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16. Abstract

The magnitude of potential highway user benefits and costs resulting from proposed highway improvements must be estimated with a reasonable degree of accuracy for highway agencies to make rational decisions in the public interest. There are procedures, some of which are computerized, in use or available for use to estimate user benefits and costs. One such procedure is the Highway Economic Evaluation Model (HEEM) developed by McKinsey and Company, Inc. and adapted for use in Texas. The HEEM is computerized and designed to evaluate user impacts of building new highways and improving old and existing facilities considering various alternatives, including the "no build" alternative. The Texas version of the HEEM has been in use by Texas State Department of Highways and Public Transportation (SDHPT) since 1975. As a result of questions raised by the SDHPT personnel and others regarding the validity of the HEEM's basic assumptions, unit costs, and updating procedures, a critical review of these aspects of the HEEM was authorized. This report presents the findings of this review. The HEEM's assumed values and unit costs are compared to those reported in the new AASHTO Redbook, another Texas Transportation Institute study, and other data reported in the literature. Procedures (including formulas) for continuous updating of the HEEM's assumed values and unit costs from 1975 to the relevant base year of a proposed highway improvement project are described and recommended in this report. The data are reported in narrative, graphic, and tabular form. Implementation of the findings and recommendations of this report should result in more accurate estimates generated from the HEEM.

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PREFACE

The authors want to express their appreciation to those who have assisted or facilitated this study. Special acknowledgement is due Mr. Harold D. Cooner, Mr. James W. Barr, and Mr. James R. Farrar, Jr., of the Texas State Department of Highways and Public Transportation.

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The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

ABSTRACT

The magnitude of potential highway user benefits and costs resulting from proposed highway improvements must be estimated with a reasonable degree of accuracy for highway agencies to make rational decisions in the public interest. There are procedures, some of which are computerized, in use or available for use to estimate user benefits and costs. One such procedure is the Highway Economic Evaluation Model (HEEM) developed by McKinsey and Company, Inc. and adapted for use in Texas. The HEEM is computerized and designed to evaluate user impacts of building new highways and improving old and existing facilities considering various alternatives, including the "no build" alternative. The Texas version of the HEEM has been in use by Texas State Department of Highways and Public Transportation (SDHPT) since 1975. As a result of questions raised by the SDHPT personnel and others regarding the validity of the HEEM's basic assumptions, unit costs, and updating procedures, a critical review of these aspects of the HEEM was authorized. This report presents the findings of this review. The HEEM's assumed values and unit costs are compared to those reported in the new AASHTO Redbook, another Texas Transportation Institute study, and other data reported in the literature. Procedures (including formulas) for continuous updating of the HEEM's assumed values and unit costs from 1975 to the relevant base year of a proposed highway improvement project are described and recommended in this report. The data are reported in narrative, graphic, and tabular form. Implementation of the findings and recommendations of this report should result in more accurate estimates generated from the HEEM.

SUMMARY OF FINDINGS

The Texas Highway Economic Evaluation Model (HEEM), developed by the McKinsey and Company, Inc. of Dallas and adopted for general use by the State Department of Highways (SDHPT) in 1975, is the subject of this report. The HEEM's "key" assumptions and unit costs are examined thoroughly to determine their appropriateness for evaluating highway improvement projects in Texas. The HEEM's procedures for updating its assumptions and unit costs are reviewed, and new or more accurate procedures are described and recommended. The major findings of this report are summarized below.

A critical review of the HEEM's assumptions and unit costs revealed the following findings:

1. One truck percentage is assumed even though the supporting data presented by the HEEM authors and in this report show considerable variation in the percentage of trucks by type of highway design and location.
2. A single value of time is assumed for occupants (excluding bus drivers) of passenger vehicles even though data presented in the new AASHTO Redbook and other studies justify the use of multiple values of time according to the amount of time saved and trip purpose. However, the single value of time assumed for 1975 by the HEEM is comparable to those suggested by other studies.
3. A single value of time is assumed for the drivers of commercial trucks and buses even though data presented in the new AASHTO Redbook and other reports justify the use of separate values of time for single-unit trucks, multiple-unit trucks, and buses. However, the single value of time assumed for 1975 by the HEEM is

comparable to those suggested for multiple-unit trucks by other studies.

4. The HEEM assumes one vehicle occupancy rate for passenger vehicles although data presented in this report justifies the use of separate occupancy rates for automobiles and buses and different rates by highway design and location. The rate assumed by the HEEM is not applicable to buses and the rural highway types.
5. The HEEM assumes vehicle operating unit costs for only two vehicle types and for all highway types combined even though other studies justify the use of unit costs for at least three vehicle types and two highway types. The Redbook gives unit costs on four highway types. Also, the HEEM's assumed values for each vehicle type, especially trucks traveling at speeds under 20 miles per hour, are considerably different from those reported in other studies.
6. The accident unit costs assumed by the HEEM include direct accident costs plus the present value of net production lost by society as the result of an accident. The more appropriate and defensible accident unit costs to use are those containing direct costs plus the present value of the gross production lost by society as the result of an accident. By using the HEEM's set of unit costs, some important benefits of projects that reduce accident rates or severity are excluded from consideration.
7. The HEEM assumes inflation and construction cost escalation factors to calculate future benefits and costs attributed to a highway improvement even though the consensus in the literature appears to be that such factors should not be applied.

8. The HEEM assumes an arbitrarily high discount rate of 20 percent even though most government agencies use rates between five and seven percent. The AASHTO Redbook suggests using a four to five percent rate for data expressed in constant dollars.

9. The HEEM assumes diversion speeds which may be too low for most highway types, even for the two-lane conventional highway which they are said to represent. Only limited data are available to establish reasonably accurate diversion speeds for a given highway type.

The review of the HEEM's procedures for updating its assumed values and unit costs revealed the following findings:

1. The unit costs, except accident costs, assumed in the model were updated to the January 1975 price level, using presumably the U.S. Consumer Price Index (CPI). The accident unit costs are based on a 1974 California Transportation Department study.

2. The HEEM authors suggest no procedure for updating the unit costs, except vehicle operating costs, from January 1975 to the base year of the proposed project. An unknown price index was used to update vehicle operating unit costs from January 1975 to August 1975.

3. The HEEM provides no updating procedure for the assumed truck percentage, inflation rate, construction cost escalation rate, discount rate, and diversion speeds.

This report describes and recommends updating procedures for all the "key" assumptions and unit costs used in the HEEM. Also, recommendations for further research to finish the evaluation of the HEEM and to generate assumed values and unit costs from a reliable data base which reflect changes in technology over the past 20 years are presented in this report.

IMPLEMENTATION STATEMENT

This report relates the findings of a critical evaluation of the Highway Economic Evaluation Model (HEEM) and presents procedures for updating the model's assumed values and unit costs. The findings can be implemented immediately which generate more accurate estimates of highway user impacts resulting from different highway improvements. It has been over three years since the HEEM's assumed values and unit costs have been updated. The general price level has changed considerably during that time.

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INTRODUCTION

The near completion of the Interstate Highway System (including loops around the center of major cities), the completion of many of the freeways planned in urban areas, and the increasing shortage of construction funds have caused state highway agencies to concentrate on upgrading and increasing the capacity of existing highways and freeways. The projected shortage of construction funds has also forced the scaling down or deletion of many planned improvements on new and existing facilities.

In order to minimize the loss of future public benefits resulting from scaling down or deleting various highway improvements, proper evaluation procedures and information must be used. The magnitude of potential user and non-user costs and benefits must be estimated with a reasonable degree of accuracy in order for highway agencies to make rational decisions in the public interest. There are procedures in use or available for use in estimating user and non-user consequences of planned highway improvements. However, these procedures have been developed and adapted mainly for measuring the impacts of new facilities instead of measuring the impacts of improving existing facilities.

User procedures are more clearly defined and easier to implement than are non-user procedures. Even so, there is a need for additional study of the basic assumptions, unit costs, and related data required to estimate user costs and benefits. The basic user cost data, especially value of time and accident cost data, are not easily adaptable to the types of highway improvements being made now and planned in the near future.

In recognition of the above problem, the State Department of Highways and Public Transportation (SDHPT) in cooperation with the Federal Highway

Administration, U.S. Department of Transportation, authorized a research study entitled "Economics of Highway Design Alternatives." This report gives the results of the evaluation of highway user procedures. A previously published report covers the non-user procedures.

Purpose and Scope of Study

The overall purpose of the highway user portion of the study is to evaluate the Highway Economic Evaluation Model (HEEM) currently used by the SDHPT in order to determine the model's suitability in evaluating user cost/benefits of alternative highway designs used in Texas [1, 2, 3].

The scope of the study is limited to an examination of the HEEM's basic assumptions, unit costs, and provisions for updating unit input data.

Objectives of Study

The specific objectives of the study are as follows:

1. Examine the appropriateness of the model's basic assumptions.
2. Examine and compare the model's unit costs with those reported by other recent studies.
3. Develop simplified procedures for updating the model's "key" assumptions and unit costs.
4. Identify the weaknesses in the model's approach and suggest methods for improvement.

CRITICAL REVIEW OF HEEM

The HEEM was orginally developed by the McKinsey and Company, Inc. of Dallas for use in California. In 1975, the developers adapted it for use in Texas under a contract with the SDHPT. The computerized model is designed as an aid in developing a highway improvement program that provides what the developers call maximum systemwide (statewide) benefits and mobility for the dollars spent [1]. The model was first used to conduct an in-depth study of a huge backlog of improvement projects proposed for the Texas Highway System conducted jointly by the McKinsey and Company and SDHPT.

The HEEM provides for a streamlined and systematic approach for evaluating highway projects on a highway segment, route, or system basis in terms of an economic measure (EM) and a mobility measure. The EM for each project is the ratio of the estimated user benefits to the estimated construction costs. The user benefits are the sum of time savings, vehicle operating cost savings, and accident cost savings less the added (incremental) maintenance costs. Mobility is measured in terms of average daily speed for both the do-nothing and if-improved alternatives.

The HEEM's estimates (outputs) are based on input data by highway type and location, and the data requirements for each highway corridor segment consist of the following:

1. Characteristics of existing highways (limited to two routes),
2. Characteristics of proposed new or improved highway,
3. Construction dates and costs (including right of way),
4. Corridor traffic (current and projected vehicles per day), and
5. Assumed values and relationships (traffic performance and allocation and unit costs).

Unfortunately, the HEEM does not estimate a highway project's effect on air pollution as do other currently used procedures [4, 5]. Also, the model does not provide for the evaluation of fuel consumption and bus or other transit projects (as opposed to highway projects) as do procedures presented in the new AASHTO Redbook [6].

The "key" assumptions of the HEEM are examined thoroughly to determine their appropriateness. The assumptions identified by the developer of HEEM and examined here are as follows: (1) truck percentage, (2) value of time (unit costs), (3) vehicle operating unit cost, (4) accident unit costs, (5) inflation and construction cost escalation rates, (6) discount rate, and (7) diversion route speed (rural and urban). The description and numerical value for each of these assumptions, except for accident unit costs, are given in Table 1. Specifically, the implications of these assumptions and their assigned values are discussed in detail and compared with other user evaluation procedures [4, 5, 6].

Table 1. HEEM's Key Assumptions for Texas

Assumption	Description	Assumed Value
1. Truck percentage	Percentage of commercial truck traffic in typical traffic flow	8%
2. Value of time	Value of time lost due to congestion or circuitous travel	
- Auto	- Average passenger/auto at 1.3 persons per vehicle	9¢/Vehicle minute
- Truck	- Average commercial truck	18¢/Vehicle minute
3. Rate of inflation	Long-term rate of general inflation	8%
4. Construction cost escalation rate	Long-term rate of construction cost escalation including inflation and the effects of higher environmental and design standards	8%
5. Discount rate	Minimum anticipated annual return of user benefits on dollars invested in highway construction projects	20%
6. Diversion route speed	Speed assigned to traffic diverted from a corridor that has reached capacity	
- Rural	- Rural	25 mph
- Urban	- Urban	15 mph

Source: Texas Department of Highways and Public Transportation, Deriving HEEM's Assumptions for Texas, Discussion Draft, Austin, Texas, February 1976.

Truck Percentage

A single statewide average percentage of trucks is assumed in the HEEM model for separating corridor traffic into two vehicle types, namely, passenger cars and trucks. It is unclear whether the assumed statewide average of eight percent is based on extensive supporting data and excludes pickups and panel trucks. The only supporting evidence given to support the eight percent was collected in the Houston area [p. 3].

Data based on a selected random sample of 326 highway sections scattered over the state indicates that eight percent is too low for a statewide average. These data are shown in Table 2 and represent the percentage of trucks in each section's average daily traffic (ADT). Even the small sample of nine urban projects, one in the Houston area, indicates that eight percent is too low for a statewide average. These data compare favorably with national data compiled by the U. S. Department of Transportation, as shown in Table 3. Also, the data used in the new AASHTO Redbook [6], as shown in Table 4, indicate the eight percent is too low for interstate highways and rural roads. Data in Table 2 and 3 support a statewide average of at least 12 percent.

Due to the wide fluctuation in the percentage trucks by highway system and location, a single statewide average is not recommended for use in the HEEM model. Instead, each highway project should be assigned a locally determined percentage of trucks, which possibly is being practiced by the SDHPT in using the HEEM. If a valid estimate cannot be determined locally, the data provided in Tables 2 and 3 should be used as a guide.

Using a single percentage of trucks to represent single-unit and multi-unit trucks can also lead to biased and less accurate estimates of time and vehicle operating costs. As shown in Tables 3 and 4, the proportion of single-unit trucks to multi-unit trucks varies considerably by highway type

Table 2. Percentage of Trucks on Texas Highways, by Highway System and Location[a]

Highway System	Location[bc]		
	Rural	Urban	All
Interstate Highways	23.33(24)	10.84(3)	21.91(27)
Loop Highways	2.27(1)	11.25(4)	9.56(5)
U.S. Highways	17.68(116)	2.86(1)	17.55(117)
State Highways	15.26(56)	10.37(1)	15.50(57)
Farm-to-Market Roads	10.68(121)	- (0)	10.68(121)
All Roads	14.99(317)	9.73(9)	14.85(326)

[a]Based on 1975 data collected from the SDHPT's Roadway Information System File for use in another Texas Transportation Institute study (Research Study 2-8-75-207) to be published at a later date.

[b]Excludes pickups and panel trucks.

[c]The numerals in parentheses represent the number of sample sections upon which the percentages are based.

Table 3. Percentage Distribution of National Vehicle Miles of Travel, by Type of Vehicle, Highway Type, and Location

Type of Vehicle	Type of Highway and Location			
	Main Rural	Local Rural	Urban Streets	All Roads
	Percent			
Cars	70.7	82.6	83.5	78.9
Buses	0.4	0.8	0.3	0.4
Single-Unit Trucks[a]	19.1	15.5	14.8	16.4
Combination Trucks	9.8	1.1	1.4	4.3

[a]Includes panels and pick-ups.

Source: U.S. Department of Transportation, Highway Statistics, Washington, D.C., 1974.

Table 4. Representative Percentage Distributions of Traffic by Vehicle Class and Federal Highway Type and Location

Highway Type and Location	Passenger Cars[a]	Single Unit Trucks[b]	Combinations	Truck Total
Interstate	Percent			
Rural	87.9	2.9	9.2	12.1
Urban	85.7	4.5	9.8	14.3
Primary				
Rural	93.4	2.7	3.9	6.6
Urban	93.2	3.6	3.2	6.8
Secondary				
Rural	88.4	6.0	5.6	11.6
Urban	93.2	4.2	2.6	6.8

[a]Includes passenger cars, motorcycles, and panel and pickup trucks.

[b]Includes buses.

Source: From a 1973 Vehicle Gross Weight and Traffic Count Study sponsored by the Federal Highway Administration, as reported in the AASHTO Redbook [6].

and location. Therefore, the user cost calculations for each highway project evaluated by the HEEM should be done separately for single-unit and multi-unit trucks, expecially when the overall percentage of trucks is high. Such procedure is recommended by the AASHTO Redbook.

Value of Time Unit Costs

Since time savings usually account for the greatest portion of user savings resulting from a highway improvement, the assumed unit values of time used in calculating time savings is of utmost importance. Also important is the decision whether to use multiple values of time by vehicle types and/or by the amount of time saved. Even the occupancy rates assigned to passenger vehicles can significantly influence the estimated amount of time savings attributable to a highway improvement project. The implications of these decisions are discussed under separate headings.

Assumed Values of Time

The HEEM's assumed values of time, lost due to congestion or circuitous travel, are nine cents per vehicle minute (assuming 1.3 persons per vehicle) for the average automobile and 18 cents per minute (assuming one driver and considering value of equipment) for the average commercial truck, as shown in Table 1. As indicated in the discussion draft on deriving the HEEM's assumptions [3], the assumed automobile value of time, in 1975 dollars, is almost identical to that recommended by Buffington and McFarland [5] as well as by Thomas [7], and Lisco [8]. Also, this value is near the upper end of the range of values recommended in the AASHTO Redbook [6]. Therefore, the HEEM's assumed value of time for automobiles is acceptable for time savings calculations if the amount of time saved, income level of occupants, or purpose of trip are not taken into account. Of course, the basic value of time should be updated continually to account for past inflation and real wage increases. Also, if the vehicle occupancy rate for the highway project being evaluated is considerably different from the assumed 1.3 occupants per vehicle, then the value per vehicle minute used in the HEEM should be changed accordingly.

The HEEM's assumed value of time (in 1975 dollars) for the average commercial truck is almost the same as that recommended by Buffington and McFarland [5] as well as by Adkins [9] for heavy multi-unit trucks (diesel truck-tractor-semi-trailers). Actually, a lower value of about 16 cents per vehicle minute, as seen in Table 5, would be more representative of the average commercial truck. The developers of the HEEM do not define the average commercial truck for comparison purposes. The average value of 16.4 cents per vehicle minute is based on the truck type distribution assumed in Table 5, and such truck type distributions differ by highway type and location, as is seen in Tables 2, 3, and 4.

The AASHTO Redbook recommends somewhat lower values of time by truck type based on a study conducted by Wilbur Smith and Associates [10]. As is seen in Table 5, the Redbook values are from 1.9 to 5.0 cents lower than the values recommended in a study by Buffington and McFarland [5] for single-unit trucks and multi-unit trucks, respectively. Since the values of time recommended by the latter study are based on truck and driver costs prevailing in the Southwest, they are preferred over those recommended by the AASHTO Redbook for the evaluation of Texas highway improvement projects.

Therefore, if a single value of time for commercial trucks is used in the HEEM, a weighted average value of 16 cents per vehicle minute (in 1975 dollars) is recommended. However, if the truck type distribution for the highway project to be evaluated is considerably different from that assumed in Table 5, then a new weighted average value of time should be calculated and used in the HEEM. Also, the truck value of time should be updated continuously.

Multiple Values of Time by Vehicle Type

Using multiple values of time by vehicle type would eliminate the need for recalculating a weighted average truck value of time necessitated by a change in the vehicle type distribution. The new distribution could be used directly in the model by modifying the HEEM equations which calculate the amount of traffic by vehicle type [2]. Currently, the model uses percent of trucks to allocate the traffic between cars and trucks.

A percentage distribution of four vehicle types is recommended for the model as follows:

1. Passenger cars, pickups and panel trucks (2-axle and 4-tires),
2. Single-unit trucks (2-axle and 6-tires or larger),
3. Multi-unit trucks (combinations), and
4. Buses (commercial).

The AASHTO Redbook recommends a percentage distribution composed of three vehicle types, except when bus transit projects are involved. One reason for keeping buses and trucks in separate categories is because the value of time for buses is higher than that for trucks. Buffington and McFarland [5] recommend 19.5 cents per vehicle minute (1975), to cover driver and equipment costs. Another reason for keeping buses in separate category from cars and trucks is to provide a means to properly calculate bus passenger travel time savings.

Table 5. Comparisons of Values of Time by Truck Type from Two Data Sources

Literature Source	Value of Time (1975)		
	Single-unit Truck	Multi-unit Truck	Average Truck[a]
	Cents per Vehicle Minute		
AASHTO Redbook [6]	11.5	13.0	12.5
TTI Study [5] by Buffington and McFarland	13.4	18.0	16.4

[a]Assuming a truck type distribution of 34.7 percent single-unit trucks and 65.3 percent multi-unit trucks.

For bus improvement projects, such as reserve bus lanes, which may also cause commuters or travelers to change modes, i.e., from automobile to bus, two values of time for bus passengers are in order: one for walking and/or waiting times and one for in-vehicle travel. The AASHTO Redbook recommends that for average conditions waiting and/or walking time is probably worth 1.5 times the in-vehicle travel time for high time savings of over 15 minutes and that this value could be adjusted upwards to 2.0 times the in-vehicle travel time for below average comfort and safety conditions.

Therefore, a vehicle type distribution which includes buses and a bus occupancy rate must be determined or assumed for the project under study in order to calculate time savings attributable to buses and bus passengers. Table 3 shows nationwide vehicle type distributions by type of highway and location that include buses [11]. Table 6 shows vehicle occupancy rates for buses and passenger cars operating in rural and urban areas [12]. These distributions and occupancy rates can be used if local data are not available. The occupancy rate of 1.3 persons per passenger car assumed in the HEEM is acceptable only for urban peak hours, especially since the HEEM's calculations include non-peak hours.

Multiple Values of Time by Amount of Time Saved

Different highway improvement projects provide varying amounts of time savings to highway users. The amount of time saved per trip may vary considerably depending on type of highway improvement, trip length, time of day trip is made, etc. Also, there is evidence in the literature to indicate that the value of time for passenger cars and buses varies with the amount of time saved per trip, family income of traveler, and the purpose of the trip [6, 13, 14]. Thomas and Thompson [13] pioneered the research in this

Table 6. Vehicle Occupancy Rates for Passenger Cars and Buses, by Location

Vehicle Type and Location	Occupancy Rate		
	Average	Peak Hour	Practical Maximum
	-------------- Persons per Vehicle --------------		
Passenger Cars			
All trips[a]	2.2	1.6	3.5
Intercity trips	2.9	-	-
Buses			
Transit Buses[b]	9.0	18.0	25.0
Intercity Buses	20.0	-	30.0

[a]Includes work trips and intercity trips.

[b]Based on cities with populations of at least 300,000.

Source: Voorhees, Alan M., and associates, Inc.; Energy Efficiencies of Urban Transportation, technical study memorandum No. 9; Westgate Research Park, McLean, Virginia; May 1974.

area in the late 1960's using a "revealed behavior" approach. Their findings are based on a survey of motorists, at sites in 10 states (one in Texas), who faced a choice between a faster toll road and a slower free road. Among the data collected were (1) purpose of trip, (2) trip length, (3) amount of time saved per trip, (4) toll fee, and (5) family income level of driver. Regression or discriminant analyses were used to determine the nature and extent of the relationships among these variables. The value of time saved was based on how much money motorists were willing to pay in tolls to save a certain amount of time. They concluded that the value of time saved is dependent on the amount of time saved, the motorist's family income, and the trip purpose.

The AASHTO Redbook [6] presents a procedure for using the findings of Thomas and Thompson. A graph (Figure 1) shows the values of traveler time, in 1975 dollars, as a function of the time saved per trip for different types of trips and for all trip types combined for travelers having average family incomes ranging from $14,000 to $17,000 per year. Also, a table similar to Table 7 shows values of traveler time saved as a function of the amount of time saved and trip type even in a more condensed form, i.e., with the values of traveler time saved divided in three general categories of time saved per trip for three types of trips and for the average of all trips. The weighted average values of time by length of time saved, as shown in Table 7, are based on the following trip type percentage distribution: work trip - 36.7%, personal business trips - 40.8%, and social recreational trips - 22.5 %. This distribution is based on data from the National Personal Transportation Survey conducted by the U.S. Department of Transportation in 1969-70 [15]. If the local percentage distribution differs from this one, new weighted averages should be computed.

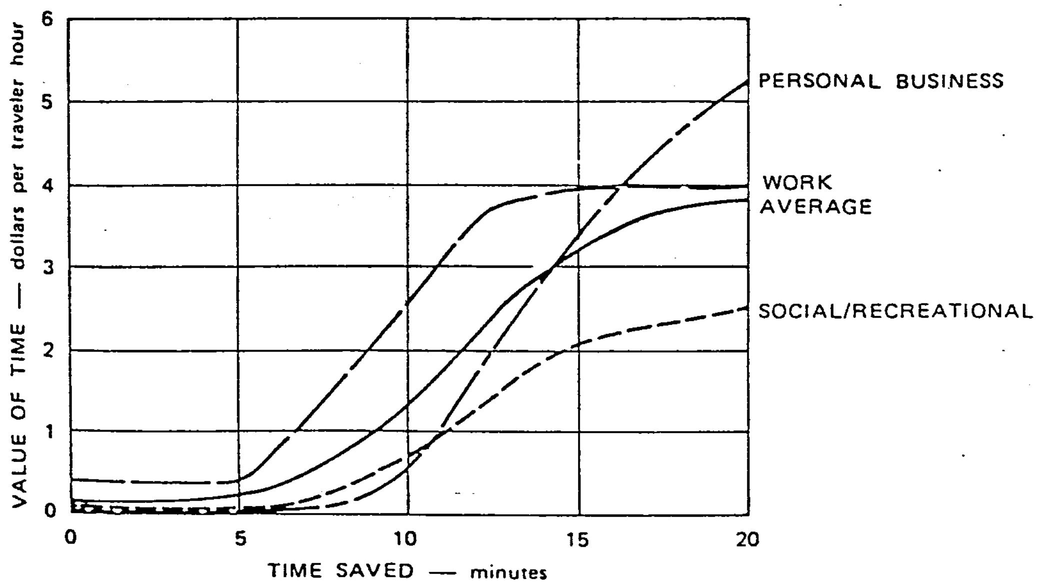


Figure 1. Value of Time as a Function of Time Saved, by Trip Type.

Source: American Association of State Highway and Transportation Officials, A Manual for User Benefit Analysis of Highway and Bus Transit Improvement, (Redbook, Washington, D.C., February 1977.

Table 7. Value of Time as a Function of Time Saved and Trip Type.[a]

Time Saved and Trip Type	Value of Time per Traveler Hour[b]	Percentage of Average Hourly Family Income[c]
For Low Time Savings (0-5 minutes)		
Work Trips	$0.47	6.3%
Personal Business Trips	0.01	0.1
Social/Recreational Trips	0.05	0.7
Weighted Average Trips	0.18[d]	2.4
For Medium Time Savings (5-15 minutes)		
Work Trips	2.42	32.5
Personal Business Trips	1.12	15.0
Social/Recreational Trips	0.87	11.7
Weighted Average Trips	1.47[d]	19.7
For High Time Savings (15-20 minutes)		
Work Trips	4.06	54.5
Personal Business Trips	4.31	57.9
Social/Recreational Trips	2.24	30.1
Weighted Average Trips	3.54[d]	47.5

[a]Based on procedure used in AASHTO Redbook [6].

[b]Original values in Thomas and Thompson report [13] are updated to 1975 values using the U.S. Consumer Price Index.

[c]Based on 2,080 working hours per year for the $15,500 average income of the $14,000 to $17,000 range or $7.45 per hour. Use these percentages to adjust value of time factors proportionately when average family incomes where projects are located outside the $14,000 to $17,000 range.

[d]Arrived at by weighting individual values of time by trip purpose by following percentage of trips distribution [15]: work trips - 36.7%, personal business trips - 40.8%, and social/recreational - 22.5%.

The traveler values of time per person, as shown in Figure 1 and Table 7, can be converted to average values of time saved per vehicle by multiplying by the appropriate vehicle occupancy rate. Where specific vehicle occupancy data are not available for the particular state or region of interest, occupancy rates from the original value of time study [13] or the above mentioned national survey can be used. These rates are as follows:

	Value of Time Study [13]	National Survey [15]
	Adults per Vehicle	
Work	1.22	1.4
Social-recreational	1.98	2.5
Personal Business	1.64	2.1
Average	1.56	2.0

The percentages of average hourly family income by amount of time saved and trip type are given in Table 7 for use in adjusting the value of time factors proportionately when the average family incomes where highway improvement projects are located are outside the $14,000 to $17,000 range. The 1975 average family income for Texas was $15,008, which is very close to the $15,500 upon which the values of time presented in Table 7 are based.

According to the Redbook, once the time savings per trip for each trip type or for all trips for a particular highway or transit improvement are known, Figure 2 or Table 7 can be used to select estimates of the travel time value per traveler hour. Then the values of time per vehicle hour can be calculated by multiplying by the selected vehicle occupancy factor. In determining the amount of time saved per trip, all improvements planned for a particular facility over the long-term should be considered. Also, the values of traveler time in Figure 2 and Table 7 must be updated continuously to reflect current costs and family incomes.

Hensher [16] questions the statistical techniques used by Thomas and Thompson to derive different (actual) values of time as a direct function of traveler income. However, he concludes that stratification of the data into three ranges of amount of time saved avoids any double inference stemming from the ex post exclusion of income as a variable which has an ex ante perceptual influence on the internal structure of the relative times and relative costs. Also, he warns the analyst who might use a unique value of time in an economic model without consideration of variations in the value of time with respect to income, trip length, and amount of time saved, because a unique value could be as misleading as no value.

But Dudley Anderson, who conducted the research reported in the Redbook, disagrees with Hensher's criticisms and indicates that the findings of Thomas and Thompson are not significantly affected by the techniques they used. Anderson does caution those who attempt to use values of time by amount of time saved about the difficulty of obtaining reliable travel time estimates. Thomas and Thompson also state this concern in their original report [13] and in a paper based on that report [17]. They indicate that trip and highway improvement data are generally unavailable for rural improvements and would have to be calculated from traffic assignment data in urban areas. However, their recommendation to those developing benefit-cost estimates by using the values of time by length of time saved is to make what assumptions that are necessary in conducting the analysis.

Since Thomas and Thompson made the above recommendations about ten years ago, little progress has been made in developing improved techniques for calculating the quantitative amount of time by vehicle type and/or by amount of time saved. Therefore, even though it is recommended that the HEEM model eventually be modified to perform these more detailed calculating for values of time, it should be recognized that the HEEM will have to be modified considerably to calculate a distribution of amounts of time saved for different vehicles within the corridor, by trip purpose. It appears that this would be a major research effort. The following inputs would be needed to accomplish this revision:

1. Assume appropriate vehicle type percentage distribution,
2. Assume the appropriate speed by vehicle type,
3. Assume appropriate occupancy rate for automobiles and buses,
4. Assume the amount of walking or waiting time saved per person trip on bus,
5. Assume appropriate trip type percentage distribution for automobiles and buses,
6. Assume the appropriate values of time per traveler minute by trip purpose and amount of time saved for passenger cars and buses,
7. Assume the appropriate values of time per vehicle (driver) minute for trucks and buses.

The appropriate equations, as used in the HEEM and reported in the Programmer's Supplement [2], will have to be reworked to include the new assumptions. First, Assumption 1 will have to be used in the equations that calculate the amount of traffic by vehicle type allocated to each of the existing and proposed routes in a corridor segment. Second, Assumption 2 must be used in the equations that calculate the lapsed time (minutes) per vehicle trip for each vehicle type on each of the routes. Third, Assumptions 3, 4, and 5 must be used in the equations that calculate the total lapsed traveler time (minutes) by trip type for the passenger vehicle types using each route. This assumption is not applicable to trucks. Fifth, the equations that calculate the total time saved annually by using the proposed route over the existing or alternate route must be altered to give the total traveler time saved for cars and buses and total vehicle (driver) time saved for buses, single-unit trucks, and multi-unit trucks. Sixth, Assumptions 6 and 7 must be used in the equations which calculate the annual value of time savings. For computing the value of traveler time saved, the values of time presented in Table 8 can be used after being updated to reflect the latest costs and family income levels. The vehicle (driver) values of time saved for trucks and buses can be computed by using the truck values of time presented in Table 5 and the bus value of time of 19.5 cents per vehicle minute mentioned previously.

To summarize, the use of multiple values of time in the HEEM model to rank highway improvement projects on a statewide basis should provide the decision-maker with more accurate estimates of time costs with or without a specific highway improvement. This conclusion should be true even if separate values of time by trip purpose are not used. The accuracy of these estimates depends mainly upon the accuracy of the estimated travel time saved per trip with or without the highway improvement. Further study is needed to determine the time savings resulting from specific highway improvements. Last, it should be pointed out that changing the HEEM model to calculate value of time savings based on multiple vehicle types and/or amount of time saved per trip enables it to calculate vehicle operating cost savings using multiple vehicle types, i.e., using more than two types.

Vehicle Operating Unit Costs

The HEEM model uses two types of vehicle operating unit costs to calculate vehicle operating cost savings due to a highway improvement, namely running costs and cycling or speed change costs, as shown in

Table 8. Value of Traveler Time in Passenger Vehicles, by Amount of Time Saved and Trip Purpose

Amount of Time Saved by Trip Purpose	Value of Time by Vehicle Type[a]		
	Cars, Panels and Pickups	Bus	
		In Vehicle	Out of Vehicle[b]
	- - - Cents per Traveler Minute - - -		
0-5 Minutes Saved			
Work Trips	0.78	0.78	1.18
Personal Business Trips	0.02	0.02	0.03
Social/Recreational Trips	0.08	0.08	0.13
Weighted Average Trips	0.30	0.30	0.45
5-15 Minutes Saved			
Work Trips	4.03	4.03	6.05
Personal Business Trips	1.87	1.87	2.80
Social/Recreational Trips	1.45	1.45	2.18
Weighted Average Trips	2.45	2.45	3.68
15-20 Minutes Saved			
Work Trips	6.77	6.77	10.15
Personal Business Trips	7.18	7.18	10.78
Social Recreational Trips	3.73	3.73	5.60
Weighted Average Trips	5.90	3.73	8.85

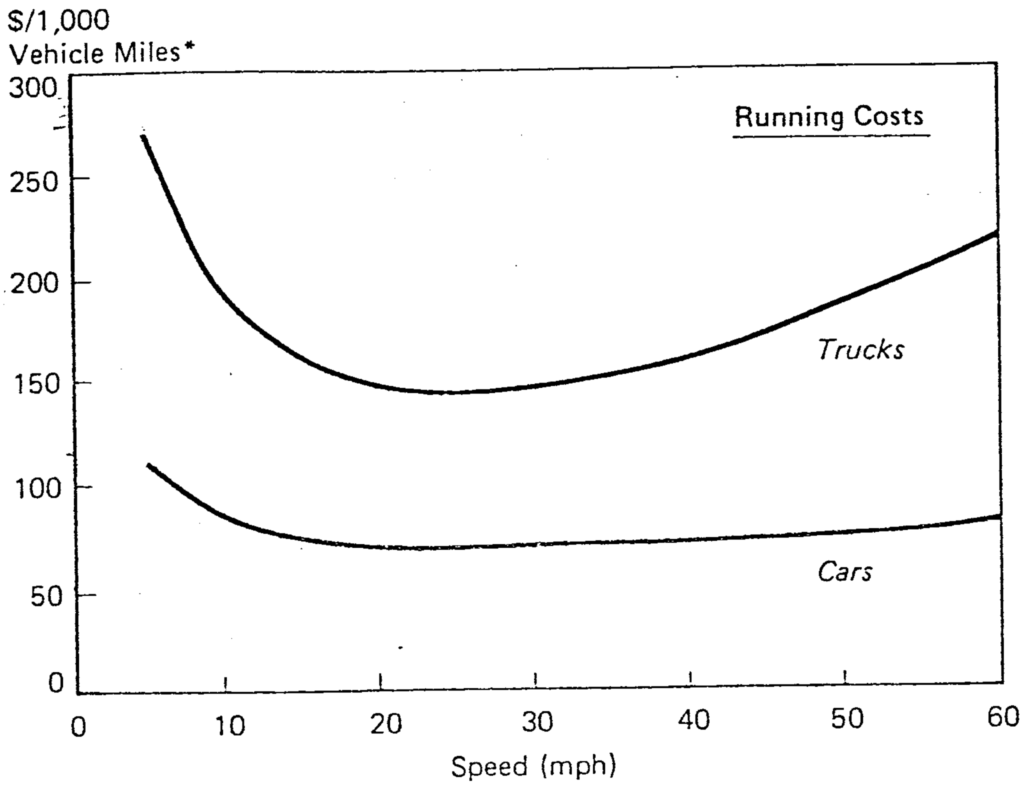
[a]Based on values of time presented in Table 7 for travelers with annual family incomes in the $14,000-$17,000 range as of 1975.

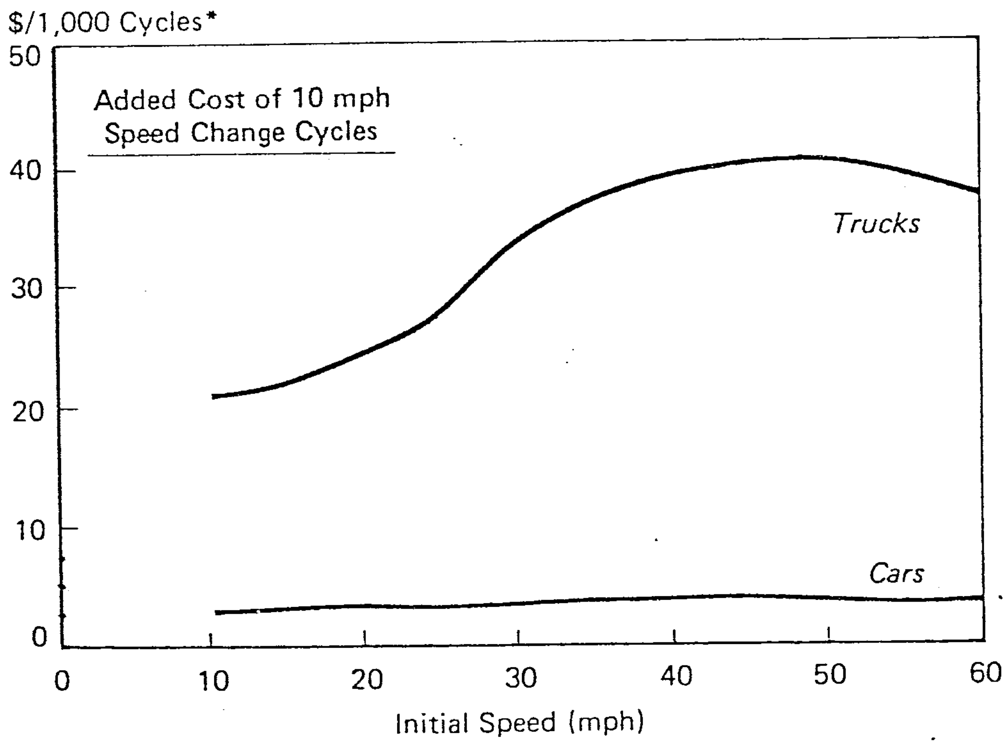
[b]Value of waiting and/or walking time which is 1.5 times the in-vehicle value of time.

Figure 2. The running costs, updated to March 1975, are based on those used by Winfrey [18] and the AASHTO Redbook [6]. The cycling costs are based on those used by Winfrey.

The HEEM model's running and cycling unit costs for cars and heavy trucks (assumed to be the multi-unit types) are fitted to separate curves as a function of average daily speed. Coefficients describing each curve are used in the equations that calculate vehicle operating cost savings. Separate equations are used for speeds above and below the minimum cost speed shown by the curves in Figure 2. The cycling cost equations use coefficients that describe the relationship between the number of 10 miles per hour cycles and average daily traffic volumes by highway type and number of lanes, as shown in Figure 3. These coefficients were developed in other studies [19, 20]. Certain technical performance factors are used to adjust the number of cycles per vehicle mile for atypical performance. Adjustments are made for the width of shoulders and lanes, vertical alignment, and percentages of trucks. The HEEM model assumes that the vehicle operating cost for diverted traffic is the same as that for a 2-lane conventional highway.

The vehicle operating costs used by the HEEM model are compared with those recommended in Buffington and McFarland TTI 202-2 report [5] and the AASHTO Redbook by combining the running and cycling costs into one curve for each data source, as shown in Figures 4 and 5. These costs apply to a 70 mph design speed on an 8-lane freeway. The HEEM cycling costs are based on 5.4 cycles per vehicle mile. It is not known how many cycles per mile are represented in the costs recommended by the other two data sources.





* - 1975 prices

Figure 2. Vehicle Operating Cost/Speed Relationships by Vehicle Type Used by the HEEM [1].

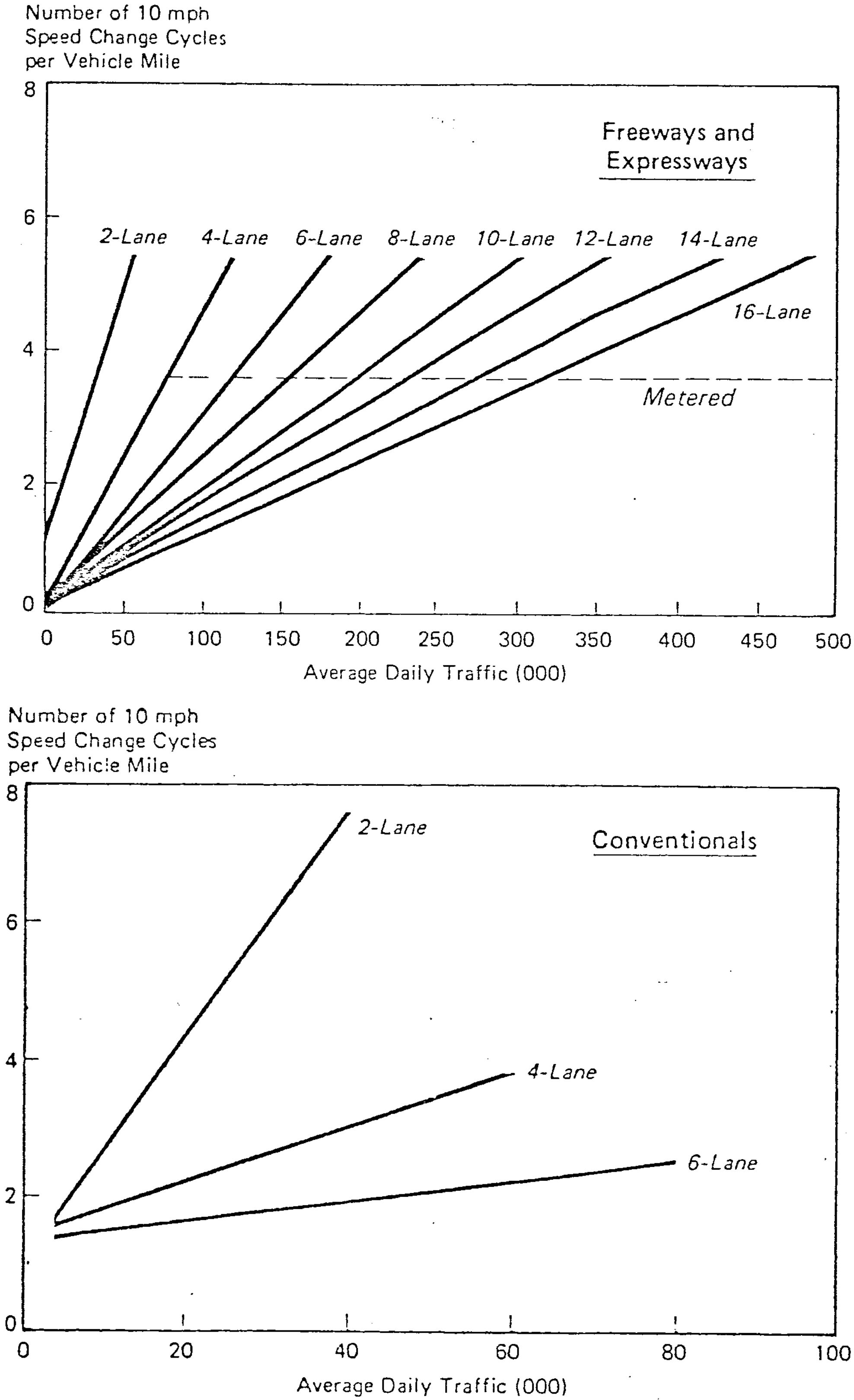


Figure 3. Speed Change Cycle/Traffic Relationships by Highway Type as assumed by the HEEM Model [1].

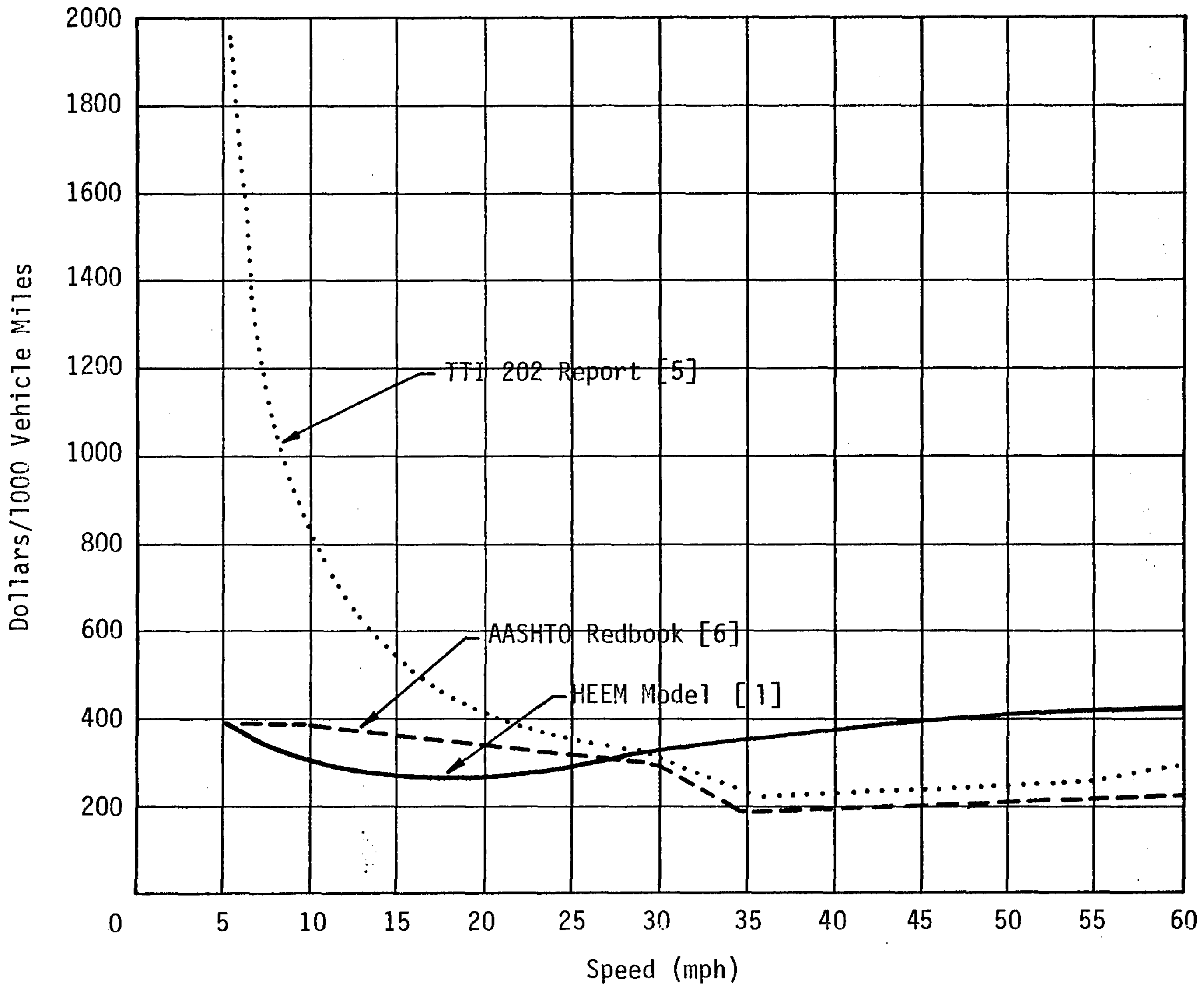


Figure 4. Combined Running and Cycling Costs for Heavy Trucks Based on HEEM Data Compared to Data From Other Studies.

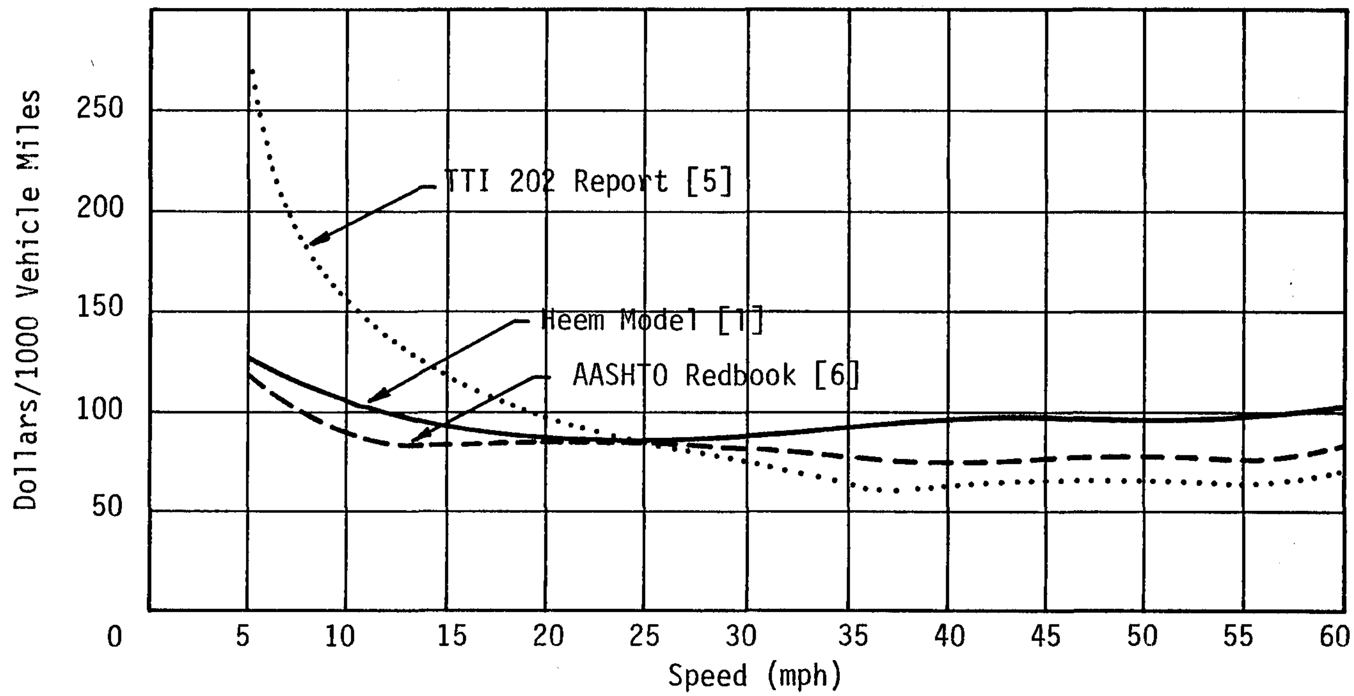


Figure 5. Combined Running and Cycling Costs for Cars Based on HEEM Data Compared to Data from Other Studies.

As can be seen from Figures 4 and 5, there are considerable differences in the combined unit costs of the three data sources, especially at speeds below 20 miles per hour. The cycling cost component accounts for most of the difference in the combined costs generated from these data sources. All of the data sources used somewhat different base data. For speeds below 20 miles per hour, the HEEM unit costs are more similar to the AASHTO Redbook costs, and for speeds above 35 miles per hour, the HEEM costs are more similar to the TTI 202-2 report costs. It is obvious that new cycling data, compiled for different types of highways and traffic conditions, are needed to indicate which set of unit costs is the most accurate.

As is pointed out earlier in this section, the HEEM model uses unit vehicle operating costs for only two vehicle types (cars and trucks) to calculate vehicle operating cost savings that could result from a highway improvement. The operating costs for all truck types are based on the unit costs attributed to one truck type, assumed to be the multi-unit type. As seen in Table 9, there is a considerable difference in the unit operating costs of single-unit trucks and multi-unit trucks, especially at lower speeds. These unit cost differences are based on the combined unit costs for each of the two truck types given in the AASHTO Redbook. As shown in Table 9, a significant error can result from assigning all truck traffic one set of unit costs, particularly unit costs representing either single-unit trucks or multi-unit trucks. The errors shown in Table 9, are based on the assignment of all trucks the unit operating costs of multi-unit trucks in a case where the truck distribution is assumed to be 34.7 percent single-unit trucks and 65.3 percent multi-unit trucks. As in the case of unit cost differences, the error becomes larger at lower speeds.

Table 9. Difference in Unit Vehicle Operating Costs of Single-Unit and Multi-Unit Trucks by Average Speed and the Error Caused by Assignment of Multi-Unit Truck Costs to All Trucks

Average Speed	Absolute Difference in Unit Cost[a]	Assignment Error[b]
	--Dollars per 1000 Vehicle Miles--	
5	225	78
10	208	72
15	195	68
20	181	63
25	154	53
30	126	44
35	41	14
40	41	14
45	43	15
50	36	12
55	33	11
60	30	10

[a]Based on the AASHTO Redbook's combined unit costs which include uniform speed costs on level surface with no curves and speed change costs.

[b]Assuming a truck distribution of 34.7% of single-unit trucks and 65.3% of multi-unit trucks and assigning multi-unit truck operating costs to all trucks.

If one set of unit costs is used, then such a set of costs should represent an average of the single-unit truck costs and multi-unit truck costs, weighted by the appropriate truck type distribution. The use of weighted average unit costs will yield the same total vehicle operating costs arrived at by using separate unit costs for each truck type only when the assumed truck type distribution used in the weighting calculations is the same as the truck type distribution represented on the facility being improved. Therefore, assuming one set of weighted average unit costs for statewide use will yield vehicle operating cost estimates of varying accuracy.

In view of the wide differences in the truck type distributions and/or vehicle type distributions, especially by type and location of highway, it is recommended that the appropriate vehicle type distribution be used directly with given vehicle operating unit costs for each vehicle type identified in the vehicle distribution to calculate vehicle operating cost savings for each highway improvement being evaluated. Then the comparison of user savings among highway improvement projects over the state or in a highway district would be more accurate. The next best thing to do would be to assume several vehicle type distributions by highway type and location and use the appropriate one with the given vehicle operating unit costs for each vehicle type to calculate vehicle operating cost savings for each highway improvement.

In light of the above recommendations, the HEEM model's assumptions and equations in the Programmer's Supplement [2] will have to be altered so that it can calculate vehicle operating costs for the three vehicle types recommended earlier in this report. This will require that the set of unit running and cycling costs currently used for trucks be replaced with a set for single-unit trucks and a set for multi-unit trucks. The

AASHTO Redbook would be the best source to obtain such unit costs. Also, the overall percentage of trucks assumed in the model must be replaced with a vehicle type distribution that allows the calculation of vehicle-miles with and without the highway improvement for the three vehicle types. The vehicle type distribution assumed should be subject to change on a project basis. Also, the unit costs should be updated continually.

Accident Unit Costs

The accident unit costs assumed in the HEEM for fatal, injury, and property damage only accidents are developed from 1974 California accident cost estimates [21] and weighted from Houston experience by accident type. The California values are in turn based chiefly on the Wilbur Smith study of the Washington, D. C. area [22]. HEEM's accident unit costs are shown in Table 10.

Before any conclusions can be drawn as to the appropriateness or inappropriateness of the values used in HEEM, the different types of accident unit costs must be defined [23, pp. 72-74]. The wide variation among the accident unit costs currently in use can be ascribed, at least in part, to what cost components are used.

The first type of accident unit costs is limited to only those cost components directly resulting from the accident, such as property damage, medical expenses, temporary lost worktime due to injuries, legal costs, damage awards, loss of vehicle use. Indirect cost components, such as loss of production to society, are excluded by some analysts because they have to be estimated.

Table 10. Unit Accident Costs Used in HEEM Model [3]

Type of Accident	Location of Accident[a]	
	Urban	Rural
	- - - Dollars per Accident - - -	
Fatal	110,000	140,000
Injury	3,500	4,500
Property Damage Only	1,000	1,400
Average[b]	1,800	2,300

[a]Developed from California accident cost estimates [21] which were based on a Wilbur Smith study [22].

[b]Weighted by Houston experience by accident type distribution as follows: 0.4% fatal, 14.6% injury, and 85.0% property damage only.

The second type of accident unit costs includes direct costs and the estimated present value of net production lost by society resulting from an accident in which one or more persons are killed or rendered permanently and totally disabled. The net production lost by society is defined as the present value of expected future earnings less the present value of expected future consumption of the accident victims. By excluding a victim's expected future consumption from the accident cost estimate, this type of accident unit cost understates the social loss from an accident, by implying that the victim has no worth to society other than as a producer.

The third type of accident unit costs includes direct costs and the present value of the accident victim's gross future production. Unlike net future production, gross future production includes a victim's expected future consumption in the accident cost estimate, thereby more closely approximating the social loss of an accident than does the net future production approach

The fourth type of accident unit costs is based on "willingness to pay" to avoid a fatal accident. Unlike the other three, this approach to estimating the cost of an accident is not in current use. Although extensive research has been done in this area, no efficient way of empirically implementing this estimation technique has yet been developed. It also has the relative disadvantage that is measures only the value of a person's life to himself [24, 25, 26, 27, 28, 29, 30, 31] or to others [32]; it does not measure society's loss from a nonfatal injury or PDO accident. This approach does have the advantage that it includes intangible but significant factors valued by members of society, such as the pleasures of home, family, and friends.

The 1973 survey by Roy Jorgensen and Associates gives the following frequency of use of different types of accident unit costs for a sample of highway and safety agencies [33, p. 67]:

Source	Used	Not Used
NHTSA Tables	5	35
National Safety Council	25	15
NCHRP Research Tables	6	34
In-House Accident Cost Studies	15	25

This survey indicates that the NSC values, which are the second type of accident unit costs described above, are the most frequently used [3.g., 21, 22, 34, 35]. Accident unit costs based on direct costs only is the second most popular type, used by many state highway departments [3.g. 36, 37, 38, 39, 40, 41; see also 33, p. 6, Table 2]. The NHTSA values, which represent the third type of accident unit costs [6, p. 99; 42], are used comparatively infrequently.

Table 11 presents the revised Redbook summary of accident unit costs that are currently being used. All costs are updated to 1975 dollars [6, pp. 99-100]. From this table it is seen that the California and thus the HEEM values, are of the second type of accident unit costs.

As suggested by the above discussion of types of accident unit costs, those accident unit costs representing direct costs only or of direct costs plus net expected future production are inadequate [23, pp. 77-78]. By failing to account for all significant costs, such measures of social losses due to traffic accidents fail to capture some important benefits of projects that reduce accident rates or severity. Cost estimates comprised of direct

Table 11. Representative Accident Costs Per Reported Accident

Data Source	Fatal Accidents	Injury Accidents	Property Damage Only
NHTSA Societal Cost of Motor Vehicle Accidents, 4/72 [42]	$307,210[a]	$14,600[a]	$ 650
CALTRANS Memo, 10/74 [21, based cheifly, in turn, on [22]			
Urban	112,000	3,500	1,000
Suburban	127,000	4,000	1,200
Rural	142,000	4,500	1,400
National Safety Council Traffic Safety Memo #113, 7/72 [34]	113,500[b]	6,200[b]	570
Stanford Research Institute Questionnaire to State Highway Agencies, 5/74 [43]	64,000[c]	4,800[c,d]	840[d]
Illinois Accidents Study, 1958 [39] Modified in NCHRP Report 133, 1970 [4]			
Urban	18,800	4,200[d]	700[d]
Rural	25,200	6,500[d]	960[d]

[a]Scaled up from costs for injuries and fatalities based on an average of 1.17 fatalities and 2.03 injuries per fatal accident and 1.5 injuries per injury accident.

[b]Scaled up from costs for injuries and fatalities based on an average of about 1.40 fatalities and 2.49 injuries per fatal accident and 1.6 injuries per injury accident.

[c]Scaled up from costs for injuries and fatalities based on an average of 1.15 fatalities per fatal accident and 1.56 injuries per injury accident.

[d]These injury accident costs have been increased by seven percent and PDO accident costs by 90 percent since CALTRANS data show that ten percent of injury accidents and 60 percent of property damage only accidents are not reported [18]. Assuming that unreported accidents average only 60 percent of the cost of reported accidents, the costs per reported accident have been adjusted as indicated to obtain estimated average costs per reported accident. CALTRANS accident costs were already adjusted for unreported accidents. The degree of allowance by NHTSA and NSC for unreported accidents is not clear because of their use of nationally aggregated statistics and secondary accident cost studies, some of which include unreported accidents and some of which do not (e.g., see [42, page E-2]). Hence, NHTSA and NSC costs have not been adjusted for unreported accidents.

Soure: AASHTO Redbook [6, p. 64].

costs plus gross expected future production are the best currently available, but even these do not represent the full value of a lost life. The best way to estimate accident costs would be to use the direct costs plus net production approach in conjunction with a willingness to pay measure. The former would account for injury and property damage losses, while the latter would account for fatality losses. Of course, the willingness to pay concept must first be developed into an easily quantifiable and applicable calculation algorithm.

In conclusion, the HEEM accident unit costs are deemed to be too low in that they exclude the present value of an accident victim's expected future consumption and hence better reflect the social loss from an accident. In a format similar to that currently used in HEEM, recommended costs per accident in 1975 dollars are shown in Table 12. Since the NHTSA accident costs are not subcategorized by location of accident, California Department of Transportation (CALTRANS) accident costs by location (Table 11) and statewide average costs by severity (Table 12, Footnote a) are used to compute percentage distributions which are used on the NHTSA costs to arrive at accident unit costs by location and severity, as shown in Table 12. Then these unit accident costs should be updated and applied to the most up-to-date and accurate percentage distributions of accidents by severity of accident, location, and type of highway in order to arrive at weighted average accident unit costs for use in the HEEM model.

Inflation and Construction Cost Escalation Rates

HEEM uses both a general inflation rates of eight percent and an eight percent construction cost escalation rate, itself a type of inflation rate,

Table 12. Unit Accident Costs Recommended for HEEM Model

Severity of Accident	Location of Accident[ab]		
	Urban	Suburban	Rural
Fatal	$264,673	$300,121	$335,568
Injury	12,775	14,600	16,425
Property Damage Only	591	709	827

[a]Based on National Highway Transportation Safety Administration (NHTSA) societal costs of motor vehicle accidents shown in Table 11. These accident costs by severity, i.e., fatal, injury and property damage only, are adjusted for location of the accident by using the same proportions that the corresponding California Department of Transportation (CALTRANS) accident costs by location in Table 11 are to the following statewide average: fatal, $130,000; injury, $4,000; and property damage only, $1,000.

[b]Updated to April 1975.

to adjust future benefits and costs of a proposed highway improvement for changes in prices. Although it certainly is relevant to consider the effects of inflation when dealing with future costs and benefits, the consensus in the literature appears to be that inflation should not be included in present value calculations. Lee and Grant [44] conclude that inflation should not be considered except in those cases "when there is overwhelming evidence that certain inputs or outputs. . .are expected to experience significant prices changes relative to the general prices level." In a similar fashion, Burke and McFarland [45] concur with HEEM's own conclusion regarding construction cost escalation rate, concluding that, while construction costs have recently been increasing at a faster rate than prices in general, this trend is unlikely to continue over an extended period of time, suggesting that changes in construction costs should be treated no differently than other price changes. They go on to point out that, if costs and benefits increase at the same rate, then benefit-cost ratios are undisturbed. Winfrey [18, p. 248] agrees, stating that:

> Within the economy of highway transportation, the inclusion of an inflationary factor on the future highway costs of construction and maintenance would call for similar consideration of inflation in the road-user costs for motor vehicle operation and in the value of travel time. Thus, both costs and benefits would be inflated, so their relative magnitude may be the same with or without the factor of inflation.

NCHRP Report 162 [33, p. 7] emphasizes the difficulty of predicting future inflation rates and hence the undesirability of including an inflation factor in present value calculations of highway project costs and benefits. In the same vein, the new AASHTO Redbook [6, p. 14] recommends using constant dollars rather than inflated or current dollars in economic analysis, "since it avoids the need for speculation about future inflation in arriving at the economic merit of the project." McFarland, et al. [23, p. 86] conclude that present value calculations for public projects should be made in terms of constant dollars, with no inflation factor.

In practice, most highway agencies follow the above recommendations and use no inflation factor in their economic analyses of highway improvement projects. Reporting the results of its 1973 survey, NCHRP Report 162 [33, p. 68] indicates that agencies typically use no inflation rate, although a very few use rates between five percent and slightly over seven percent. Alabama [46, pp. 20-37] uses no inflation rate in its CORRECT program for Section 209 funds, although Kentucky [47, p. 48] implicitly includes an inflation rate by using a discount rate of ten percent in its present value calculations of future costs and benefits of proposed safety improvement projects (AASHTO Redbook [6, pp. 14-15] states that a discount rate exceeding four to five percent implicitly includes an inflation rate). A 1976 national highway safety needs study [48, p. V-24] makes all cost estimates in constant 1974 dollars in an attempt to exclude the effects of inflation.

In light of the theoretical arguments and recommendations against including an inflation rate in present value calculations of anticipated costs and benefits of highway projects, it is recommended that no inflation rate be used in HEEM present value calculations. Also, because it is deemed unlikely that a significant difference between the rate of construction cost inflation and the general rate of price inflation will continue on a long-term basis, it is recommended that no construction cost escalation rate be applied to project costs in HEEM. Calculations should be made in constant dollars; choice of base year is not critical.

Discount Rate

HEEM applies a discount rate of twenty percent to all expected benefits and maintenance costs of a proposed improvement, after allowing for an eight percent inflation rate. This discount rate represents the "time value of money" and also "a minimum estimate of the return from alternative uses of highway funds" [1, p. 214]. It is also called the "social rate of discount," which represents taxpayers' "opportunity cost of capital" [6, 49].

While a positive discount rate is essential in evaluating costs and benefits that occur over the typically long service life of a public investment project, there is some disagreement as to what rate is appropriate. The primary reason for the divergence in suggested discount rates is disagreement among authors as to which interest rate represents taxpayers' "opportunity cost of capital." Some interest rates, upon which the selected discount rate is based, come closer to representing the "low risk" and "inflation free" return on invested capital. Other interest rates more nearly represent "high risk" and "inflated" returns on invested capital. NCHRP Report 146 [49, pp. 15-17] discusses the problem of determining the appropriate discount rate for transportation projects, finally recommending an eight percent "social rate of discount" to reflect the opportunity cost of capital. NCHRP Report 133 [4] recommends extremes of six and ten percent; Buffington and McFarland [5, p. 52] decide on eight percent, as a compromise between the extremes. The AASHTO Redbook [6, pp. 14-15] suggests that a discount rate of four to five percent, for data expressed in constant dollars, appropriately reflects taxpayers' opportunity cost of capital used in public projects of average risk. Research by Citibank of New York [50, p. 9] indicates that the real interest on capital has hovered between two and four percent between 1950 and 1973; consequently, SEMTA recommends a four percent rate [51]. McFarland, et al. [23, pp. 81-86] examine numerous recommendations and practices and conclude that a discount rate of **four** to five percent is appropriate for public projects. A 1962 survey [52, p. 130] gives a distribution of rates used by a sample of a 64 highway agencies:

INTEREST RATE (%)	AGENCIES USING (%)
0.0	20
0.1 - 3.9	22
4.0 - 5.9	45
6.0 - 7.0	13
above 7.0	0

The results of a 1973 survey [33, p. 68] roughly correspond to those of the earlier survey; rates used by sampled agencies range from zero to ten percent, with most agencies using rates between five and seven percent. A 1974 survey [43, p. 22, Table 3] found the median discount rate to be seven percent, although many agencies used a rate of ten percent. More specific examples include Alabama [46, p. 20-52], which uses a zero percent rate for discounting future maintenance costs, and the above-mentioned federal highway safety needs study [48, p. V-25] that used a ten percent rate.

In light of the above discussion, as well as the preceding discussion on use of an inflation rate in present value calculations, it is recommended that a discount rate of between four and five percent be used in calculating the present values of benefits and costs in HEEM. A discount rate higher than this implicitly includes an inflation rate [6, pp. 24-26]. Also, a relatively high discount rate, such as the one currently being used in the HEEM, tends to penalize highway improvements that yield more of their benefits in the later years of the analysis period. Thus, longer-run solutions to transportation problems may not be implemented.

Diversion Speeds

The HEEM assumes diversion speeds of 25 miles per hour on rural roads and 15 miles per hour on urban roads for all traffic projected to be diverted from primary and alternate routes during the planning horizon [3, p. 2]. The HEEM Guide is unclear as to whether the diversion route is always located within the travel corridor. Also, both the rural and urban diversion speeds are assumed to be less than the speed on facility types specified in the model [3, p. 9]. Last, the diversion route is assumed to be a conventional two-lane highway which is a circuitous and less attractive route than the primary route or the alternate route being evaluated.

All of the above assumptions are questionable and need more supporting data to prove them to be realistic. As far as the first assumption is concerned, the assumed speeds appear to be low, if a conventional two-lane highway (state or farm to market type) is the diversion route. According to the highway statistics compiled by Federal Highway Administration [53], the average speed of all vehicles combined on rural secondary highways was 51.7 miles per hour in 1975. The average speed on secondary urban highways was 39.4 miles per hour. These speeds were calculated from data furnished from several unspecified states. In Texas, the average speed on 11 secondary rural highways was 59.9 miles per hour in 1978.[1] No secondary urban highways were monitored at that time.

[1] Furnished by the Planning Services Section of the Transportation Planning Division of the SDHPT.

Granted these are free flow speeds and represent only a small sample of secondary highways (not county roads) having varying traffic volumes and capacities, but they do indicate that additional study of diversion route speeds probably is warranted.

As for the second assumption, it has a direct bearing on setting the assumed speeds. Assuming that the speed on the diversion route must be lower than the speed on the primary and alternate routes does not seem logical. Motorists probably switch from the primary route to the alternate and subsequently to the diversion route because they think they can make better time. However, they probably wouldn't switch from the primary facility as soon as the HEEM assumes they would [1, Exhibit 5], and the same would be true for the alternate route. The switch from the primary route to the alternate route would more likely occur closer to the time when the primary route is approaching capacity or severe congestion. This same sequence would be followed in choosing between the alternate and diversion routes. The HEEM has motorists switching to the alternate route with a less than 35 miles per hour speed when speed on the primary route has dropped only slightly below 60 miles per hour. Then, it has motorists switching back to the primary facility with a speed of about 55 miles per hour when the speed on the alternate route has dropped only about five miles per hour. Next, HEEM has motorists switching back to the alternate route until it reaches capacity or is severely congested. It is at that time that motorists will divert to another route, the speed of which must be lower than the speed at capacity on the alternate route. Such a sequence is overly simplistic and HEEM probably could be improved by developing a more detailed route choice model that explicitly considers characteristics of alternative routes in allocating forecasted traffic among routes at each level of corridor traffic.

PROCEDURES FOR UPDATING KEY ASSUMPTIONS AND UNIT COSTS

The key assumptions and unit costs used by any benefit-cost procedure, such as the HEEM, should be updated almost continuously in order to furnish accurate outputs, i.e. economic measures (EM's), benefit-cost (B/C) ratios, etc. There are three reasons for updating unit costs:

(1) Correct for changes in the general price level (inflation),

(2) Correct for changes in relative prices of the specific elements determining each unit cost, and

(3) Correct for changes in the unit costs brought about by technological innovations.

Updating for changes in the general price level should be performed on a continuous basis. Updating for relative price changes between cost elements should be performed about every two or three years. Updating for technological changes should be performed about every 10 years. The updating procedures for unit costs are limited to changes in general and/or relative prices.

The reasons for updating the HEEM assumptions vary from only a change in the general price level to only a change in the average daily traffic (ADT). General procedures for coping with these changes are presented below.

Values of Time

The HEEM equations presented in the Programmer's Supplement [2, p. 7] use values of time which were updated to the January 1975 general price level, as reflected by the composite Consumer Price Index (CPI) for the United States (U.S.). Since the model assumes that the values of time will escalate with this index, it is implied that model users should also use the same index to update the assumed values of time. HEEM used the CPI to update both the unit values of time for occupants of passenger vehicles and drivers of commercial vehicles (trucks and buses) now being used by the model.

The AASHTO Redbook [6] used the composite U.S. CPI index to update its unit values of time for occupants of passenger vehicles and used the U.S. Wholesale Price Index (WPI) for industrial commodities to update its unit values of time for drivers of commercial trucks and buses. The Redbook also updated its values of time to January 1975.

Buffington and McFarland [5] updated their unit values of time to January 1975 by using appropriate income series for Texas only. They used annual personal per capita gross income (reported by the U.S. Bureau of the Census) to update the unit values of time for occupants of passenger vehicles and used average hourly income for production workers (reported by the U.S. Bureau of Labor Statistics) to update the values of time for drivers of commercial trucks and buses. Buffington and McFarland used income series because the values of time are more highly related to income levels than to the general price level.

Changes reflected by the two income series compared to changes reflected by the two national price indexes can be considerably different over a period of five or more years, especially if the two income series for Texas are used. For example, the differences in changes in the income series and the price indexes occurring between 1969 and 1975, a six year period, is about 15 percentage points. The CPI understated the change in personal per capita income by 16 percentage points, and the WPI overstated the change in the average hourly wage for production workers by 14 percentage points. If an overall CPI or WPI for Texas was available for use, the difference in Texas could be averaged and used to more nearly reflect changes in general price level in Texas. Unfortunately, the CPI and WPI are not computed for individual states.

The CPI and WPI are more appropriate for use in adjusting for inflation or changes in the general price level, especially on a continuous basis. However, the appropriate income series should be used periodically, every two or three years, to adjust the values of time to more nearly reflected actual income levels in Texas.

The use of the U.S. CPI and WPI does offer the advantage of being published (by the U.S. Bureau of Labor Statistics) more frequently than the personal income data. In fact, CPI and WPI are published monthly, and the unit values of time can be updated continuously, with only a month's lag required. Also, the CPI and WPI, or some component thereof, are even more suited for updating vehicle operating and accident costs than for updating values of time cost. Therefore, it is recommended that such indexes be used to keep all unit costs, including values of time, adjusted for inflation.

The formulas to use in obtaining the updating multipliers for each value of time are as follows:

(1) Multiplier of passenger vehicle occupants = $\dfrac{\text{CPI for all commodities at latest date reported}}{\text{CPI for January 1975}}$

(2) Multiplier for drivers of commercial vehicles and buses = $\dfrac{\text{WPI for industrial commodities at latest date reported}}{\text{WPI for industrial commodities for January 1975}}$

The CPI and WPI, based on 1967 = 100, for January 1975 were 156.1 and 167.5, respectively.

Updating unit values of time to reflect relative price changes or changes in technology will require new base studies similar to those conducted to derive the presently used values of time. This would be especially true in the case of unit values of time for drivers of commercial vehicles. To get some idea of the type of studies that were made to estimate the value of time for occupants of passenger vehicles, the reader is referred to studies conducted by Thomas [7] and Lisco [8]. Adkins, Ward, and McFarland [9] conducted a study to estimate values of time for drivers of commercial vehicles.

Using the "willingness to pay" and "cost of travel time" methods, Thomas and Lisco surveyed commuters in passenger cars who chose a toll road instead of a free alternate route to establish commuters' values of time. The primary variables used to determine route choice were changes in travel costs (toll fee), travel times, and traffic impedances. Regression coefficients were generated for each of these variables, and then the value of time was determined by <u>dividing</u> the coefficient for change in travel time <u>by</u> the coefficient of change in travel cost. Later, Thomas and Thomson [13] developed different values of time as a direct function of traveler income.

Using the "cost savings" and "revenue" methods, Adkins *et al*. collected cost and travel time data on a sample of regulated truck and bus carriers obtained from Interstate Commerce Commission (ICC) reports to establish the value of time for drivers of commercial vehicles. The value of time savings components used in the model were: (1) interest, (2) depreciation, (3) property tax, (4) driver wages, (5) driver's welfare, (6) workmen's compensation, and (7) social security (employer's cost). The value of an hour saved for each of these components was calculated and added together to arrive at the value of time saved.

As can be seen from above, considerable data must be collected and analyzed to truly update unit values of time, especially for drivers of commercial vehicles. This type of updating is overdue since over ten years have passed since these base studies were conducted.

Vehicle Operating Unit Costs

The HEEM equations, as reported in the Programmer's Supplement [2], have updating factors which were used to update the assumed vehicle operating costs (cycling and running costs) from January 1975 to August 1975. These factors are based on changes in an unspecified price index during this short period of time. Thus, the HEEM manual implies the need to continuously update HEEM's vehicle operating costs, which are in 1975 prices, based on changes in a price index.

HEEM running cost curves are derived from vehicle operating cost information obtained from the new AASHTO Redbook [3, p. 10]. The vehicle operating costs represent January 1975 prices. HEEM cycling cost curves are derived from Winfrey's book [18] which was published in 1969 [8, p. 11]. Documentation indicates that HEEM's cycling costs represent 1975 prices, but the updating procedure is not specified. In all probability, the CPI was used.

To update the HEEM vehicle operating unit costs for changes in the general price level, one component of the national or local CPI and one component of the national or local WPI should be used. For updating operating costs for passenger cars, the private transportation component of the CPI is the most relevant index to use. For updating operating costs for trucks and large buses, the industrial commodities component of the

WPI should be used. The formulas to use in obtaining the general price level updating multipliers (factors) for each vehicle type are as follows:

$$\text{(1) Multipliers for Passenger Cars} = \frac{\text{CPI for private transportation at latest date reported}}{\text{CPI for private transportation for January 1975}}$$

$$\text{(2) Multipliers for Trucks and Buses} = \frac{\text{WPI for industrial commodities at latest date reported}}{\text{WPI for industrial commodities for January 1975}}$$

The AASHTO Redbook also recommends this approach. Using a base of 1967 = 100, the private transportation component of the CPI was 142.2 in January 1975 and the industrial commodities component of the WPI was 167.5.

After two or three years have passed, which has been the case with the HEEM, the vehicle operating unit costs should be adjusted for relative price or nonproportional changes. Since the overall vehicle operating unit costs used by HEEM are made up of several components priced separately in the market place, such an adjustment is necessary. For example, the components of vehicle operating unit costs used by the HEEM are as follows: (1) fuel costs, (2) maintenance costs, and (3) depreciation. During a two or three year period, the cost of fuel components may have experienced a greater percentage increase than the other two components. If such be the case, then each cost component should be adjusted separately, using the appropriate price index. Also, since each component represents a greater or lesser share of the total vehicle operating unit cost, an adjustment must be made to keep the correct proportions between the components before arriving at an overall updating multiplier for a particular driving condition and vehicle type.

The AASHTO Redbook provides updating multiplier formulas which perform both of the above adjustments [6, p. 137-139]. The coefficients in these formulas are based on the average percentage of total running cost allocated to each cost component computed as of January 1975 and the corresponding January 1975 index value. At that time, fuel costs comprised about 28 percent of the total passenger car running costs on level tangents and the corresponding CPI component index for gasoline (regular and premium) was 160.2. The coefficient for this fuel component is obtained by dividing .28 by 160.2 which equals 0.0017. A similar computation must be made for each cost component and the resulting answers added together to derive the overall updating multiplier for passenger cars driven on level tangents.

Using the appropriate coefficients from the Redbook, the formulas that can be used to derive updating multipliers for the HEEM are presented in Table 13. A formula is given for each driving condition and vehicle type used by the HEEM. Since the HEEM uses only one truck type, the coefficients in the formulas are averages of the corresponding Redbook coefficients for single-unit and 3-52 combination trucks, weighted in the proportion of 34.7 percent single-unit trucks and 65.3 combination trucks.

The latest CPI and WPI should be used in the updating formulas appearing in Table 13. Then, the updating multipliers derived from those formulas are applied in the HEEM equations to the appropriate 1975 tangent running or cycling unit costs to obtain the corresponding updated unit costs.

Table 13. Multiplier Formulas for Updating 1975 Vehicle Operating Unit Costs, by Highway Condition and Vehicle Type.

Highway Condition and Vehicle Type	Updating Multiplier Formula[a,b,c]			
	Multiplier	Fuel	Maintenance	Depreciation
Running Costs (on Level Tangent)				
Passenger Cars	M	= $0.0017\ CPI_F$ +	$0.0016\ CPI_M$ +	$0.0032\ CPI_D$
Trucks	M	= $0.0015\ CPI_F$ +	$0.0020\ CPI_M$ +	$0.0014\ CPI_D$
Cycling Costs (Speed Changes and Stopping)				
Passenger Cars	M	= $0.0022\ CPI_F$ +	$0.0001\ CPI_M$ +	$0.0017\ CPI_D$
Trucks	M	= $0.0011\ WPI_F$ +	$0.0002\ CPI_M$ +	$0.0005\ WPI_D$

[a]The truck coefficients are averages of the corresponding coefficients for single-unit and 3-52 combination unit trucks, weighted as 34.7 percent single-unit and 65.3 percent combination unit trucks.

[b]CPI_F = Consumer Price Index, private transportation, regular and premium gasoline.

CPI_M = Consumer Price Index, private transportation, auto repairs and maintenance.

CPI_D = Consumer Price Index, private transportation, automobiles, new.

WPI_F = Wholesale Price Index, diesel fuel for commercial users.

WPI_D = Wholesale Price Index, motor trucks.

[c]Adopted from the new AASHTO Redbook [6].

The coefficients in the above formulas should be acceptable for use for about 10 years or until the proportion of total vehicle operating costs among the separate components has changed significantly. Technological changes could bring about a significant shift in the proportion of vehicle operating costs among the separate component costs. Therefore, new base studies should be conducted about every 10 years to update the assumed costs.

Accident Costs

The HEEM uses 1974 accident unit costs in its equations which were developed to calculate annual accident costs. No provision was made in these equations for updating such unit costs. The equations only provide an inflation factor to increase the base year unit costs by the assumed inflation rate for future years.

The new AASHTO Redbook used the national CPI to update accident unit costs [6, p. 139]. Buffington and McFarland used appropriate components of the national CPI to update accident unit costs [5, p. 23-25]. For fatal and injury accident costs, they used the medical care component of the CPI. For property-damage-only accident costs, the automobile repairs and maintenance component of the CPI was used. The national indexes were used since no comparable state indexes were available.

The national CPI or an appropriate component thereof can be used to update the HEEM's current general price levels. The AASHTO Redbook recommends this approach [6, p. 139]. The Redbook suggests that U.S. Census income statistics could be used for updating fatal and injury accident unit costs. As was indicated earlier in this report, income statistics do not lend themselves as well to a continuous updating procedure as do the national price indexes.

The overall CPI is recommended for updating the HEEM's 1974 accident unit costs for the first two to three years, at the most. Since these unit costs have not been updated in five years, they should be updated with relevant component indexes of the CPI. For fatal and injury unit costs, automobile insurance rates components should be used. For property damage unit costs, the automobile repairs and maintenance cost components should be used. The formulas to use in obtaining updating multipliers for each type of accident unit costs are as follows:

$$\text{(1) Multiplier for fatal and injury accidents} = \frac{\text{CPI for automobile insurance rates at latest date reported.}}{\text{CPI for automobile insurance rates for 1974 (annual index)}}$$

$$\text{(2) Multiplier for property damage only} = \frac{\text{CPI for auto repair and maintenance at latest date reported}}{\text{CPI for auto repair and maintenance for 1974 (annual index)}}$$

The automobile insurance rates index for 1974, based on 1967 = 100, was 137.5, and the automobile repair index was 123.1.

The formula for a general price level multiplier for all accident unit costs is as follows:

$$\text{(3) Multiplier for all types of accidents} = \frac{\text{CPI for all commodities at latest date reported}}{\text{CPI for all commodities for 1974 (annual index)}}$$

The latest available indexes should be used to calculate the above updating multipliers. Then, the updating multipliers can be used in the HEEM equations to calculate current accident costs.

Like the other user unit costs used in the HEEM, accident unit costs change not only due to inflation or general price level changes but also due to other factors, such as changes in the design of motor vehicles, design and condition of roads, and incomes of the vehicle occupants. Therefore, about every 10 years new accident cost base studies should be conducted to update accident unit costs for these factors. Some of the base studies still in use are already over 10 years old. Therefore, the time has come for new studies to be conducted.

Truck Percentage

The percentage of trucks, on the types of highways analyzed by the HEEM, needs updating periodically using trend or current data obtained from the SDHPT's Roadway Information System File. The trendlines shown in Figure 5 are based on this data source. Each trendline represents the percentage of trucks of the ADT on a particular highway as of 1951, 1960, and 1975.

The data shown in Figure 5 were collected from 11 manual count and loadometer stations. If annual data are available, a three year moving average can be computed and used as the trendline. The data should be grouped by highway type and location (urban and rural) before computing the trendlines. By projecting these trendlines into the future, say 10 years, the analyst can select a more realistic percentage of trucks for each highway type used in the HEEM.

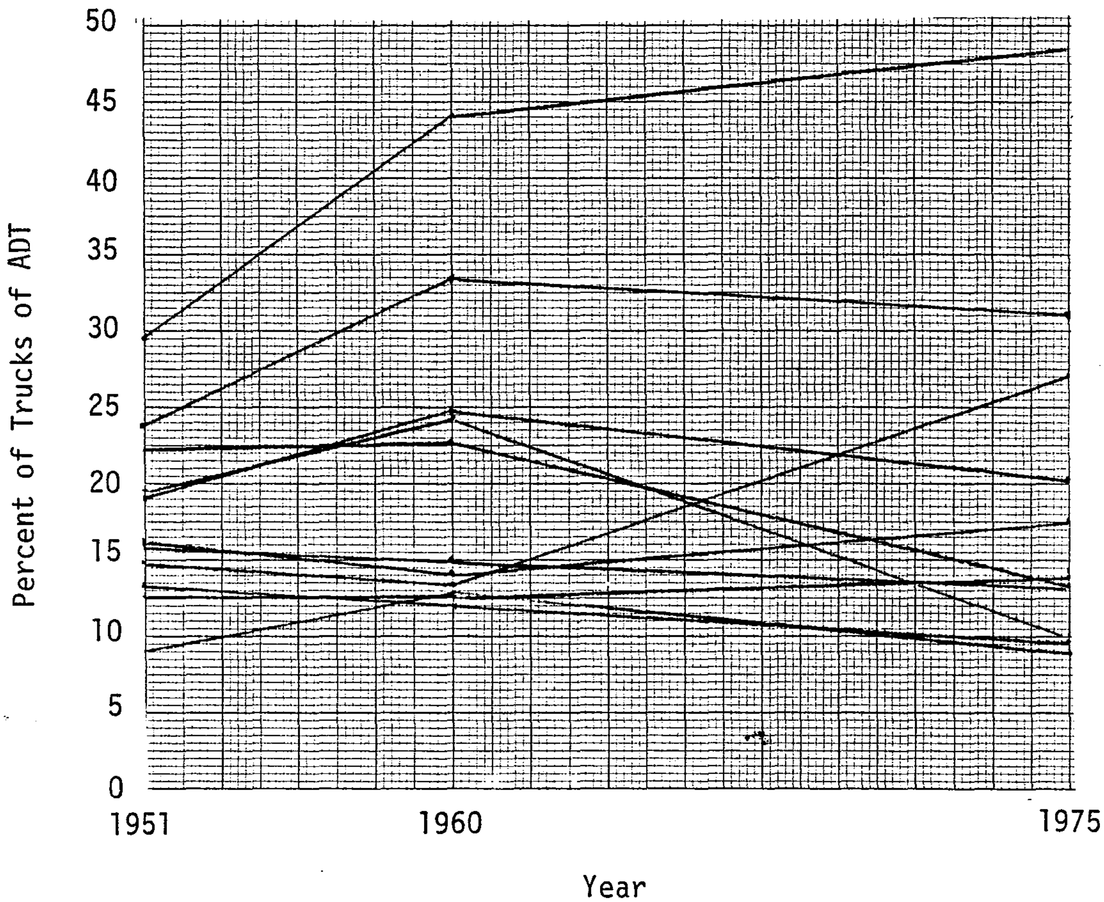


Figure 6. Percent of Trucks of Average Daily Traffic (ADT) on Various Highways as of 1951, 1960, 1975.

Inflation Rate

As is pointed out earlier in the report, one of the problems encountered when estimating a proposed highway project's future benefits and costs in current dollars is the difficulty of choosing an inflation rate for the planning horizon of the project. Predictions of the inflation rate even for one year into the future can be off several percentage points. However, over a 20 year period, the average inflation rate assumed is not likely to follow a general trend. For this reason, it is important to use historical trend data to predict the future inflation rate assumed in the HEEM. At least eight years of data are necessary to establish a reasonable long-run trendline for predictive purposes.

The general indicators of inflation are the CPI, WPI, and the Gross National Product Implicit Price Deflator (IPD). The relationships among these indicators are very close. For example, in establishing procedures for calculating the Texas Highway Cost Index, the SDHPT found that the correlation coefficient for the CPI and IPD is 0.9995 out of a possible 1.0 for the years 1968 through 1977 [53, p. 4-5].

It is not clear which of the above inflation indicators was used by the HEEM authors to decide what level of inflation to assume in the model. But a three year moving average of the selected inflation indicator is shown graphically as supporting evidence for assuming an inflation rate of eight percent for the 1975 planning cycle [3, p. 6].

The CPI is recommended for use in generating data upon which to predict the inflation rate to be assumed in the HEEM. The actual between-year changes or a three-year average of the between-year changes were calculated for each year, using 1971-1979 (approximation) data. These between-year changes are shown graphically in Figure 7. As can be seen,

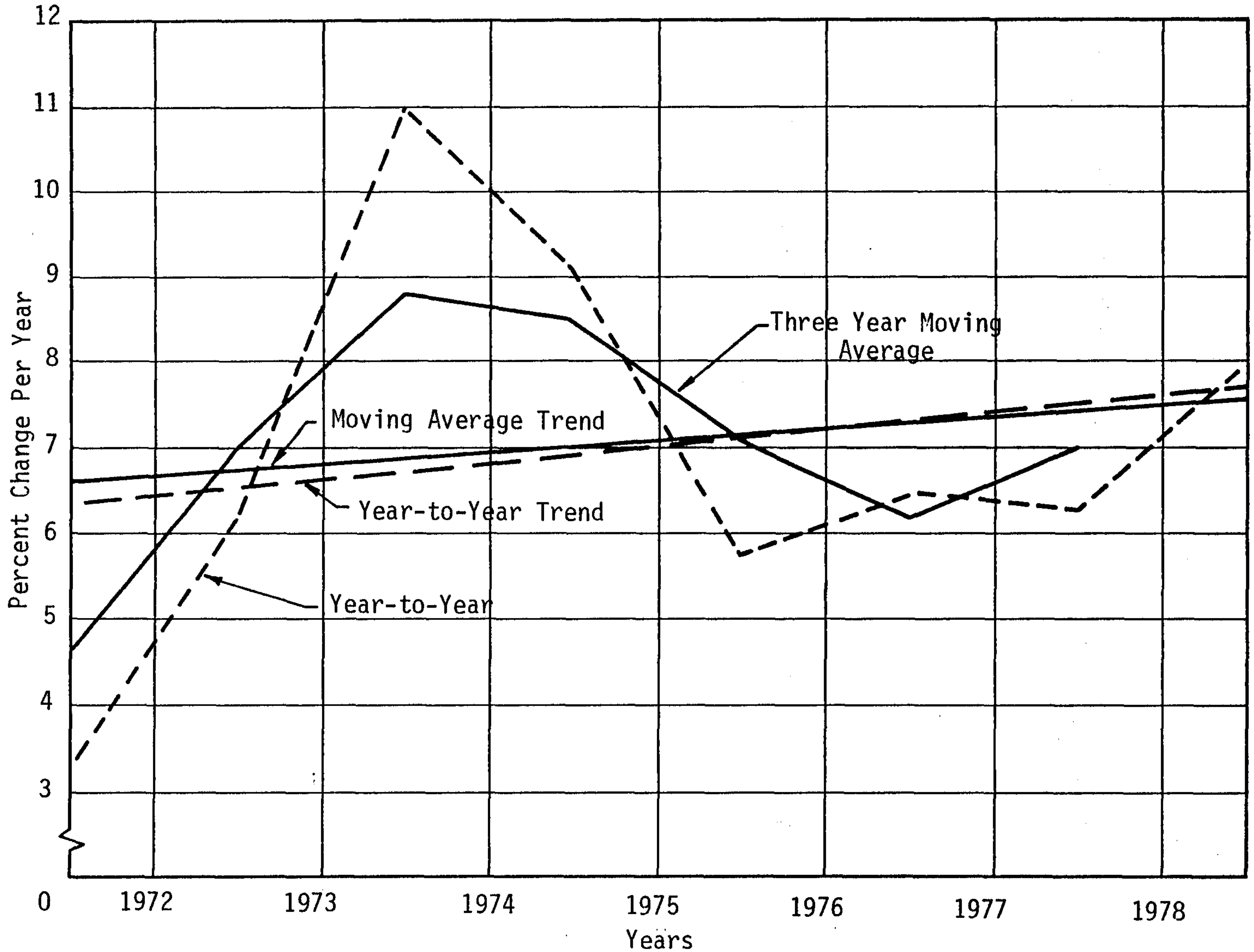


Figure 7. Annual Percentage Change in the U.S. Consumer Price Index (CPI) from 1971 to 1979.

the three-moving average changes don't fluctuate as much as the actual year-to-year changes. Therefore, the former is recommended for predictive purposes. Actually, it doesn't make much difference which is used to draw a trendline for use in predicting the future inflation rate.

A freehand trendline can be drawn across the graph to match the data points as closely as possible. However, it is better to use a simple regression equation to generate the constant value and regression coefficient to use in plotting the trendline and predicting the future inflation rate. This was done for both sets of data points, using the following regression equation:

$Y = A + BX$, where

Y = Predicted inflation rate (percent) for year X

A = Constant value (at half way point between 1971 and 1972),

B = Regression coefficient (change in Y for each unit change in X), and

X = Number of years after mid-1971.

The constants and regression coefficients for use in calculating the inflation rate, in percent per year are as follows:

Type of Data Used	Constant Value	Regression Coefficient
Year-to-Year Changes	6.14	.1976
Three-Year Moving Average	6.47	.1393

The trendlines, based on the above values, are shown in Figure 7. To forecast the rate in mid-1989, ten years into the future, the predicted inflation rate would be 9.70 percent using year-to-year changes and 8.98 percent using the three-year moving average changes.

The analyst should update the constant values and regression coefficients every two or three years, using the most recent eight years of changes in the CPI. The last year of actual data used in this analysis was 1978.

Construction Cost Escalation Rate

The HEEM assumes an eight percent construction cost escalation rate to adjust the initial base year construction and expansion costs to the year(s) of construction of the proposed highway improvement [3, p. 2]. HEEM describes this rate as the long-term rate of construction cost escalation including inflation and the effects of higher environmental design standards. The assumed rate is the same as that assumed for general inflation. The HEEM authors suggest using the same rate as assumed for inflation, because "there is no historical or theoretical reason for this trend to continue in the long run" [3, p. 7]. They do acknowledge that the two rates have diverged sharply in recent years.

An investigation of the year-to-year changes in the CPI and the Texas Construction Cost Index (TCCI) confirms the post-1972 divergence between the two rates. However, this divergence had closed to within one percentage point by 1979. Therefore, it is recommended that the construction cost escalation rate be the same as the general inflation rate. Every two or three years, the divergence between the two rates should be checked. The SDHPT maintains a Texas Construction Cost Index and a Texas Highway Cost Index

(THCI) and the formulas to predict year-to-year changes in each index [53]. These values can be used to compare with the CPI values generated by the formula suggested in the last section for predicting the inflation rate.

Discount Rate

As is indicated earlier in the report, a 20 percent discount rate is assumed by the HEEM to arrive at the present value of future costs and benefits accruing from a proposed highway improvement [3, p. 8]. The HEEM authors admit that a 20 percent discount rate is somewhat arbitrary and is a substantially high hurdle to generate EM's or benefit-cost ratios greater than 1.0. The 20 percent rate is justified on the grounds of (1) a shortage of funds for constructing a large back log of proposed highway improvements, and (2) ensuring intuitively reasonable benefit-cost ratios or EM's. The discount rate is defined as the minimum anticipated annual return of user benefits on dollars invested in highway construction projects [3, p. 2] or the return associated with the first project the SDHPT would like to build but cannot because of limited funds [1, p. 1-4]. Also, the discount rate is referred to as the time value of money [1, p. 2-9]. The interest rate of six percent paid by a savings bank for the use of an investor's funds is referred to in an example as being the measure of the time value of money.

It is clear from the above discussion that the HEEM authors did not use conventional criteria for selecting a discount rate (especially the 20 percent rate) commonly referred to as the taxpayer's opportunity cost of capital used in public projects. As indicated earlier, the real interest cost on capital has been between two and four percent between 1950 and 1973. The real cost of capital does not include costs due to inflation [55, p. 10]. The AASHTO Redbook also refers to a study by

Hirshleifer and Shapiro [56, p. 5-7] that estimated the real cost of capital at about four percent in recent years for low-risk investments [56, p. 14]. For evaluating highway improvements in Texas, the real rate of discount should reflect the rate at which Texas motorists (and taxpayers) are willing to trade future benefits for present benefits. Thus, a five percent real rate indicates that the average Texas motorist equates $1.00 of benefits now with $1.05 of benefits one year from now (assuming zero inflation). Based on these studies and the AASHTO recommendation it is recommended that Texas use a real discount rate of four to five percent for projects of average risk, with benefit and cost streams calculated in constant dollars. If an eight percent inflation rate is assumed, a discount rate ranging from 12.3 to 13.4 percent is permitable.[1]

A ten-year trend in inflation rates should be observed every two or three years for purposes of updating the nominal discount rate, should Texas not switch to a use of real discount rate. Other studies to update the real interest rate should perhaps be conducted every 20 years or so.

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[1]The nominal rate of interest, i_n, can be calculated from the following formula:

$$(1 + i_n) = (1 + i_r)\,(1 + i_{CPI})$$
$$= 1 + i_r + i_{CPI} + i_n i_{CPI}$$

$$\text{or, } i_n = i_r + i_{CPI} + i_r i_{CPI}$$

where i_r = the real rate of discount, and

i_{CPI} = the annual rate of inflation as indicated by the Consumer Price Index.

In the example with $i_{CPI} = .08$, i_n would equal either .1232 (12.32%) with $i_r = .04$ and .1340 (13.40%) with $i_r = .05$.

The real interest rate, i_r, can be calculated as $i_r = \frac{1 + i_n}{1 + i_{CPI}} - 1$.

Diversion Route Speeds

Additional speed studies are needed to arrive at or update the average diversion route speeds assumed in the HEEM. Statistically reliable samples of the observed speeds of vehicles on all of the highway types used in the HEEM should be taken. Such samples should be taken every year to establish long-term trends in the average speed of vehicles by highway type.

Currently, the SDHPT is monitoring vehicle speeds on various types of highways. However, very little speed data are being collected on urban secondary roads by the SDHPT or cities.

CONCLUSIONS AND RECOMMENDATIONS

This report presents findings of a review of the HEEM's key assumptions and unit costs as well as procedures for updating the model's assumptions and unit costs. It should be stressed again that only the key assumptions, as identified by the HEEM's authors, are reviewed and discussed in this report. Other assumptions need a similar review, among them being: pattern of traffic growth, technical and safety factors for each highway type, design life of highway improvements, procedure for allocating traffic among alternative routes in a corridor, congestion speed, speed of trucks, accident rates, vehicle operating cost/speed relationships, cycling costs based on 10 mile per hour cycles, and maintenance unit costs.

The conclusions and recommendations resulting from the HEEM review and evaluation are presented separately below.

Conclusions

The HEEM provides for a streamlined and systematic approach for evaluating alternative highway improvement projects, including the "no build" alternative. The model provides both an economic and mobility measures for evaluating and comparing alternative highway improvement projects at the corridor highway segment level and at the district or state highway system level. Before implementation of the HEEM in 1975, the SDHPT made only limited use of cost-benefit analyses in evaluating proposed highway projects. Since the HEEM is computerized and assumes many of the required inputs, the data collection and operating costs of the model are not prohibitive to continuous use by SDHPT analysts.

The general weaknesses in the HEEM's key assumptions and unit costs identified in this report are as follows:

1. Applying the same assumed values to all projects regardless of type or location,

2. Using a weak data base to arrive at assumed values,

3. Keeping the evaluation too simple and general,

4. Limiting model to analyze conventional highway projects (exclusive bus lanes and other mass transit alternatives not included),

5. Providing only EM's and mobility measures (measurement of energy use and air pollution not included), and

6. Having only a limited capability for updating the assumptions and unit costs.

The more specific weaknesses in the HEEM assumptions and unit costs are as follows:

1. Using one truck percentage to represent all commercial truck traffic on all types of highways,

2. Using a single value of time for the drivers of buses and commercial trucks,

3. Using only one vehicle occupancy rate regardless of the vehicle type or highway type,

4. Using unit operating costs for only two vehicle types,

5. Using accident unit costs, especially for fatal accidents, that are too low,

6. Using inflation and construction cost escalation factors,

7. Using an arbitrarily high discount rate that favors projects which may provide only short-term solutions to a problem,

8. Using diversion speeds which may be too low and only applicable to one highway type, and

9. Providing no procedures for updating costs, except vehicle operating costs, from January 1975 to the base year of proposed project.

Recommendations

The above weaknesses and data deficiencies dramatize the need to refine the HEEM and to assume more accurate and up-to-date values and unit costs that are adaptable to the specific characteristics of each traffic stream and facility being evaluated. Therefore, the following recommendations are suggested for implementation:

1. Allocate the traffic stream into four vehicle types (passenger cars, single-unit trucks, multiple-unit trucks, and buses) by using a percentage distribution for each highway type,
2. Use unit values of time by the four vehicle types.
3. Use vehicle occupancy rates by passenger vehicle type and highway type,
4. Use vehicle operating unit costs for three vehicle types (passenger cars, single-unit trucks and buses, and multiple unit trucks),
5. Use the accident unit costs recommended in this report,
6. Stop using inflation and construction cost escalation factors to arrive at future costs and benefits attributable to a highway improvement,
7. Use a discount rate based on the real cost of capital for public investments to arrive at the present value of future costs and benefits estimated in current dollars. If the future costs and benefits are inflated by the appropriate inflation factors, then the discount rate should be increased by the amount of the inflation factor, and
8. Use the updating procedures suggested in this report.

The findings of this report indicate the need for further research to finish the evaluation on the HEEM and to generate assumed values and unit costs from a reliable data base which reflect changes in technology over the past 20 years. Therefore, the following research is recommended:

1. Evaluate the HEEM assumptions not covered in this report,

2. Establish new values of time in urban and rural areas based on the amount of time saved and level of income of users by vehicle type,

3. Establish new vehicle operating costs by type of vehicle, type of highway, and level of service,

4. Establish accident costs in urban and rural areas by type of accident and type of vehicles involved,

5. Relate land use changes to traffic volume changes documented on previously studied projects and determine how such data can be used to select the proper corridor traffic growth rate used in the HEEM, and

6. Determine the proper fuel consumption and air pollution factors to incorporate into the HEEM to provide additional project evalutation measures.

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