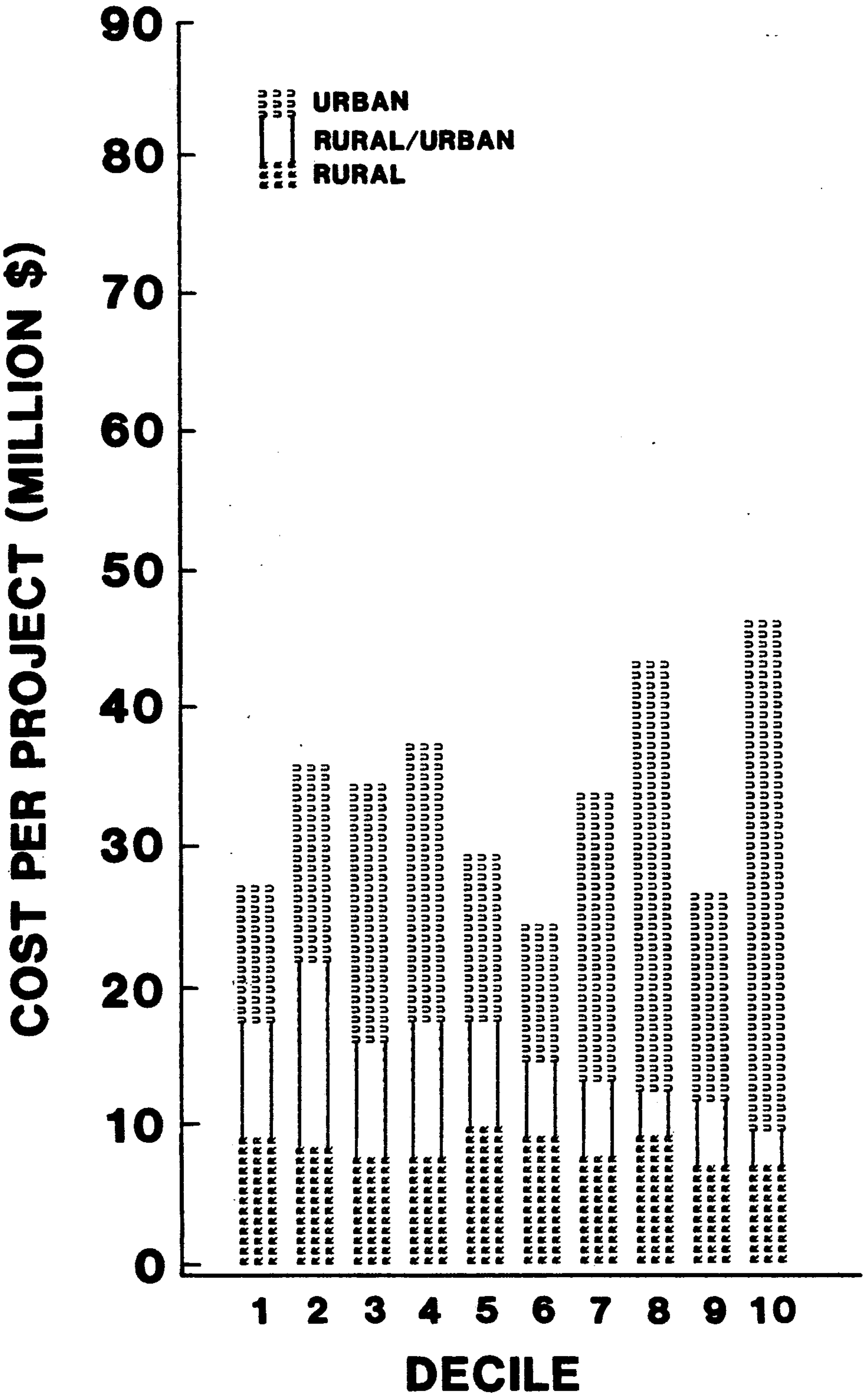

Figure B26. Average Cost Per Project for Urban, Urban/Rural, and Rural Areas, by Deciles of Total Project Cost for Rankings by Modified HEEM-II (H).

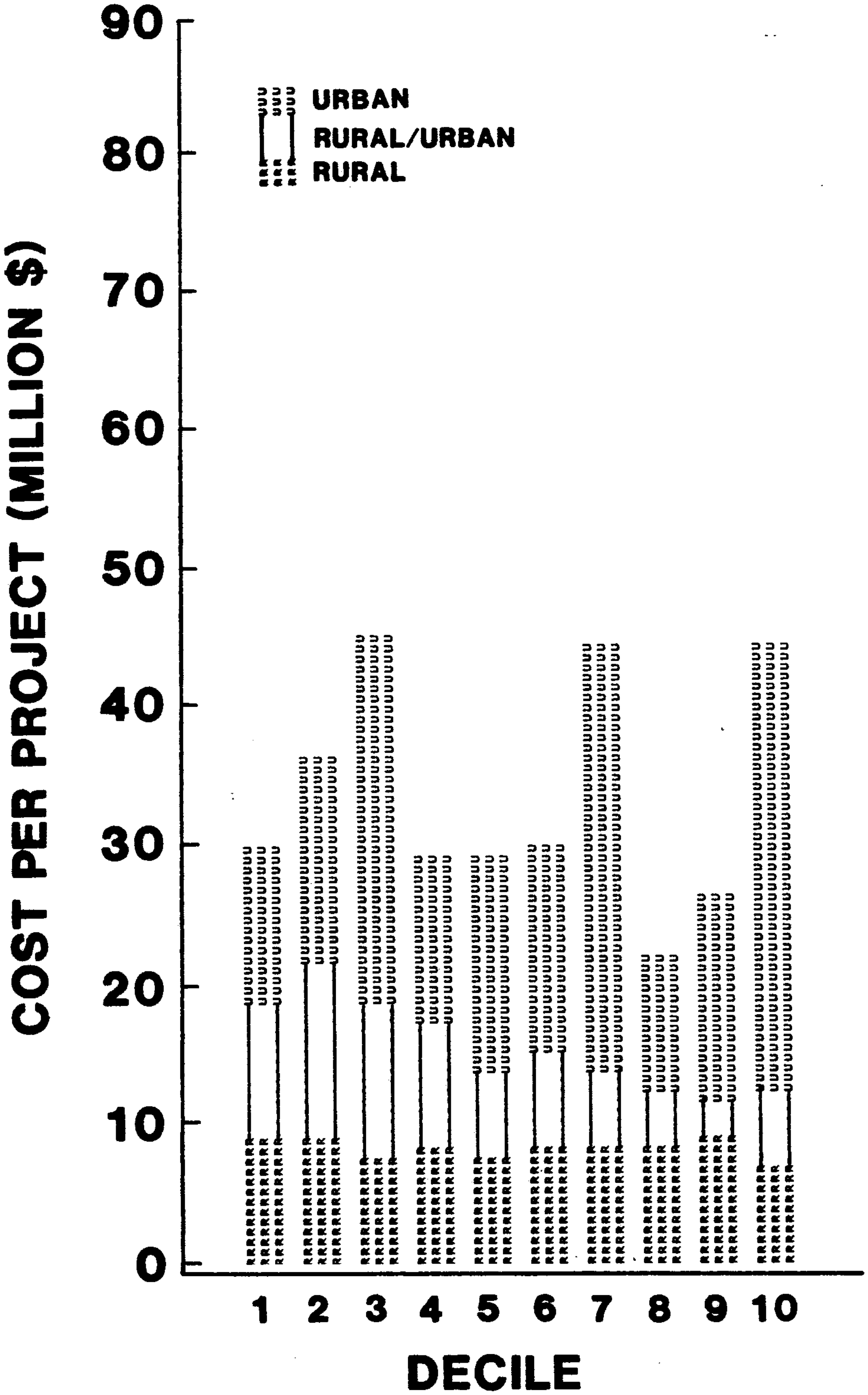

Figure B27. Average Cost Per Project for Urban, Urban/Rural, and Rural Areas, by Deciles of Total Project Cost for Rankings by the Ranking Formula (R).