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| 16. Abstract The increasing importance of improving the efficiency of transportation facilities has resulted in a need for a systematic economic model to evaluate High Occupancy Vehicle (HOV) projects. These projects encourage higher vehicle occupancy rates by restricting the use of some portion of the facility to some vehicle types or minimum number of occupants. This report examines the feasibility of using the Texas Highway Economic Evaluation Model (HEEM) to evaluate HOV projects. Three major deficiencies are examined: limited variety of highway types, assumptions in the model, and method of allocating corridor traffic to specific routes within the corridor. Additional highway types are recommended to evaluate HOV projects, along with parameter specifications for those highway types. Changes in the assumptions of the model include percent trucks, the occupancy rates, value of time, and future vehicle demand. The allocation of corridor traffic is an important aspect of evaluating HOV projects as well as other types of highway projects. An alternative allocation method is presented which is based upon minimized total user costs. This method results in corridor allocation such that the marginal user costs for each route in the corridor are equal. User cost functions are derived, based upon the user cost calculations in the HEEM, which can be used to allocate corridor traffic for any number of routes within the corridor. Recommended programming changes to the HEEM are presented to implement HOV analyses. This includes the marginal cost allocation method, and recommended values for (continued on back side) | | | | | |
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THE EVALUATION OF HIGH OCCUPANCY
VEHICLE PROJECTS IN THE HEEM

by

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PREFACE

The authors wish to express appreciation to those who have assisted in this study. Special acknowledgement is due Mr. James W. Barr and Mr. James R. Farrar of the Texas State Department of Highways and Public Transportation (SDHPT). Mr. Hans C. Olavson of the Houston-Galveston Regional Transportation Study Group of the SDHPT was also helpful in providing data. Special thanks should go to Mr. Eric Schulte for the preparation of the graphs and the flow chart in this report.

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 increasing importance of improving the efficiency of transportation facilities has resulted in a need for a systematic economic model to evaluate High Occupancy Vehicle (HOV) projects. These projects encourage higher vehicle occupancy rates by restricting the use of some portion of the facility to some vehicle types or minimum number of occupants.

This report examines the feasibility of using the Texas Highway Economic Evaluation Model (HEEM) to evaluate HOV projects. Three major deficiencies are examined, limited variety of highway types, assumptions in the model, and method of allocating corridor traffic to specific routes within the corridor.

Additional highway types are recommended to evaluate HOV projects, along with parameter specifications for those highway types. Changes in the assumptions of the model include percent trucks, the occupancy rates, value of time, and future vehicle demand.

The allocation of corridor traffic is an important aspect of evaluating HOV projects as well as other types of highway projects. An alternative allocation method is presented which is based upon minimized total user costs. This method results in corridor allocation such that the marginal user costs for each route in the corridor are equal. User cost functions are derived, based upon the user cost calculations in the HEEM, which can be used to allocate corridor traffic for any number of routes within the corridor.

Recommended programming changes to the HEEM are presented to implement HOV analyses. This includes the marginal cost allocation method, and recommended values for the assumptions in the model as they relate to HOV projects.

SUMMARY OF FINDINGS

The HEEM was examined to determine the feasibility of its use in analyzing High-Occupancy Vehicle (HOV) projects. The program itself was examined along with the assumptions in the input and output data.

The findings are summarized as follows:

1. The HEEM cannot currently analyze HOV projects for a number of factors.
 - a. The HEEM can analyze only those highway types contained in HEEM's Highway Specification Table. There are no freeway highway types which have less than 4 lanes or contain an odd number of lanes. This would eliminate any consideration of most HOV treatments.
 - b. Some of the input assumptions for the HEEM are not appropriate for HOV analyses, including constant percent trucks, occupancy rates, and values of time.
 - c. The current method of allocating traffic in the HEEM program would seriously distort any HOV analysis, putting too many vehicles on the HOV lane(s) when the unrestricted lanes congest.
2. An alternative marginal cost allocation method was derived, with the following features.
 - a. The allocation procedure is based upon minimizing total user cost. Corridor traffic is allocated such that the marginal user cost for each corridor route are equal.

- b. HEEM's cost calculations were used to derive a total user cost function, with some approximations and modifications necessary to convert those calculations into smooth continuous cost functions. Those approximations include the speed-volume relationship, vehicle running costs, speed change cycles on metered freeways, and accident costs.
 - c. A total yearly user cost function was formed based upon average daily traffic (ADT).
 - d. A yearly marginal user cost function was derived, along with an approximation which could be manipulated in the HEEM.
3. Recommended specifications and assumptions for analyzing HOV projects were presented, including the following.
- a. Five HOV highway types are recommended for inclusion in the Highway Specification Table.
 - b. Parameters for each HOV highway type are presented, including values for average speeds and ADT volumes, the number of speed change cycles per vehicle mile, the number and mean cost of accidents, and the annual maintenance costs.
 - c. Variable assumptions are recommended, including percent trucks, values of time, and occupancy rates. In addition, the assumption of a constant corridor vehicle demand should be changed to a constant corridor person demand.

IMPLEMENTATION STATEMENT

This report relates the findings of the feasibility of the Highway Economic Evaluation Model (HEEM) to evaluate High Occupancy Vehicle (HOV) projects. Changes are proposed to the HEEM which will enable HEEM users to perform an economic evaluation of HOV projects. The findings can be implemented immediately to provide estimates for proposed HOV projects.

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INTRODUCTION

Purpose and Objective of Study

The near completion of the Interstate Highway System and an increasing shortage of funds has caused highway agencies to examine methods to increase the efficiency of existing facilities rather than relying exclusively on new location construction or adding additional lane capacity to existing facilities.

An important method which is receiving considerable attention is priority treatment of High Occupancy Vehicles (HOV). This generally involves reserving the use of one or more lanes of a facility for certain types of vehicles or vehicles with a minimum number of occupants. The period of operation for these reserved lanes may be continuous or may involve only certain peak hours.

This report examines three major HOV treatments applicable to freeway systems, including contraflow lanes, concurrent flow lanes, and separate HOV facilities. Some mixed results have been obtained thus far from HOV projects in different parts of the country. A number of projects have not attained the desired results and as a consequence have been substantially modified or abandoned. TTI Research Report 205-1 [2] contains a summary of those results.

It is therefore important to evaluate proposed HOV projects on the basis of the benefits and costs the project will generate before it is implemented. The Texas State Department of Highways and Public Transportation (SDHPT) has a computerized model named the Highway Economic Evaluation Model (HEEM) used to calculate benefits and costs

for a proposed highway construction project. However, HEEM is not currently capable of evaluating HOV projects. This report examines the limitations in HEEM for evaluating HOV projects and recommends changes which will allow the HEEM to adequately evaluate HOV projects.

The specific objectives of this study are as follows:

- (1) Determine the assumptions and data requirements to use the HOV lane alternative in the HEEM model.
- (2) Recommend the unit costs, occupancy rates, traffic volumes (rider demand) and vehicle frequency distributions that should be assumed.
- (3) Determine program alterations and calculations which would have to be performed to produce unbiased user costs of the HOV lane alternative.

HOV Alternatives to be Considered

The HEEM is designed to evaluate large new location construction projects and improvements which add additional lanes to existing capacity. Within that type of analysis, three types of HOV projects are most appropriate for HEEM analysis, contraflow lanes, concurrent flow lanes, and separate HOV facilities. A contraflow lane involves reserving one lane of the off-peak direction of travel for exclusive use of HOV vehicles traveling in the peak direction. A concurrent flow lane is a designated lane in the peak direction for exclusive use of HOV's which is not physically separated from the other lanes.

A separate HOV facility involves a physically separate lane or lanes for exclusive use of HOV's.

Contents of Report

The report contains three major sections. The first section examines the limitations in the current HEEM program which prevents it from being used, without changes, in evaluating HOV projects. The general areas examined include the limited highway types, the assumptions in the model, and the current allocation method.

The second section derives a method of allocating traffic based upon minimizing total corridor user costs. The total user cost function is derived using approximations of HEEM's user cost calculations. Marginal user cost functions are then derived which are used to allocate corridor traffic.

The third section recommends several HOV highway types as well as the specification of parameters for these highway types. Recommended values for some key assumptions are also presented, including values for the traffic mix, values of time, and occupancy rates.

HEEM'S LIMITATIONS IN EVALUATING HOV PROJECTS

The HEEM was designed to provide a streamlined, systematic, benefit-cost evaluation of major conventional highway construction projects along a particular highway segment or a whole highway system. The basic input is average daily traffic volume (ADT) and changes in user costs are calculated for both new location construction and additional lane capacity to existing facilities. However, HOV projects are generally designed to increase the efficiency of the facility rather than the capacity, and possibly for that reason were not included as potential highway projects for evaluation with the HEEM.

It is becoming increasingly apparent, however, that a HEEM type of evaluation should be performed, in view of the difficulties throughout the country in successfully implementing HOV treatments. If the HEEM can be modified to evaluate HOV projects, a systematic and objective analysis could be performed on proposed HOV treatments before they are implemented. However, a number of limitations in HEEM must be addressed before such analyses can be performed.

Limited Highway Types

HEEM is limited to evaluating highway types in its specification table. The Highway Specification Table (HST) gives relevant parameters for each of 41 different highway types, including speed and volume relationships, and cost parameters including accident costs and maintenance costs. The table contains a variety of highway types

and speed limits including 2, 4, and 6 lane divided and undivided rural and city streets; 2, 4, and 6 lane rural and urban expressways; 4 through 16 lane urban freeways including metered freeways; and 4 through 12 lane rural freeways. But the table does not provide for a one-lane route such as an HOV lane, nor an odd number of lanes which may occur for the unrestricted portion of the facility.

In addition the HST's parameters for vehicle speeds and volumes, number and costs of accidents, etc. could be significantly different from those observed on conventional facilities. Studies of HOV treatments have found some significant differences for some of these parameters and those differences should be incorporated into any additions to HEEM's Highway Specification Table [1,2].

Assumptions in the Model

It would not be sufficient to simply add additional highway types to the HST to encompass HOV treatments. The HEEM assumes a corridor vehicle demand which is independent of the transportation facilities in the corridor. That assumption is questionable in many highway projects, especially for HOV projects, since one of the objectives of these projects is to reduce vehicle congestion by increasing occupancy rates, resulting in reduced vehicle volume.

Another problem involves the "key" assumptions in the HEEM. These are parameters used in the cost calculations which the HEEM user can specify or default values are provided by the model if not specified. TTI Research Report 225-8 [3] examines each one of the assumptions in detail, but two assumptions are especially critical in

evaluating HOV projects. They are the percentage trucks; and the value of time, which includes an implicit occupancy rate.

The HEEM can evaluate user costs for only two vehicle types, cars and trucks. When an assumed percentage truck is specified, that same percentage applies to all routes in the corridor being evaluated. A constant vehicle distribution is clearly not appropriate for HOV projects where a far different vehicle distribution would generally occur.

A similar situation is present in the assumptions for the value of time. A separate value of time can be specified for both cars and trucks, but that same value is used for all corridor routes. Implicit in the time values are assumed occupancy rates. The default values for time in the HEEM assume a 1.3 occupancy rate for cars and 1.0 occupancy rate for trucks. A constant occupancy rate for all corridor routes would negate the major benefits of HOV projects which are specifically designed to encourage higher occupancy rates.

This is especially evident in calculating bus user costs. The operating costs of a bus may be sufficiently similar to a large truck that a separate vehicle category for buses may not be necessary in evaluating HOV projects with the HEEM. However, the value of time for the average bus passenger would not be similar to that of an average truck driver, and certainly the average occupancy rate for a bus would be far higher than 1.0. A variable value of time and occupancy rate must be incorporated into the HEEM in order to evaluate HOV treatments.

Method of Allocating Traffic

Perhaps the most difficult problem using the HEEM for evaluating HOV projects is the current HEEM method uses for allocating traffic to each route within the corridor. Obviously, one of the critical factors in HOV projects is the vehicle utilization of the restricted lane(s). The HEEM uses as an input the projected corridor ADT for some future year, and then calculates the projected ADT for each intervening year using either a constant growth rate or a declining growth rate formula [4].

The HEEM has the capability to evaluate the user costs of up to three different routes within a given corridor, including a proposed route, an existing route (if any), and an alternate route (if any). Any excess traffic above the combined capacities of the specified routes is assigned to an unspecified diversion route. This is done in order to calculate the change in costs resulting from the proposed project based upon the projected traffic on each route.

The HEEM uses a very simple method to allocate corridor traffic. The route with the highest vehicle capacity receives all the corridor traffic up to its congestion point, or breakpoint as it is referred to in the Guide to the HEEM [5]. The breakpoint varies for most routes but it is about 50 percent of capacity ADT on city streets and about 75 percent on rural streets. For rural divided highways and freeways the percentage is about 60 percent, compared to about 65 percent for urban expressways and freeways.

After the breakpoint for the highest capacity route is reached, all unallocated corridor traffic is then allocated to the next highest capacity route up to its breakpoint. This process continues until all routes being examined in the corridor have allocated traffic up to the breakpoint. Traffic is then allocated to the highest capacity route up to its capacity, and the process continues in the same order as before until all routes have allocated traffic to their capacities. Any additional unallocated traffic is then placed on the unspecified diversion route which is severely penalized with an extremely low diversion speed of 15 miles per hour in urban areas and 25 miles per hour in rural areas.

It would be unlikely that this method would approximate actual traffic allocation in most corridors. It would be especially unrealistic for HOV projects where the typical experience has been underutilization of the HOV lane(s) even when the peak direction lanes experience severe congestion [1]. It would also tend to bias the calculated economic measure. If the proposed project had the highest capacity of the corridor routes being evaluated, then the economic measure would tend to be too large. If the proposed project did not have the highest capacity then the economic measure would tend to be too small. Therefore an alternative allocation method is necessary which would more accurately approximate actual corridor allocation, especially as it applies to HOV projects. The next section presents an alternative allocation method based upon user costs.

MARGINAL COST ALLOCATION METHOD

The problem of allocating future corridor traffic to specific routes within the corridor is important in any analysis of user costs, but is especially important in evaluating HOV projects, since the number of vehicles which will use the restricted lane(s) is certainly one of the most important factors and probably one of the hardest to estimate.

The previous section described the current allocation method in the HEEM and its inapplicability to HOV analysis. The question is what allocation method will approximate actual traffic allocation within the limitations of HEEM's input data. There are several sophisticated traffic demand models which can be used to predict corridor traffic and the allocation of corridor traffic, but the data requirements to calibrate the models are too large and expensive to be used regularly in evaluating highway projects, and certainly outside the data limitations of the HEEM.

Theoretical Derivation

Another approach to traffic allocation is to examine user costs. A basic axiom of microeconomic theory is that individuals seek to maximize their satisfaction or utility. If transportation facilities are thought of as instruments to get to some desired place, then individuals will seek to minimize their perceived or expected user costs in choosing both the mode and route to travel. Most traffic demand models use as the objective minimizing travel time or distance,

but they are just components of user costs and more accurate results could be obtained by including a greater number of relevant factors in the allocation model.

Each individual will have a different relevant cost function which is used in selecting a travel mode and route. Specification of cost functions for each individual would be impossible, but if individual cost functions were fairly normally distributed, then some average cost functions would approximate actual traffic allocation. This is because persons on either end of the distribution will tend to be insensitive to changes in average user costs for alternate routes. The allocation will be determined at the margin, by motorists who are indifferent as to which route to choose, and if these motorists are near the mean of the distribution, then an average cost function may approximate the allocation process.

The equilibrium condition using user cost functions can easily be derived. Total user costs of corridor traffic are defined as the sum of user costs for each route in the corridor,

$$TC = \sum_{i=1}^n C_i(y_i) \quad (1)$$

where TC = total corridor user cost

C_i = total user cost for route i

y_i = average daily traffic volume along route i

n = number of routes in corridor

Since total corridor traffic equals the sum for each route,

$$T = \sum_{i=1}^n y_i \quad (2)$$

where T = total corridor ADT

The problem is to minimize total user cost (Equation 1) subject to the ADT constraint (Equation 2). Forming the Lagrangean,

$$L = \sum_{i=1}^n C_i(y_i) + \lambda (T - \sum_{i=1}^n y_i)$$

where λ = Lagrangean multiplier

The first-order conditions are,

$$\frac{\partial L}{\partial y_1} = C'_1(y_1) - \lambda = 0$$

⋮

$$\frac{\partial L}{\partial y_n} = C'_n(y_n) - \lambda = 0$$

$$\frac{\partial L}{\partial \lambda} = T - \sum_{i=1}^n y_i = 0$$

where $C'_i(y_i)$ = marginal user cost for route i

Eliminating λ from any two of the first n first-order conditions, gives,

$$C'_i(y_i) = C'_j(y_j) \text{ for all } i \neq j$$

In order to minimize total user cost, the marginal cost for each route must be equal. For a given corridor traffic volume, an equilibrium will occur where the marginal motorist is indifferent as to which route in the corridor to take.

Approximation of HEEM's Cost Calculations

The HEEM provides cost calculations as part of the process of calculating a benefit-cost ratio for a proposed highway project. However not all of these cost calculations are smooth, continuous

functions from which marginal cost functions must be derived. Therefore approximations to HEEM's cost calculations are required to adapt a cost allocation technique for the HEEM, using HEEM's user cost calculations.

Speed-Volume Relationship

The daily speed-volume relationship in the HEEM is approximated using two straight lines, one running from the initial speed at zero ADT to the breakpoint. The second line runs from the breakpoint to the point where the facility reaches capacity. The following function provides a good approximation to that relationship,

$$f(y) = tpf(C - e^{ay^b}) \quad (3)$$

where y = average daily traffic (ADT)

$f(y)$ = speed (mph) for a given ADT

tpf = technical performance factor, adjusts speed for atypical performance

$$0 < tpf < 1$$

$$b = \frac{\ln(C-E) - \ln(C-D)}{\ln A - \ln B}$$

$$a = \ln(C-E) - b \ln A$$

A = capacity ADT in the HST

B = breakpoint ADT in the HST

C = beginning speed (mph) in the HST

D = breakpoint speed (mph) in the HST

E = capacity speed (mph) in the HST

Figure 1 gives a graphical comparison of HEEM's approximation with the fitted approximation using Equation 3. The fitted approximation passes through the same three critical points, at zero ADT, breakpoint ADT, and capacity ADT, though for most levels of ADT, the estimated average speed is slightly higher than the average speed calculated in the HEEM.

Vehicle Running Costs

The running cost calculations also require approximations which are smooth continuous functions. The HEEM calculates separate running costs for two vehicle types, cars and trucks. For each curve there is a downward sloping portion for average speeds less than or equal to 25 mph and a different upward sloping curve for average speeds greater than 25 mph. For that reason the running cost curves used in the HEEM are discontinuous at 25 mph. These equations can closely be approximated using the following formulas, which are in terms of dollars per 1000 vehicle miles in January 1975 prices,

$$R_C = 194.3965 + 3.4337f(y) - 0.01926f(y)^2 - 61.75851nf(y) \quad (4)$$

$$R_t = 413.2859 + 4.3159kf(y) + 0.00947[kf(y)]^2 - 119.73131n[kf(y)] \quad (5)$$

where R_C = automobile running costs

R_t = truck running costs

$$k = \frac{\text{av. speed trucks}}{\text{av. speed cars}} \text{ for a given traffic volume } y \text{ (assumed 0.9 in HEEM)}$$

Figure 2 compares the HEEM's running cost calculations to those using Equations 4 and 5 above. The fitted curves give very close

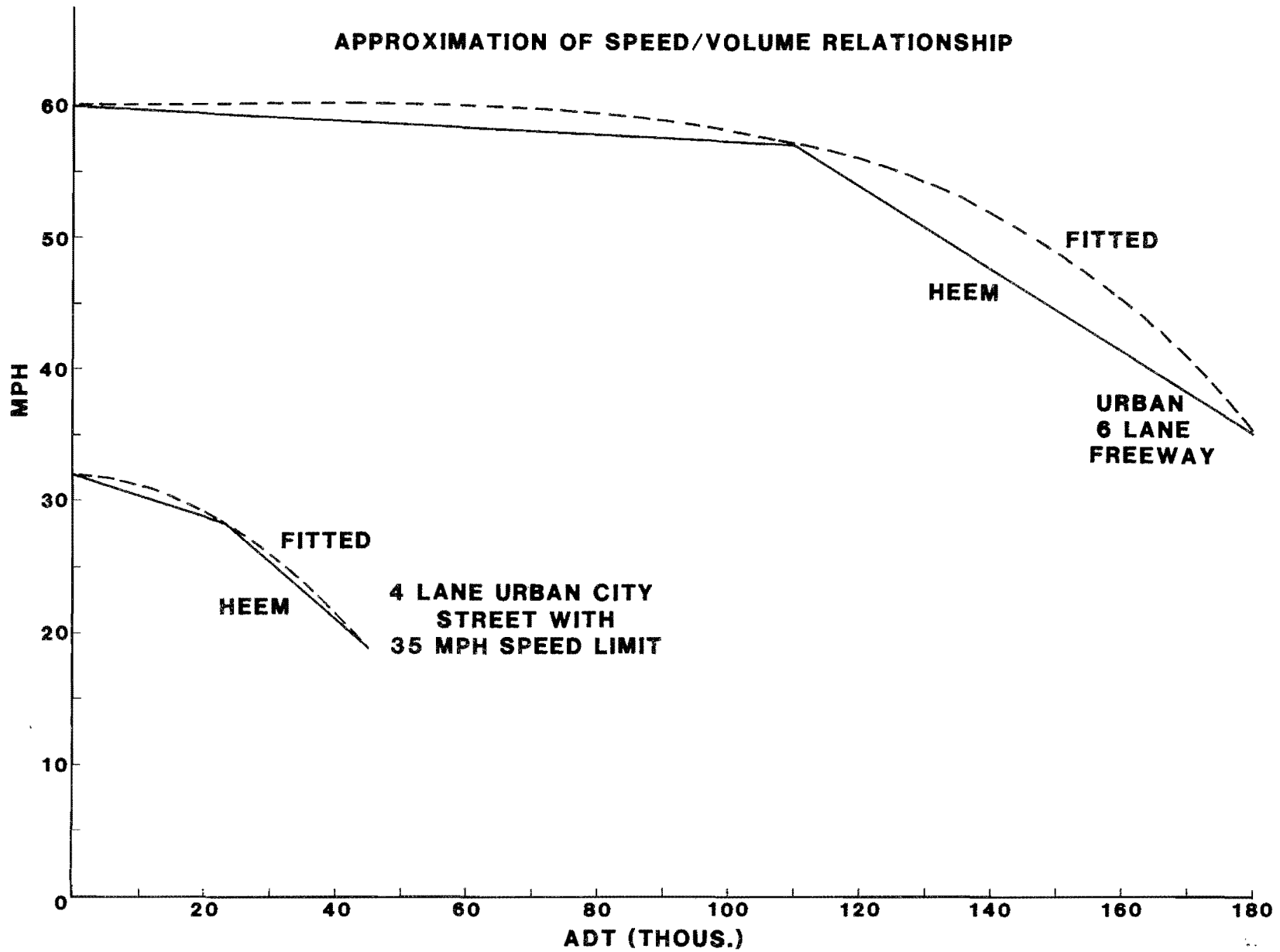


FIGURE 1

APPROXIMATION OF DAILY RUNNING COSTS

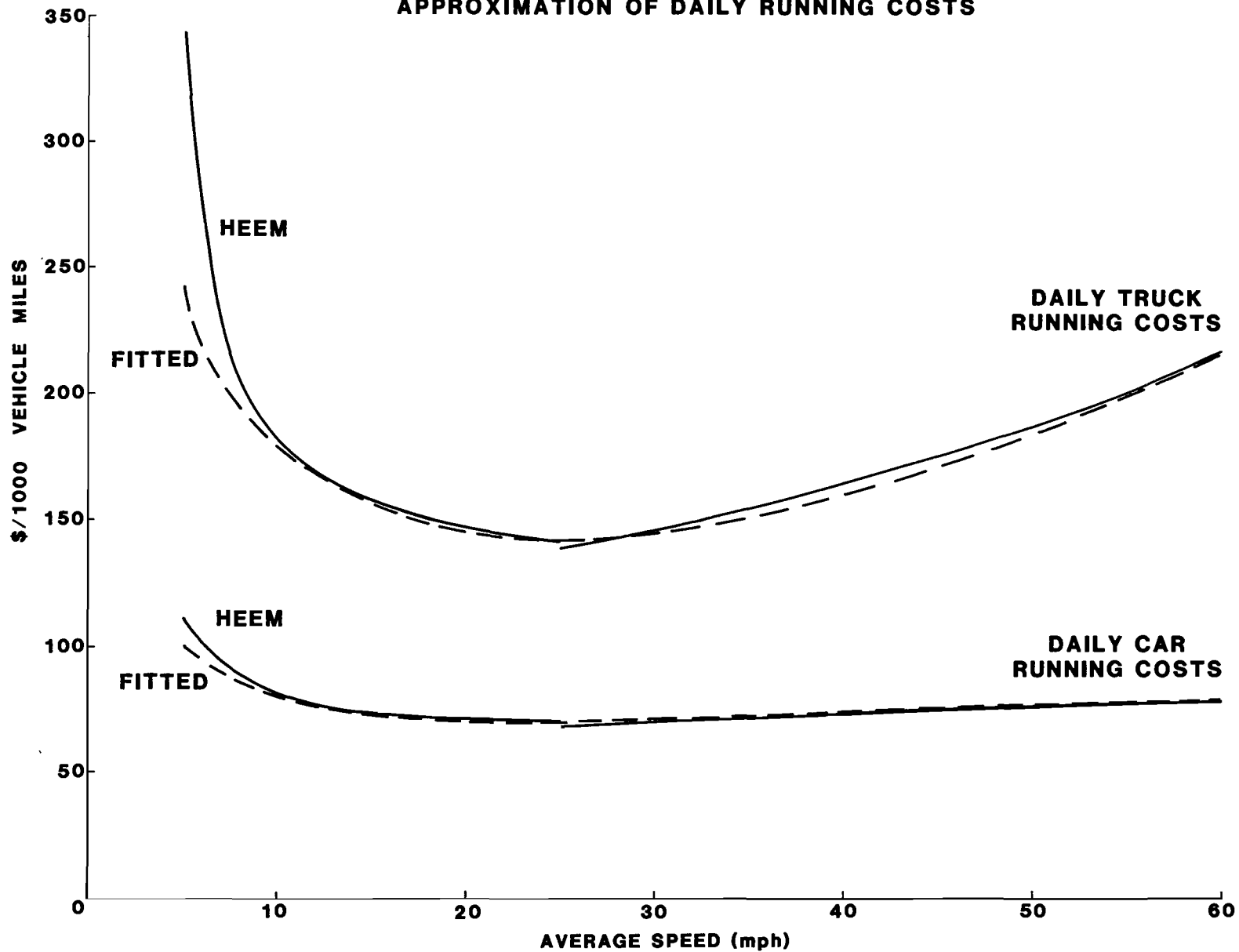


FIGURE 2

approximations for average speeds above 10 mph, and since HEEM does not use average speeds below 15 mph, the approximations provide a very good functional relationship for user running costs.

Metered Freeway's Speed Change Cycles

Another relationship which must be approximated in developing user cost functions involves the assumed behavior of speed change cycles on a metered freeway. The HEEM assumes an upward sloping linear relationship between ADT for a particular highway type and the number of 10 mph speed change cycles per vehicle mile. The effect of freeway metering is assumed to result in the number of cycles stopping at 3.1. This relationship is depicted in Figure 3. The HEEM relationship is approximated using the following formula:

$$NCY_m = \frac{F + cy + dy^3}{tpf} \quad (6)$$

where NCY_m = number of cycles on a metered freeway

F = intercept term for the number of cycles in HST

G = slope term for the number of cycles in HST

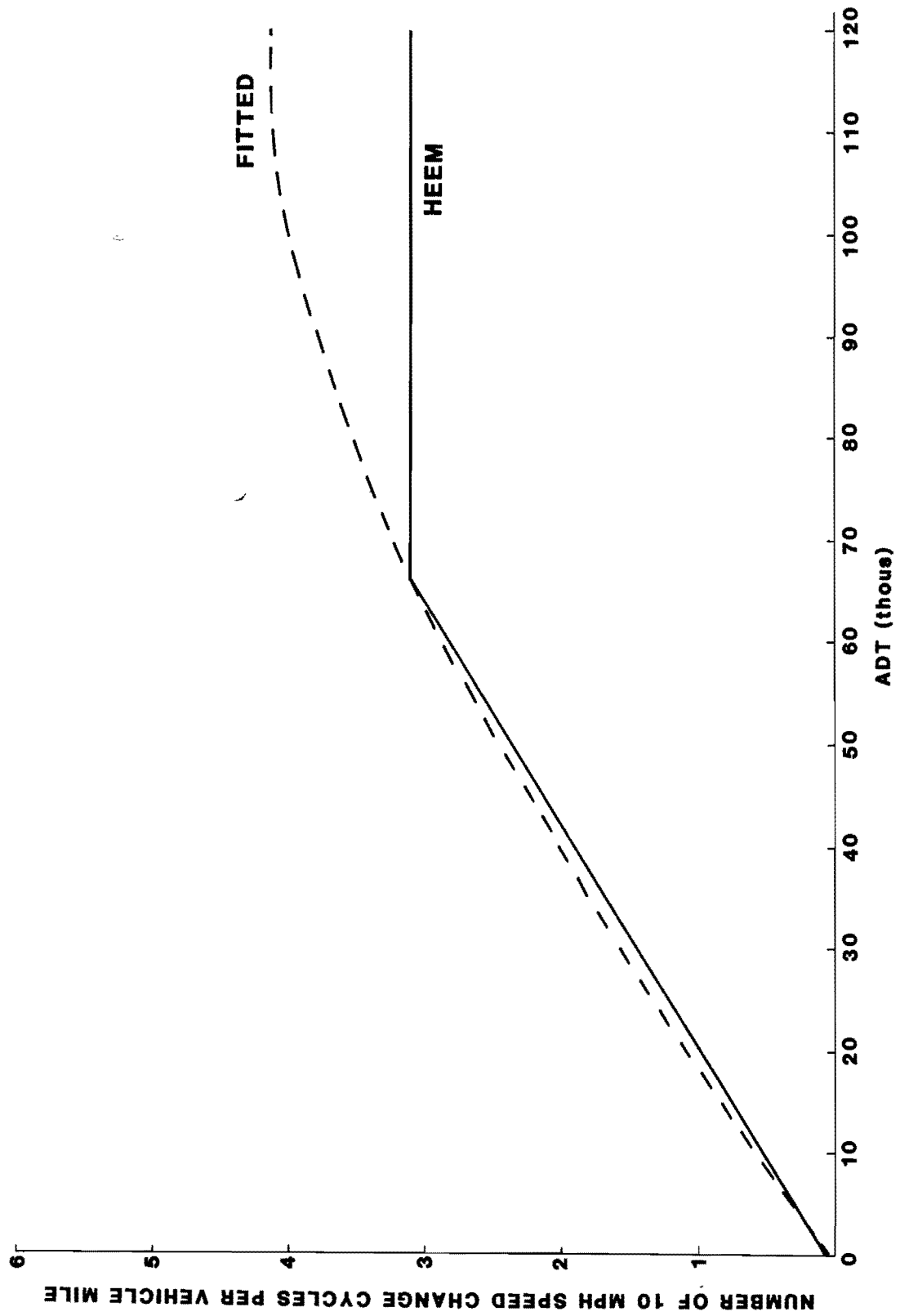
$$d = \frac{G^3}{(3.1-F)^2 - 3A^2G^2}$$

$$c = -3A^2d$$

A = highway vehicle capacity (ADT) in HST

Figure 3 gives a graphic comparison of the approximation using Equation 6. The coefficients in Equation 6 are calculated so that the function passes through the point where the HEEM's cycles reach 3.1 and the function's maximum occurs at capacity ADT. While the fitted

APPROXIMATION OF NUMBER OF CYCLES ON A 4-LANE METERED FREEWAY



ADT (thous)
FIGURE 3

curve does not provide a good approximation for the HEEM's curve at high traffic volumes, no other functional form was found which would approximate the assumed HEEM relationship with a smaller error, and the fitted curve (Equation 6) may provide a more realistic approximation of metered freeways, with the increase in number of cycles assumed to slow down as metering occurs rather than completely stopping as the HEEM assumes.

Accident Costs

In addition, implicit occupancy rates for both the time and accident cost calculations are assumed in the HEEM. As mentioned in the previous section, HEEM assumes a constant 1.3 automobile occupancy rate and a 1.0 truck occupancy rate for all corridor routes. These are clearly inappropriate for analysis of HOV lanes. As a result adjustment must be made in the accident cost calculations to incorporate a variable occupancy rate.

Buffington, et al. in TTI Report 225-8 [3] describe the accident cost figures used in the HEEM. The mean cost per accident figure in the HEEM is a weighted average of the unit accident costs for three categories, fatal, injury, and property damage only. If it is assumed that fatal and injury accident costs are sensitive to the occupancy rate but the property damage is not, then the following adjustment factor (AR) should be included in the accident cost calculation,

$$AR = 0.47 + 0.414[(1-r)OCP_c + rOCP_t] \quad (7)$$

where r = percentage trucks

OCP_c = car occupancy rate

OCP_t = truck occupancy rate

Total User Cost Function

With the approximations given above for the HEEM cost calculations, total user cost functions can be derived. The yearly running costs (RN) are

$$RN = \frac{365 \cdot L \cdot y}{1000} [(1-r) R_c + rR_t] \quad (8)$$

or

$$RN = \alpha_0 y [\alpha_1 + \alpha_2 f(y) + \alpha_3 f(y)^2 + \alpha_4 \ln f(y)]$$

where L = length in miles of route

$$\alpha_0 = \frac{365 \cdot L}{1000}$$

$$\alpha_1 = 194.3965(1-r) + (413.2859 - 119.7313 \ln k)r$$

$$\alpha_2 = 3.4337(1-r) + 4.3159kr$$

$$\alpha_3 = -.01926(1-r) + .00947k^2r$$

$$\alpha_4 = -61.7585(1-r) - 119.7313r$$

The cycling costs per 1000 cycles in January 1975 prices, are calculated using the following formulas for cars (CY_c) and trucks (CY_t):

$$CY_c = 3.9499 - \frac{13.8413}{f(y)} \quad (9)$$

$$CY_t = 47.2458 - \frac{428.198}{kf(y)}$$

The number of cycles per vehicle mile for unmetered highway types are given as

$$NCY_{um} = \frac{F + Gy}{tpf} \quad (10)$$

For metered freeways, the number of cycles is assumed to stop rising at 3.1 cycles per vehicle mile, so the number of cycles should be calculated using the approximation in Equation 6.

The yearly cycling costs (TCY), including metered freeways, are then calculated as,

$$TCY = \frac{365 \cdot L \cdot y}{1000} (NCY) [(1-r)CY_c + rCY_t] \quad (11)$$

or for unmetered highways,

$$TCY_{um} = \beta_0 y (F + Gy) \left(\beta_1 + \frac{\beta_2}{f(y)} \right) \quad (12a)$$

or for metered freeways,

$$TCY_m = \beta_0 y (F + cy + dy^3) \left(\beta_1 + \frac{\beta_2}{f(y)} \right) \quad (12b)$$

$$\text{where } \beta_0 = \frac{365 \cdot L}{1000 \cdot tpf}$$

$$\beta_1 = 3.9499(1-r) + 47.2458r$$

$$\beta_2 = -13.8413(1-r) - \frac{428.198r}{k}$$

Time costs (VT) are calculated as,

$$VT = \gamma_0 \left(\frac{y}{f(y)} \right) \quad (13)$$

$$\text{where } \gamma_0 = 21,900 \cdot L [(1-r)(OCP_c)(T_c) + \left(\frac{r}{k}\right)(OCP_t)(T_t)]$$

T_c = Car Time cost per person (\$/min)

T_t = Truck Time cost per person (\$/min)

Accident costs (AC) are given as,

$$AC = \rho_0 y \left[I + \left(\frac{Jy}{1000} \right) \right] \quad (14)$$

$$\text{where } \rho_0 = \frac{365 \cdot L \cdot H}{(10^6) \cdot sf} [0.47 + 0.414((1-r)OCP_c + rOCP_t)]$$

H = mean cost per accident in the HST

I = intercept term for accident rate per million vehicle miles in HST

J = slope term for accident rate per million
vehicle miles as a function of thous. ADT in HST

sf = safety factor, used to adjust accident rate for
abnormal conditions

Total user costs (TC) are the sum of running costs, cycling costs,
time costs, and accident costs,

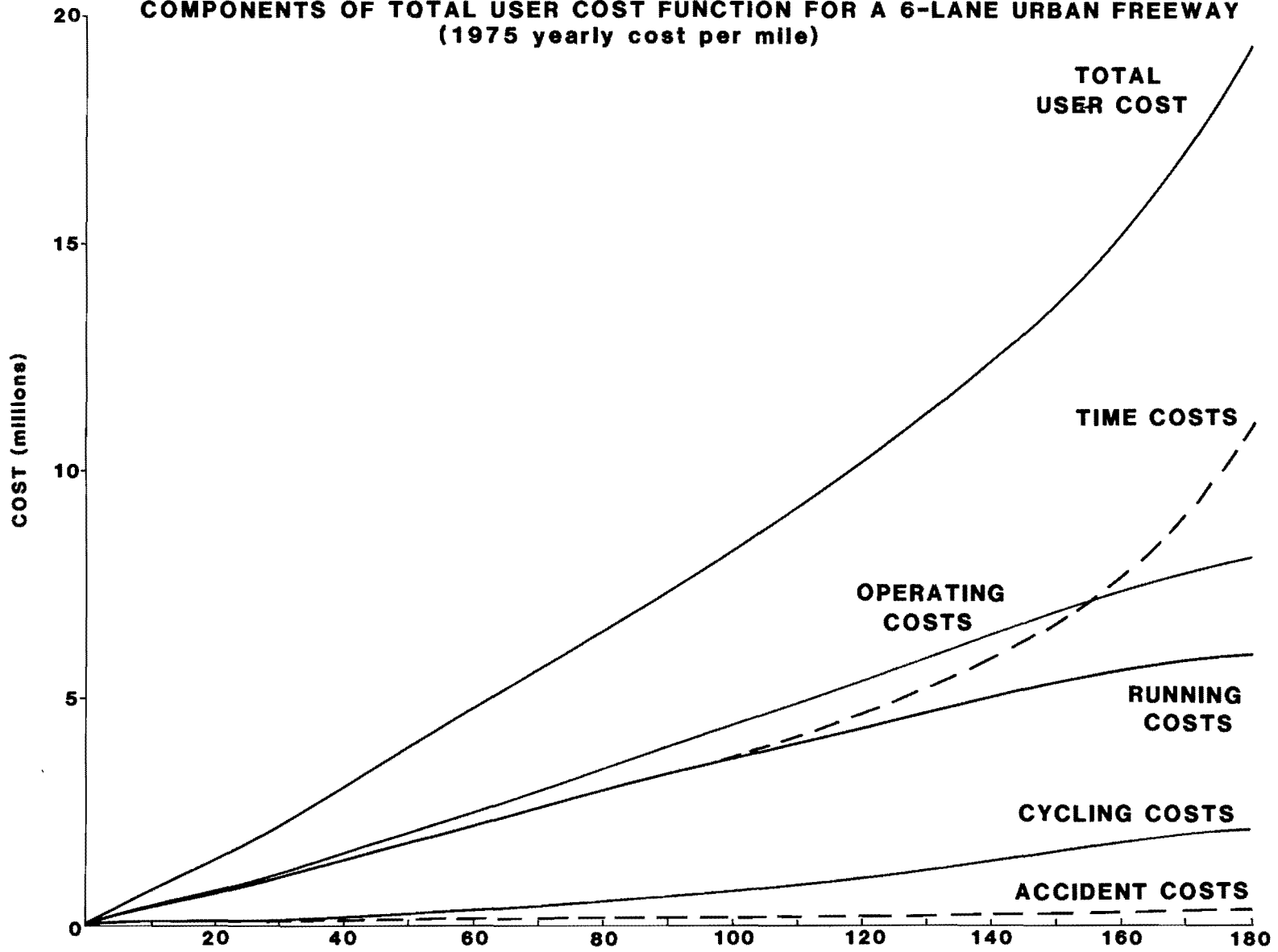
$$TC = RN + TCY + VT + AC \quad (15)$$

Figure 4 depicts the components of the total user cost function for a 6 lane urban freeway. Operating costs and time costs compose the greatest portion of total user costs using the HEEM cost calculations and the approximations presented above. As the facility reaches capacity time costs become the dominant factor in the increasing total cost function as average speeds rapidly decline.

Figure 5 gives a comparison of some representative total vehicle user cost functions. As might be expected, freeways generate lower user costs for a given traffic volume than other highway types. Total user costs on the contraflow lane rise very rapidly as it approaches capacity, much higher than conventional highway types, because of the additional time costs generated by the higher occupancy rates for the vehicles using the contraflow lane.

If the total cost functions are converted into person movement rather than number of vehicles, depicted in Figure 6, the contraflow lane compares much more favorably with the conventional lanes. For a given level of person movement, total user costs for the contraflow lane are similar to freeway user costs.

COMPONENTS OF TOTAL USER COST FUNCTION FOR A 6-LANE URBAN FREEWAY (1975 yearly cost per mile)



ADT (thous)
FIGURE 4

**COMPARISON OF TOTAL VEHICLE USER COST FUNCTIONS
(1975 YEARLY COST PER MILE)**

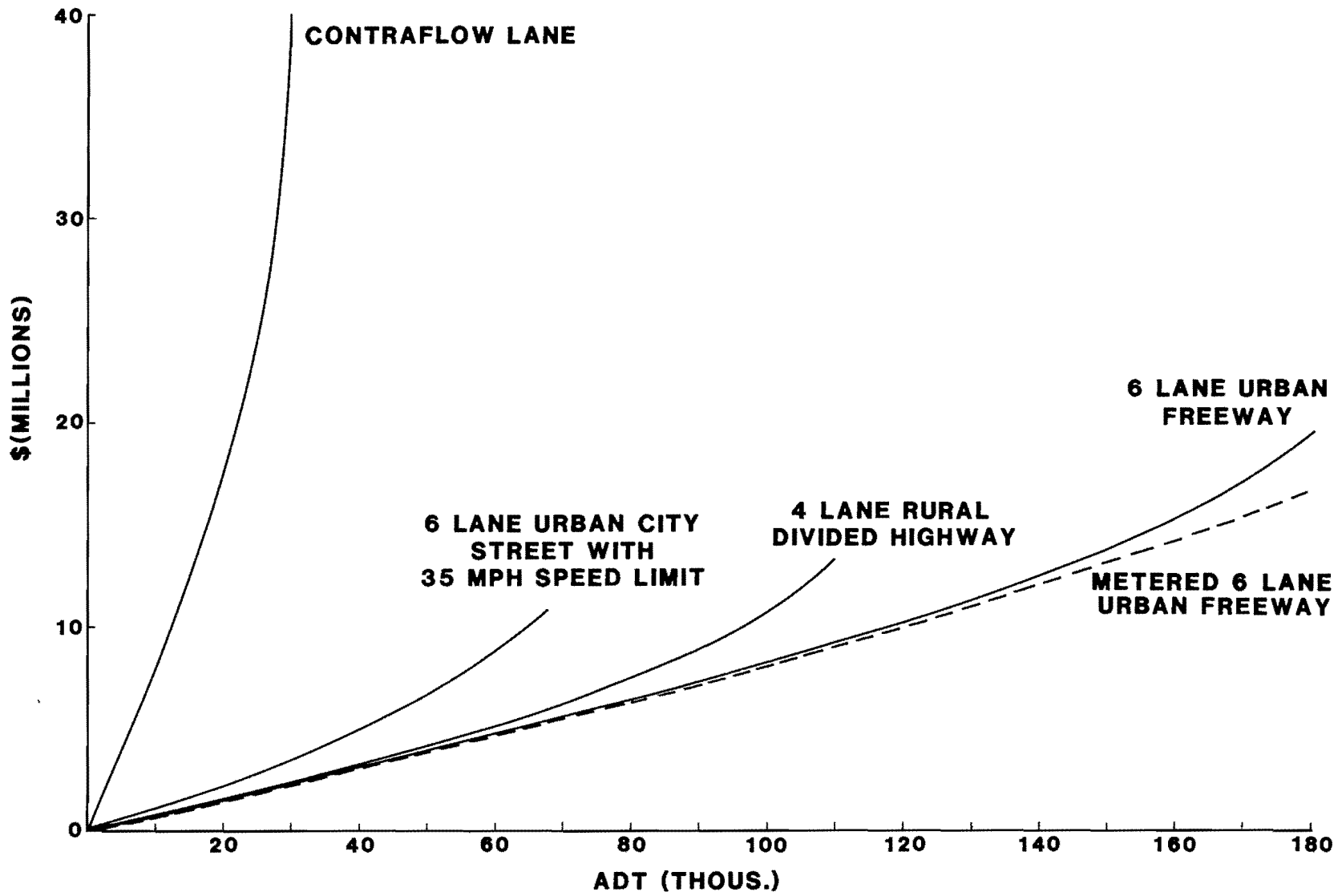


FIGURE 5

**COMPARISON OF TOTAL PERSON USER COST FUNCTIONS
(1975 YEARLY COST PER MILE)**

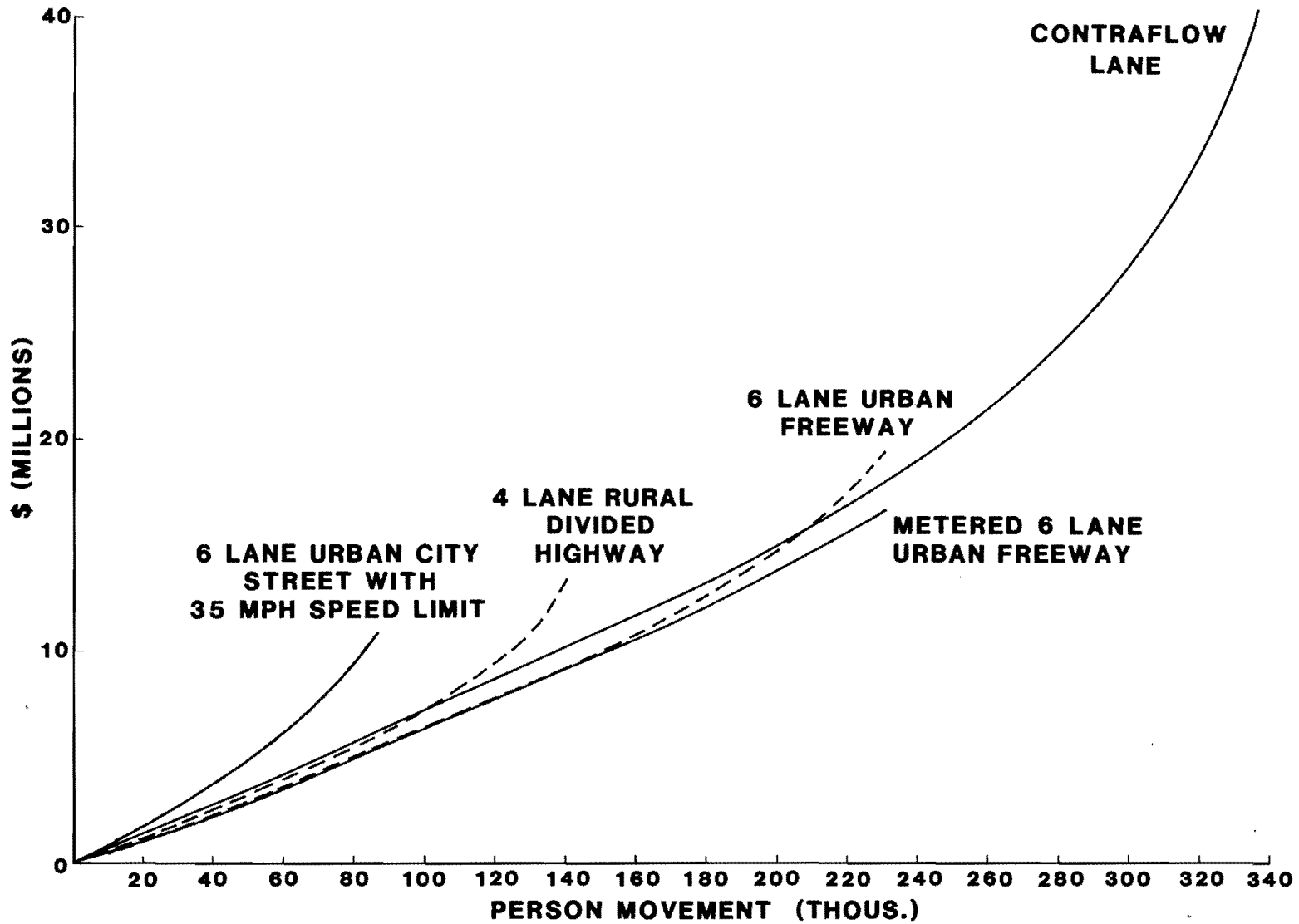


FIGURE 6

Marginal User Cost Function

The marginal cost function per person (MC) can be obtained by taking the derivative of the total vehicle cost function with respect to the average daily traffic volume and dividing by the weighted occupancy rate.

$$MC = \frac{dTC}{dy} \cdot \frac{1}{(1-r)OCP_c + rOCP_t} \quad (16)$$

Since

$$TC = RN + TCY + VT + AC \quad (15)$$

$$\frac{dTC}{dy} = \frac{dRN}{dy} + \frac{dTCY}{dy} + \frac{dVT}{dy} + \frac{dAC}{dy}$$

Therefore,

$$MC = \frac{1}{(1-r)OCP_c + rOCP_t} \left(\frac{dRN}{dy} + \frac{dTCY}{dy} + \frac{dVT}{dy} + \frac{dAC}{dy} \right) \quad (17)$$

Marginal running costs (MRN) are given as

$$MRN = \frac{dRN}{dy} = \alpha_0 [\alpha_1 + \alpha_2 (f(y)f'(y))y + \alpha_3 (f(y))^2 + 2f(y)f'(y)y + \alpha_4 (\ln f(y) + \frac{f'(y)y}{f(y)})] \quad (18)$$

where $f'(y)$ = first derivative of speed-volume function

Marginal cycling costs for unmetered highways (MCY_{um}) are given as

$$MCY_{um} = \frac{dTCY_{um}}{dy} = \beta_0 [\beta_1 (F+2Gy) + \beta_2 \left(\frac{(F+2Gy)f(y) - (F+Gy)f'(y)y}{f(y)^2} \right)] \quad (19)$$

Marginal cycling costs for metered freeways (MCY_m) are given as,

$$MCY_m = \frac{dTC_m}{dy} = \beta_0 [\beta_1 (F+2cy+4dy^3) + \beta_2 \left(\frac{(F+2cy+4dy^3)f(y) - (F+cy+dy^3)f'(y)y}{f(y)^2} \right)] \quad (20)$$

Marginal time costs (MVT) and marginal accident costs (MAC) are given as,

$$MVT = \gamma_0 \left(\frac{f(y) - yf'(y)}{f(y)^2} \right) \quad (21)$$

$$MAC = \rho_0 \left(I + \frac{2Jy}{1000} \right)$$

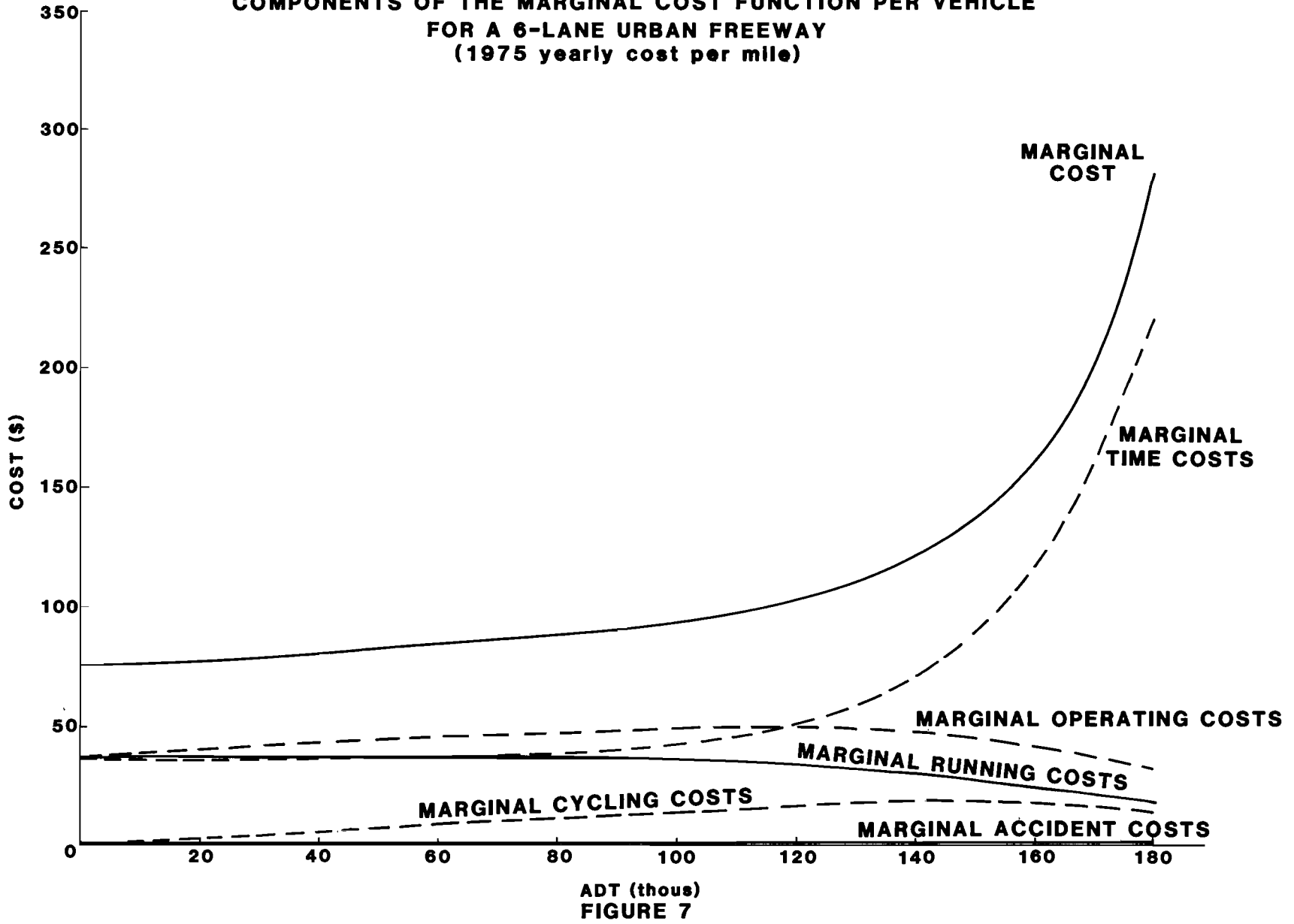
The components of the marginal cost function for a 6-lane urban freeway are presented graphically in Figure 7. Not surprisingly, marginal time costs become the dominant component of the rapidly increasing marginal cost function as the freeway congests and average speeds drop.

Figure 8 compares the marginal cost functions for some representative highway types. The marginal cost functions display the expected result that the freeways initially have a lower marginal cost, but at some point those costs will rise sufficiently that motorists will begin to use the other initially higher marginal cost routes.

Approximation of Marginal Cost Function

The marginal cost allocation method requires that corridor traffic be allocated to the corridor routes in such a fashion that the marginal user cost for each route is equal. The marginal cost functions presented in Equations 17 through 21 are sufficiently complex that an analytical solution would be quite difficult if not impossible. Therefore some iteration technique should be used. However, the HEEM currently calculates all benefits and costs using a forty-

**COMPONENTS OF THE MARGINAL COST FUNCTION PER VEHICLE
FOR A 6-LANE URBAN FREEWAY
(1975 yearly cost per mile)**



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**COMPARISON OF MARGINAL USER COST FUNCTIONS
(1975 YEARLY COST PER PERSON PER MILE)**

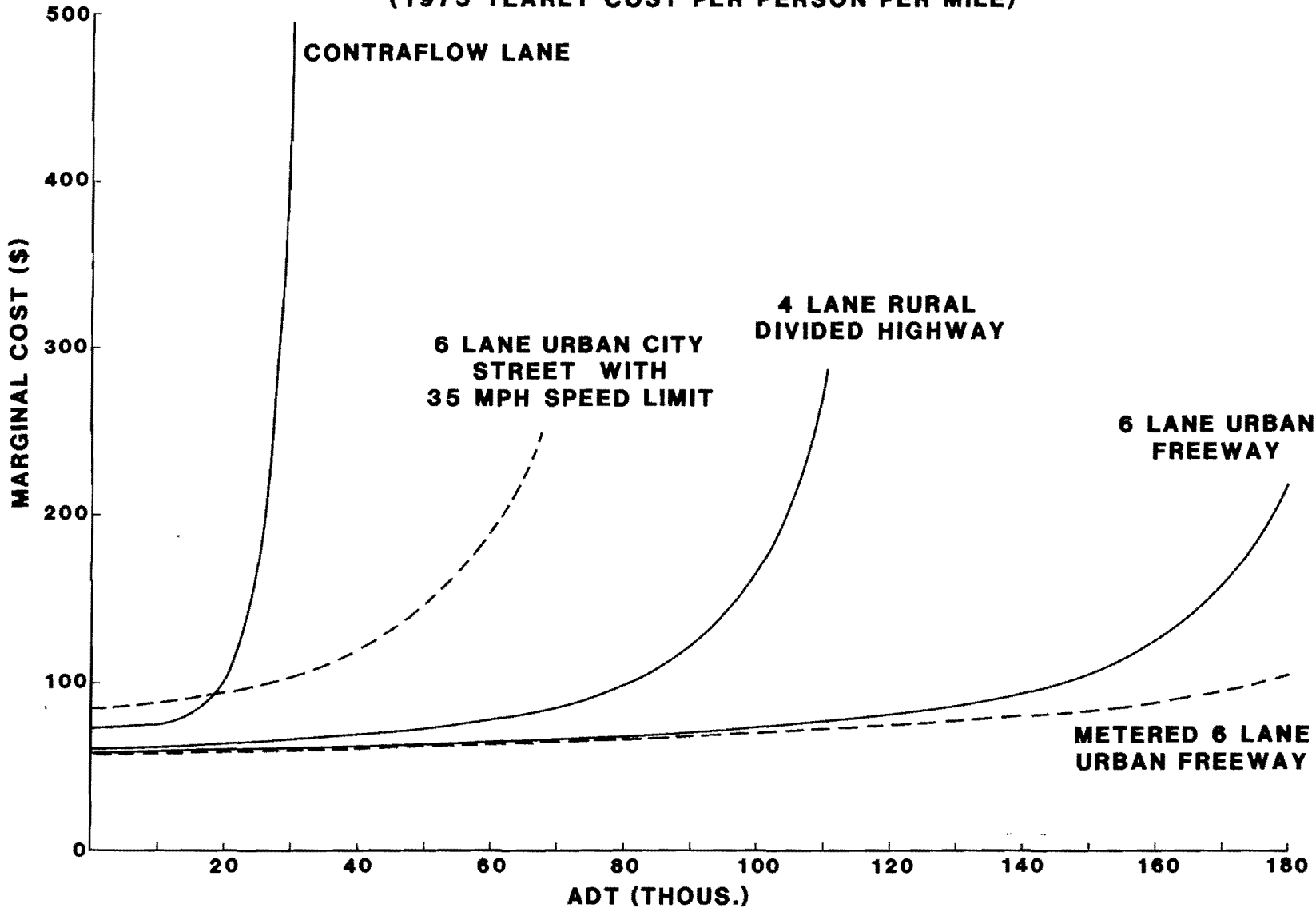


FIGURE 8

year time horizon. That means the iteration process must be repeated forty times for each proposed project segment, resulting in increased computer time when using the HEEM program.

Therefore an approximation to the marginal cost function which can be manipulated analytically was derived. The approximation to the marginal cost function is given as,

$$\frac{1}{MC(i) + a} = b + cy(i) \quad (22)$$

where $i = 1$ when $y = 0$

$i = 2$ when $y = 1/2$ route capacity

$i = 3$ when $y =$ route capacity

$$a = \frac{[y(1) + y(3)] \cdot y(2) - 2 \cdot y(1)y(3)}{y(1) + y(3) - 2 \cdot y(2)}$$

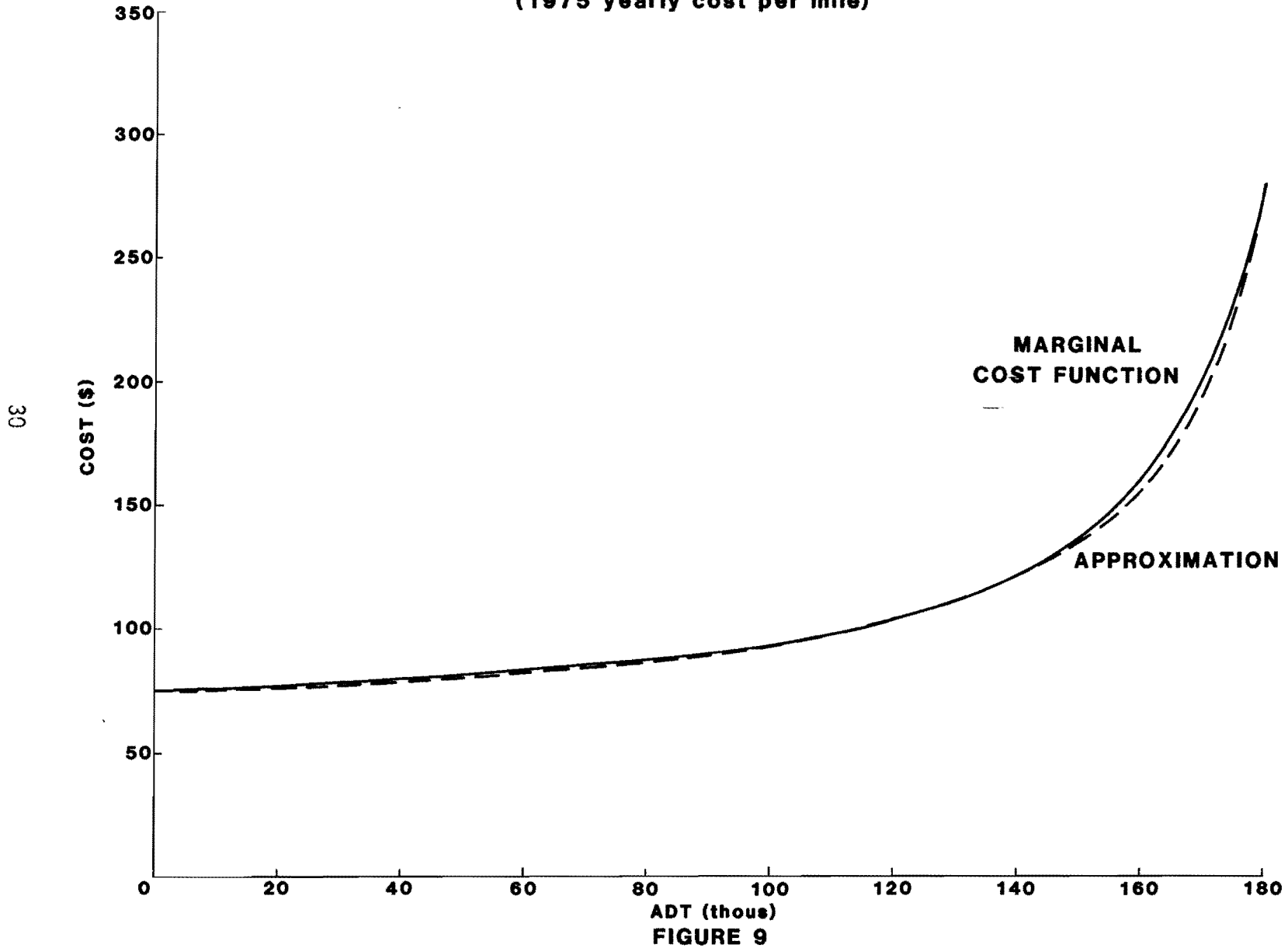
$$b = \frac{1}{y(1) + a}$$

$$c = \frac{1}{x(3) \cdot (y(3) + a)} - \frac{b}{x(3)}$$

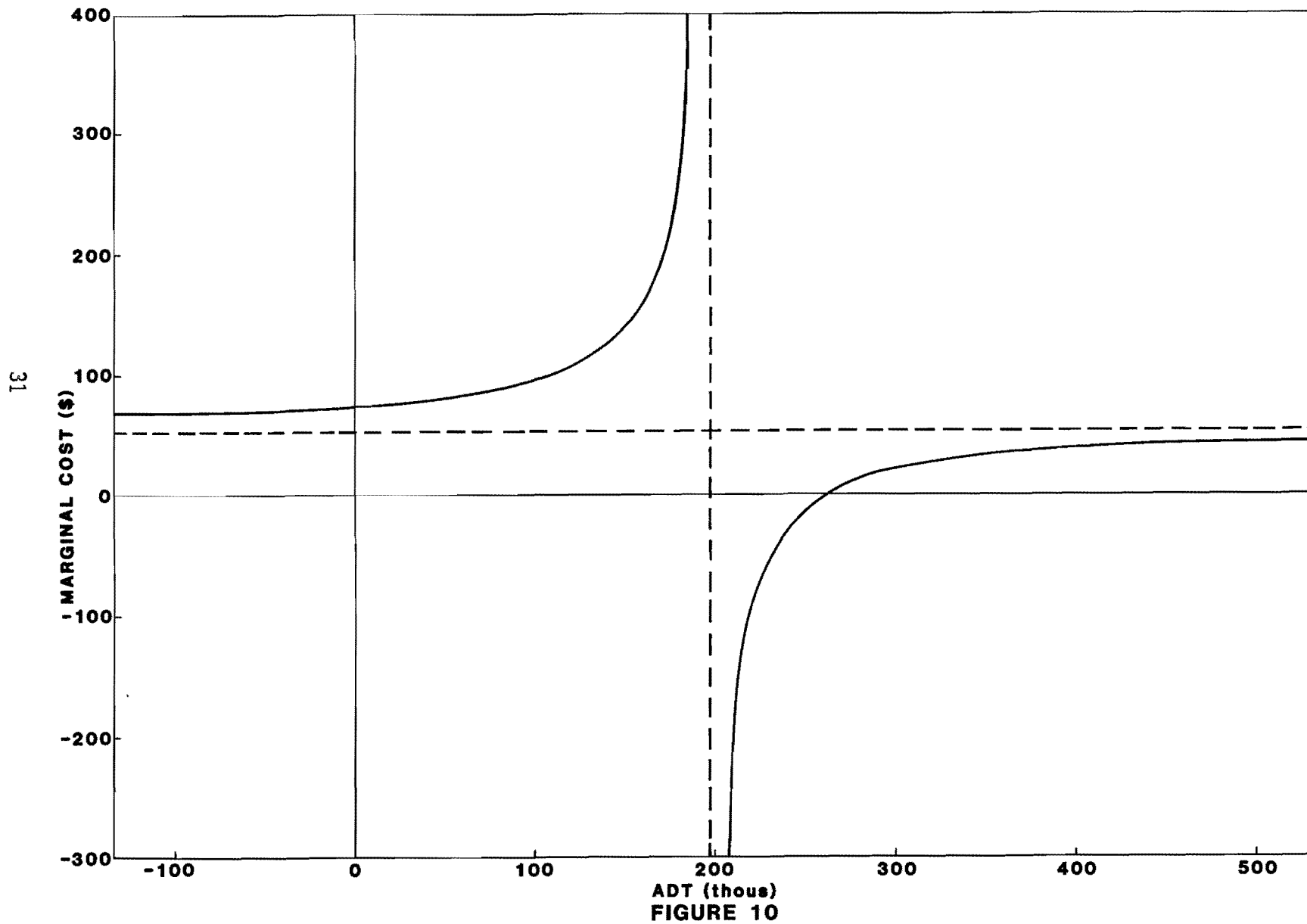
The approximation goes through three points along the marginal cost function, at the intercept with zero ADT, at the midpoint of capacity ADT, and at capacity ADT. That approximation is depicted graphically in Figure 9. Very little error is introduced using the approximation in Equation 22 and it offers the important advantage that no iterations are necessary.

However, Equation 22 does have a significant disadvantage because it is a hyperbola, as shown in Figure 10. The relevant portion of the curve is in the upper left quadrant where the curve is

**APPROXIMATION OF MARGINAL COST FUNCTION FOR A 6-LANE URBAN FREEWAY
(1975 yearly cost per mile)**



MARGINAL COST APPROXIMATION FOR A 6-LANE URBAN FREEWAY



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ADT (thous)
FIGURE 10

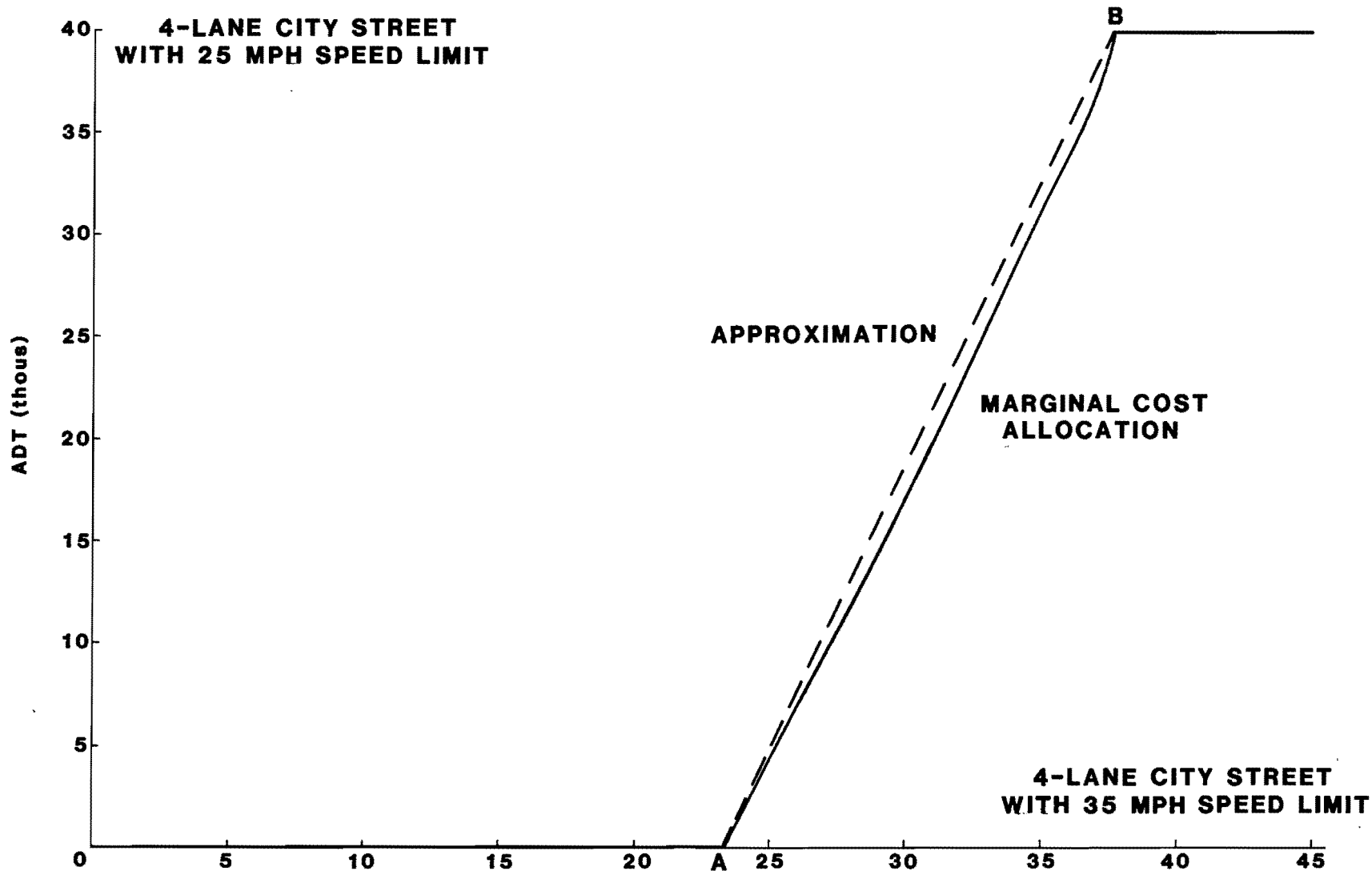
fitted to the marginal cost function. But when an attempt is made to allocate traffic outside the relevant range of one or more of the corridor routes, erroneous results can be generated with the curve in the lower right quadrant. The safeguards necessary in the computer program to eliminate the possibility of erroneous results would make the programming very difficult and complex. Therefore an alternative is presented in this report.

The approximation, Equation 22, works very well as long as the allocation is made near the relevant range of ADT values for each corridor route. Therefore the marginal cost approximation function could be used to establish the allocation relationship between corridor routes for some arbitrary values within the range where the approximation is valid. The question is what functional form should be used to characterize the allocation relationship between corridor routes.

Figure 11 depicts an example of the allocation between two city streets using the marginal cost function, Equation 17, and a linear approximation to that relationship. Several other hypothetical allocations were tested, with similar results. The allocation relationship between two highway types exhibits an approximate linear relationship. If a linear curve is used then the marginal cost approximation, Equation 22, is needed in order to estimate only two points, the two most convenient being points A and B in Figure 11.

Using these approximations, the allocation of corridor traffic can be estimated. Appendix B contains the equations to incorporate these approximations into the HEEM program.

APPROXIMATION OF MARGINAL COST ALLOCATION RELATIONSHIP



ADT (thous)
FIGURE 11

Comparison of Allocation Methods

Any calculated traffic allocation for a corridor route which is less than zero or greater than ADT capacity for the facility can be set to the appropriate value and the additional corridor traffic allocated between the remaining routes. The advantages of this proposed allocation method are that an analytical solution can be obtained in every case, iterations are not necessary, and which more closely approximates corridor allocation than the current HEEM allocation method.

An example is presented in Figure 12. In this example, traffic must be allocated between a contraflow lane and the remaining 7 lanes of a metered freeway. The marginal cost allocation method begins allocating traffic to the contraflow lane before HEEM does and allocates on a proportional basis until the conventional lanes reach capacity. The HEEM allocation, however, allocates all traffic to the unrestricted lanes up to 140,000 ADT, then allocates all additional traffic to the contraflow lane up to 18,750 ADT, then additional traffic goes to the unrestricted lanes. HEEM's current allocation method is clearly inadequate and can result in substantial errors in the calculated economic measure for a proposed highway project.

In addition, it is important to note that the marginal cost allocation method will improve the accuracy of the estimated economic measure for proposed conventional highway projects as well as HOV projects. Figure 13 compares the current HEEM allocation method with the marginal cost allocation method for two 6-lane urban freeways, one metered and the other one not metered.

COMPARISON OF HEEM TRAFFIC ALLOCATION METHOD TO MARGINAL COST ALLOCATION METHOD FOR TWO 6-LANE URBAN FREEWAYS

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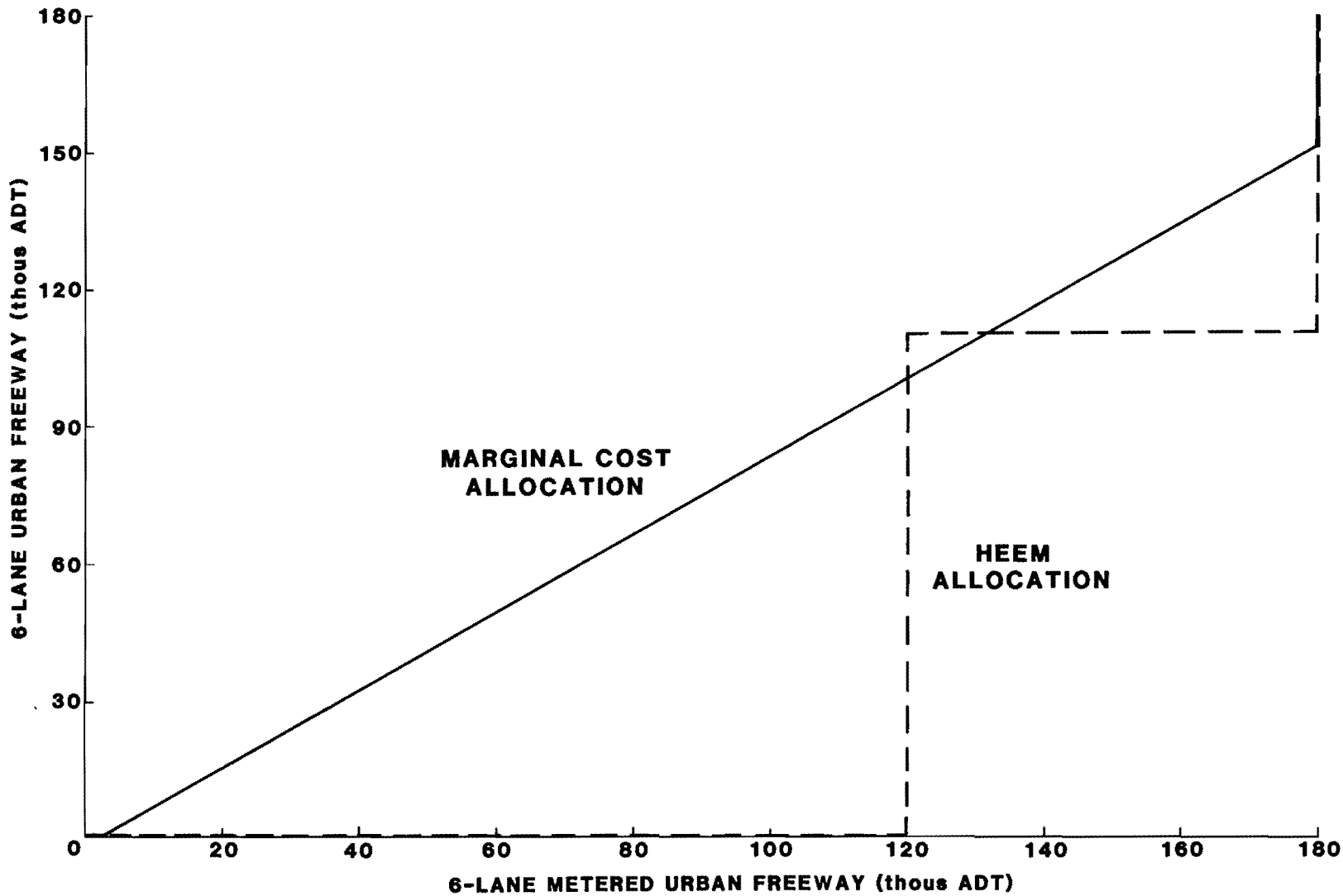


FIGURE 13

The HEEM would allocate all traffic to the metered freeway up to 120,000 ADT, which obviously will not approximate actual allocation. In addition, if the metered freeway were the proposed highway project, the calculated economic measure would tend to be significantly too large since an artificially high number of vehicles would be initially allocated to it. The converse would be the case if the conventional freeway were the proposed project. The marginal cost allocation method, on the other hand, would allocate traffic proportionately to both freeways with slightly more vehicles going to the metered freeway due to the lower user costs as a result of metering. This is a much more realistic representation of the allocation which would be expected and thus would improve the accuracy of the calculated economic measure for a proposed highway project.

The marginal cost allocation method provides a much improved method to allocate corridor traffic, based upon a theoretical derivation of the equilibrium conditions for minimizing total user costs. This type of approach is critical in evaluating HOV projects since one of the major problems is predicting the acceptance and use of HOV treatments. The marginal cost allocation method also has the additional benefit that it will improve the accuracy of HEEM's analyses of other projects, unrelated to HOV projects. The effect of the marginal cost allocation method on the calculated economic measure for a particular project should be tested empirically. It is recommended that empirical tests be undertaken after the program for the marginal cost allocation method is written. A flow chart and other recommended programming changes are provided in Appendix B to incorporate the

marginal cost allocation method into the HEEM. The parameters in the flow chart have been adjusted to include the factors which have been incorporated in the HEEM to update the cost calculations to 1981 prices.

HOV SPECIFICATIONS AND ASSUMPTIONS

Specification of HOV Parameters

As part of the input data for the HEEM, the proposed project must be specified as either a new location construction, where the existing facility (if any) will remain; or as a buildover of an existing facility. If the HOV projects are treated as buildover projects, then each different HOV treatment would have to be paired with each of the 14 urban freeway types in the HEEM, plus combinations where an existing lane is restricted for exclusive HOV use, creating an odd number of unrestricted lanes. This would require 84 additional highway types to be included in the Highway Specification Table. A much simpler and more workable solution is to treat the HOV project as a new location construction and revise the necessary parameters for the existing facility if an existing lane is restricted for HOV use, such as a contraflow lane.

Studies have shown that only contraflow lane projects where the off-peak direction can be accommodated with the remaining lanes have successfully restricted an existing lane for HOV use [1,2]. Therefore, the recommended programming changes for the HEEM in Appendix B allow only contraflow projects to reduce the existing number of lanes.

The following HOV highway types are recommended for inclusion in the HEEM.

1. Contraflow lane (UIT)
2. Concurrent Flow--one reserved lane (U1N)
3. Concurrent Flow--two reserved lanes (U2N)

4. Exclusive Busway--one lane (U1S)
5. Exclusive Busway--two lanes (U2S)

The Highway Specification Table contains certain specified parameters for each of the highway types which can be evaluated using the HEEM. These parameters include values for average speeds and ADT volumes which correspond to those speeds, the number of speed change cycles per vehicle mile as a function of ADT, the number and mean cost of accidents, and the annual maintenance costs.

The values in Table 1 are recommended for inclusion in the Highway Specification Table for the HOV highway types listed above. The speed and volume parameters, A through E, are the same as those of urban freeways in the Table, adjusted for the number of lanes. There is evidence that vehicle speeds on HOV lanes are similar to those on unrestricted lanes for a given vehicle type and volume per lane. For example in TTI Report 205-9 [6], average speeds along the I45 Contra-flow Lane in Houston are between 52 and 60 mph.

In addition, HEEM's average daily speed and traffic values are calculated in a separate computer program called TRAFFIC, using assumed hourly speed-volume relationships for various highway types and assumed peaking patterns for both urban and rural conditions. In order to calculate separate values for HOV highway types, a separate hourly speed-volume curve would be required, along with appropriate changes in the TRAFFIC program. The program could then be used to provide the estimated values for HOV highway types.

This type of analysis is outside the scope of this study and since there is evidence of similar average speeds along HOV lanes,

TABLE 1 Recommended HOV Parameters for Inclusion in the Highway Specification Table

| Highway Type | Highway Value | Speed Volume | | | | | Cycles | | Accidents | | | Maintenance |
|--------------|---------------|----------------|-------------------|-----------------------|-------------------------|----------------------|-----------|------------------|--------------------------|-----------|-------|-------------------------------|
| | | A | B | C | D | E | F | G | H | I | J | K |
| | | Capacity (ADT) | Break-point (ADT) | Beginning Speed (ADT) | Break-point Speed (ADT) | Capacity Speed (ADT) | Intercept | Slope | Mean, Cost/Accident (\$) | Intercept | Slope | Average Annual Cost/Mile (\$) |
| U1T | 42 | 30,000 | 18,750 | 60 | 57.02 | 35.30 | .3289 | $1.830(10^{-4})$ | 1,800 | 3.1 | 0 | \$45,000 |
| U1N | 43 | 30,000 | 18,750 | 60 | 57.02 | 35.30 | .3289 | $1.830(10^{-4})$ | 1,800 | 4.7 | 0 | 15,000 |
| U2N | 44 | 60,000 | 37,500 | 60 | 57.02 | 35.30 | .1644 | $9.150(10^{-5})$ | 1,800 | 4.5 | 0 | 20,000 |
| U1S | 45 | 30,000 | 18,750 | 60 | 57.02 | 35.30 | .3289 | $1.830(10^{-4})$ | 1,800 | 3.1 | 0 | 7,500 |
| U2S | 46 | 60,000 | 37,500 | 60 | 57.02 | 35.30 | .1644 | $9.150(10^{-5})$ | 1,800 | 3.0 | 0 | 10,000 |

the same urban freeway speed and volume relationships are recommended for the HOV highway types.

The number of cycles per vehicle mile, parameters F and G, are derived from the same source used in deriving HEEM's values, a study by Malcolm F. Kent [7], and which roughly correspond to a 4-lane urban freeway, adjusted for the number of lanes. Using the data in Kent's study for a 4-lane divided, controlled access highway, the following regression line is fitted.

$$NCY = .08222 + .00004575y \quad (23)$$

$$R^2 = .990$$

where NCY = average number of speed change cycles

y = average daily traffic

This equation, adjusted for the number of lanes, provides the values for parameters F and G.

The mean cost per accident and the number of accidents per million vehicle miles are represented by parameters H, I and J. The recommended mean cost per accident, parameter H, is the same as urban freeway highway types currently in the Highway Specifications Table. The adjustment of accident costs for a higher occupancy rate, using Equation 7, is to be inserted directly into the accident cost calculations in the HEEM program, as recommended in Appendix B.

The accident rate intercept term, parameter I, however does require adjustment for higher accident rates along some HOV facilities compared to conventional lanes. The following equation describes the relationship between parameter I and the number of urban freeway lanes in the Highway Specification Table.

$$I = 3.2 - 0.1(\text{FLN}) \quad (24)$$

where I = intercept term for the accident rate

FLN = number of freeway lanes

Increased accident rates seem to be most significant for concurrent flow reserved lanes due to illegal vehicles weaving in and out of the reserved lane. Using the accident data provided in TTI Report 205-4 [8] for concurrent flow lanes in the U.S., there was an average increase of approximately 50 percent in the number of accidents 4 to 6 months after implementation compared to the period before the project. Therefore the recommended values for parameter I in Table 1 for concurrent flow reserved lanes are calculated using equation 24, and adjusted for the 50 percent increase in accidents.

There does not seem to be a comparable increase in accident rates along contraflow lanes. TTI Report 205-9 [6] found no significant increase in accidents on the I45 CFL in Houston. Therefore the recommended accident rate, parameter I, for the contraflow lane is calculated using equation 24 with no adjustment. Also no adjustment is recommended for exclusive busways. Parameter J is zero in all cases, following the findings by McKenzie and Co. in adapting the HEEM for use in Texas [9].

The average annual maintenance costs per mile, parameter K, for exclusive busways are calculated using the following equation:

$$K = 5,000 + 2,500(\text{FLN}). \quad (25)$$

This is the same relationship used in the Highway Specification Table for urban freeways.

Contraflow and concurrent flow lanes, however, have additional maintenance costs which must be included in the recommended value

for parameter K. TTI Report 205-1 [2] describes the yearly maintenance costs for selected contraflow projects in the U. S. using data reported between 1975 and 1976. The average operational cost per mile is \$45,000. TTI report 205-9 [6] estimates the average yearly cost per mile for the I45 CFL in Houston to be \$55,000 for the 1979-1980 period. If this value is adjusted to 1975 prices, to make it comparable to the other values in the Highway Specification Table, the recommended value of \$45,000 would seem to be fairly accurate.

The average maintenance costs for the concurrent flow facilities are taken from a report by TTI on HOV priority treatments in San Antonio, Texas [11]. These values represent a 100 percent increase in maintenance costs compared to the maintenance costs from equation 25.

Recommended Assumptions

The HEEM calculates user costs based upon two vehicle types, trucks and cars. A default value of 8 percent trucks is provided in the HEEM, or a different value may be entered as part of the input data for corridor traffic. However, whichever assumed value is used, the same value is applied to all corridor routes being evaluated. However, the vehicle mix on an HOV lane probably would not approximate the mix on the unrestricted lanes. That obviously would occur if only one vehicle type, such as buses, was allowed on the HOV lane.

TTI Report 225-8 [3] recommends the truck category be divided into a single unit and a multiunit category, and a bus category added. However, the HEEM program is set up on such a fashion that it

would be very difficult to add additional categories of vehicles without extensive alterations to several parts of the program. In addition, previous research has found bus operating costs to be similar to that of trucks. The Redbook [10], for example, places buses into the single unit truck category unless a separate bus transit analysis is being performed.

Therefore for the present, it is recommended that the two vehicle categories be retained but that input data for the proposed highway be expanded to include a different percent trucks (buses), if the proposed project is an HOV facility. The recommended default value is the same 8 percent, taken from an average of bus traffic on HOV lanes in TTI Report 205-1 [2]. However, a separate value should be provided for each HOV project analysis, when possible, due to the wide variability of vehicle distributions for different HOV projects.

Another important assumption in the HEEM is the value of time. A separate value of time can be specified for cars and trucks, and default values are provided if none are specified. The problem is again that those same assumptions apply to all corridor routes being evaluated, which is clearly inappropriate for HOV lanes. If values of time, including the comfort of the ride, flexibility of trip timing and route, availability of park-and-ride lots, downtown parking costs, out-of-vehicle walking or waiting time, etc., were similar for individuals in the restricted lanes versus the unrestricted lanes, then vehicles would use the restricted lanes until average speeds were less than the unrestricted lanes because they are spreading the operating costs over a greater number of individuals. That clearly has not occurred.

D. Baugh and Associates [1] estimate that in order for a priority lane to be successful, time savings must be greater than one minute/mile. That means if the vehicles on the unrestricted lanes are traveling at 30 mph then the vehicles using the restricted lane must travel at more than 60 mph in order to induce people to use the restricted lane. Why is there a big difference? Persons using the restricted lane obviously perceive they are incurring a cost using the restricted lane which they must be compensated for in terms of substantial travel time savings.

A simple method to account for these additional costs is to increase the value of time for the persons using an HOV restricted lane. There are a number of costs, mentioned above, which could influence the decision to use an HOV lane. Since the HEEM can examine projects only on a segment basis, separate adjustments cannot be made for these other factors. The value of time for HOV users can be adjusted, however, to include these other factors. This adjusted value of time would be used to more accurately estimate the proportion of total corridor traffic volume each corridor route will receive. It is not recommended that these adjusted values of time be used in calculation of the economic measure for the proposed project because the other costs the adjusted value of time captures must be treated separately.

The question is what adjusted value is appropriate. Several HOV projects have been attempted in different parts of the country, so one method would be to look at the distribution of traffic and calculate what adjusted value of time that distribution implies using the marginal cost allocation method presented in the previous section. By

looking at the current distribution and calculating the implicit adjusted value of time for HOV users, the resulting value will capture those persons' valuation of the additional perceived costs of using the HOV facility.

TTI Report 205-9 [6] presents a summary of the first year operation of the I45 Contraflow lane in Houston. Using the data presented in that report with the marginal cost allocation model yields some interesting results. If the value of time for both bus and van passengers are assumed to be equal, then the value of time must rise about 160 percent in order to have the marginal cost of traveling the unrestricted lanes equal to the marginal cost of traveling the CFL.

The time savings criteria of a minute/mile presented above implied about a 100 percent increase in the value of time. If an adjustment is made for spreading the vehicle operating costs over a greater number of individuals due to the higher occupancy rate, the 160 percent increase using the marginal cost method is consistent with the minute/mile effectiveness measure of HOV lanes.

The only other vehicle category normally allowed to use a restricted priority lane are carpools with a minimum of three occupants. To calculate the implicit value of time for individuals using carpools, data for the Redwood Highway, San Francisco, in TTI Report 205-4 [8] was used. Assuming the previously calculated value of time for bus passengers, the value of time for carpool occupants must increase about 110 percent above the value of time for individuals using a car in the unrestricted lanes.

Table 2 presents the recommended value of time parameters for HOV treatments, based upon the current values used in the HEEM. The

TABLE 2 Recommended Values of Time and Occupancy Rates
for HOV Facilities

| | <u>Value of Time per Vehicle</u> | <u>Occupancy Rate</u> | <u>Value of Time per Person</u> |
|------------------------|--------------------------------------|---------------------------|-------------------------------------|
| Current HEEM Values | | | |
| Cars | 15¢/min. | 1.3 | 11.54¢/min. |
| Trucks | 28¢/min. | 1.0 | 28¢/min. |
| Recommended HOV Values | | | |
| 3+ Occupant Carpools | | 3.7 | 24.23¢/min. |
| Vans | | 8.7 | 30¢/min. |
| Buses | | 40.0 | 30¢/min. |

occupancy rates are taken as an average of occupancy rates for HOV projects in TTI Report 205-1 [2] and TTI Report 205-4 [8]. However, due to the wide variability in occupancy rates for specific projects, a separate estimate of occupancy rates should be provided for each HOV project analysis when possible. It is recommended that both the input data for the proposed highway and the expansion of the proposed highway, cards 4 and 5, be increased to include a vehicle mix, adjusted value of time, and occupancy rates different from those assumed for the corridor on card 1. Appendix B contains the specific recommended changes for the input data.

Another assumption in the HEEM which must be examined for HOV projects is the future demand of corridor traffic. As part of the input data, a projected corridor vehicle traffic volume must be

provided. HEEM then calculates a traffic volume for each year based upon that projected traffic volume using either a constant growth rate or an iterated declining growth rate. The projected vehicle traffic volume demand is independent of the proposed project being analyzed.

One of the purposes, however, of HOV projects is to increase the occupancy rates thereby reducing the vehicle demand, or at least slowing the growth of vehicle demand. A better assumption would be to treat the future corridor person demand as independent of the proposed project and let the vehicle demand vary for changes in the occupancy rate. That assumption is built into the recommended marginal cost allocation method discussed in the previous section. Also recommended changes to the output data reflecting the person corridor allocation for HOV projects are contained in Appendix B.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The HEEM provides a solid framework to use in looking at the desirability of a particular highway project by calculating a benefit/cost ratio called the economic measure. But the HEEM is not currently capable of analyzing HOV type projects. There are a number of reasons for this, including limited highway types in the Highway Specification Table, assumptions which cannot be changed for HOV lanes, and the current method of allocating corridor traffic.

This report presents a number of recommended changes to expand the capability of the HEEM program to successfully evaluate HOV projects. It is important to realize, however, that these proposed changes are not intended exclusively to provide an analysis of HOV projects, though that certainly is the major purpose. Some of these changes will also improve the analysis of other projects unrelated to HOV projects, a good example is the marginal cost allocation method.

The marginal cost allocation method described in this report allows for an unbiased analysis of HOV projects but it will also improve the accuracy and reliability of other unrelated project evaluations. The reason for this is the underlying assumptions of the marginal cost model. It allocates traffic in such a fashion that the marginal user cost for each corridor route is the same. The model can be applied to any corridor traffic analysis, with the HOV project analysis as an important application of the model, where the use of the restricted lane at some future period is of critical importance.

Recommendations

Based upon the findings presented in this report, the following changes to the HEEM are recommended:

1. Expand the number of highway types in the Highway Specification Table to include the five HOV highway types listed in this report.
2. Replace the current corridor traffic allocation method with the marginal user cost allocation method described in this report.
3. Expand the input data to include assumptions different from those of the other corridor routes including,
 - a. different percent trucks (buses)
 - b. different values of time
 - c. different occupancy rates.
4. Change the assumption of an independent corridor vehicle demand to an assumption of an independent corridor person demand.

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APPENDIX A

TABLE A1 Comparison of HEEM Approximation to Fitted Approximation for an 8-Lane Urban Freeway

| <u>Demand</u> | <u>Average Speed</u> | <u>HEEM</u> | | <u>FITTED</u> | |
|---------------|----------------------|----------------------|--------------|----------------------|--------------|
| | | <u>Average Speed</u> | <u>Error</u> | <u>Average Speed</u> | <u>Error</u> |
| 60,000 | 58.81 | 58.81 | 0.00 | 59.95 | 1.14 |
| 70,000 | 58.61 | 58.61 | 0.00 | 59.90 | 1.29 |
| 80,000 | 58.41 | 58.41 | 0.00 | 59.82 | 1.41 |
| 90,000 | 58.21 | 58.21 | 0.00 | 59.70 | 1.49 |
| 100,000 | 58.02 | 58.01 | -0.01 | 59.52 | 1.50 |
| 110,000 | 57.82 | 57.81 | -0.01 | 59.26 | 1.44 |
| 120,000 | 57.62 | 57.62 | 0.00 | 58.91 | 1.29 |
| 130,000 | 57.42 | 57.42 | 0.00 | 58.42 | 1.01 |
| 140,000 | 57.22 | 57.22 | 0.00 | 57.82 | 0.60 |
| 150,000 | 57.02 | 57.02 | 0.00 | 57.02 | 0.00 |
| 160,000 | 56.83 | 54.61 | -2.22 | 56.02 | -0.81 |
| 170,000 | 53.88 | 52.19 | -1.69 | 54.77 | 0.89 |
| 180,000 | 50.93 | 49.78 | -1.15 | 53.23 | 2.30 |
| 190,000 | 48.75 | 47.37 | -1.38 | 51.37 | 2.62 |
| 200,000 | 46.94 | 44.95 | -1.99 | 49.13 | 2.19 |
| 210,000 | 45.77 | 42.54 | -3.24 | 46.46 | 0.69 |
| 220,000 | 42.81 | 40.13 | -2.68 | 43.30 | 0.49 |
| 230,000 | 40.43 | 37.71 | -2.72 | 39.60 | -0.83 |
| 240,000 | 35.30 | 35.30 | 0.00 | 35.30 | 0.00 |

TABLE A2
Comparison of Daily Car Running Costs

| <u>Average Speed</u> <u>(mph)</u> | <u>Daily Running Costs (\$/1000 veh.miles)</u> | |
|--------------------------------------|--|---------------|
| | <u>HEEM</u> | <u>Fitted</u> |
| 5 | 111.6 | 101.0 |
| 10 | 80.9 | 80.9 |
| 15 | 74.1 | 73.2 |
| 20 | 71.1 | 70.1 |
| 25 | 69.4 | 69.4 |
| 30 | 70.0 | 69.9 |
| 35 | 71.2 | 71.0 |
| 40 | 72.5 | 72.5 |
| 45 | 73.9 | 74.1 |
| 50 | 75.3 | 75.7 |
| 55 | 76.7 | 77.0 |
| 60 | 78.2 | 78.2 |

TABLE A3
Comparison of Daily Truck Running Costs

| Average Speed (mph) | Daily Running Costs (\$/1000 veh.miles) | |
|------------------------|---|--------|
| | HEEM | Fitted |
| 5 | 343.2 | 242.4 |
| 10 | 181.7 | 181.7 |
| 15 | 157.1 | 155.9 |
| 20 | 147.1 | 144.7 |
| 25 | 141.7 | 141.7 |
| 30 | 146.4 | 144.1 |
| 35 | 154.7 | 150.3 |
| 40 | 164.0 | 159.4 |
| 45 | 174.5 | 170.9 |
| 50 | 186.5 | 184.4 |
| 55 | 200.2 | 199.5 |
| 60 | 216.1 | 216.1 |

TABLE A4
Comparison of Speed Change Cycles on a 4-Lane Metered Freeway

| <u>ADT</u> | <u>HEEM</u> | <u>FITTED</u> |
|------------|-------------|---------------|
| 0 | 0.04 | 0.09 |
| 10,000 | 0.54 | 0.59 |
| 20,000 | 0.99 | 1.09 |
| 30,000 | 1.45 | 1.57 |
| 40,000 | 1.90 | 2.03 |
| 50,000 | 2.36 | 2.47 |
| 60,000 | 2.81 | 2.87 |
| 66,400 | 3.10 | 3.10 |
| 70,000 | 3.10 | 3.22 |
| 80,000 | 3.10 | 3.53 |
| 90,000 | 3.10 | 3.78 |
| 100,000 | 3.10 | 3.97 |
| 110,000 | 3.10 | 4.09 |
| 120,000 | 3.10 | 4.13 |

TABLE A5
Yearly Total User Costs for a 6-Lane Urban Freeway
(1975 Prices, 1 Mile Length)

| ADT | Total Running Costs | Total Cycling Costs | Total Operating Costs | Total Time Costs | Total Accident Costs | Total User Costs |
|---------|---------------------|---------------------|-----------------------|------------------|----------------------|------------------|
| 10,000 | \$369,364 | \$8,421 | \$377,785 | \$360,621 | \$17,082 | \$755,487 |
| 20,000 | 738,723 | 30,816 | 769,539 | 721,261 | 34,164 | 1,524,965 |
| 30,000 | 1,108,055 | 67,183 | 1,175,238 | 1,082,046 | 51,246 | 2,308,530 |
| 40,000 | 1,477,287 | 117,518 | 1,594,805 | 1,443,345 | 68,328 | 3,106,478 |
| 50,000 | 1,846,246 | 181,806 | 2,028,071 | 1,805,954 | 85,410 | 3,919,435 |
| 60,000 | 2,214,710 | 260,016 | 2,474,726 | 2,171,293 | 102,492 | 4,748,512 |
| 70,000 | 2,582,176 | 352,085 | 2,934,261 | 2,541,655 | 119,574 | 5,595,490 |
| 80,000 | 2,947,977 | 457,906 | 3,405,882 | 2,920,490 | 236,656 | 6,463,029 |
| 90,000 | 3,311,111 | 577,299 | 3,888,411 | 3,312,796 | 153,738 | 7,354,945 |
| 100,000 | 3,670,142 | 709,985 | 4,380,127 | 3,725,651 | 170,820 | 8,276,598 |
| 110,000 | 4,023,032 | 855,529 | 4,878,560 | 4,169,017 | 187,902 | 9,335,480 |
| 120,000 | 4,366,925 | 1,013,273 | 5,380,197 | 4,657,013 | 204,984 | 10,242,194 |
| 130,000 | 4,697,883 | 1,182,209 | 5,880,092 | 5,210,028 | 222,066 | 11,312,186 |
| 140,000 | 5,010,634 | 1,360,774 | 6,371,409 | 5,858,431 | 239,148 | 12,468,987 |
| 150,000 | 5,298,529 | 1,546,459 | 6,844,988 | 6,649,454 | 256,230 | 13,750,672 |
| 160,000 | 5,554,201 | 1,735,045 | 7,289,245 | 7,660,908 | 273,312 | 15,223,465 |
| 170,000 | 5,772,271 | 1,918,934 | 7,691,206 | 9,031,144 | 290,394 | 17,012,744 |
| 180,000 | 5,957,767 | 2,083,028 | 8,040,794 | 11,03,133 | 307,476 | 19,381,403 |

TABLE A6
Comparison of Yearly Total User Costs
(1975 Prices, 1 Mile Length)

| ADT | Conventional Highway Types | | | | HOV | | |
|---------|------------------------------|--|------------------------------|----------------------|------------------------------|------------------------------|-----------------|
| | Person Movement ^a | 6-Lane Urban City Street with 35 mph Speed Limit | 4-Lane Rural Divided Highway | 6-Lane Urban Freeway | Metered 6-Lane Urban Freeway | Person Movement ^b | Contraflow Lane |
| 10,000 | 12,760 | \$1,109,674 | \$792,949 | \$755,487 | \$754,452 | 112,040 | \$8,094,637 |
| 20,000 | 25,520 | 2,273,010 | 1,608,736 | 1,524,965 | 1,524,686 | 224,080 | 17,237,117 |
| 30,000 | 38,280 | 3,533,806 | 2,449,887 | 2,308,530 | 2,310,566 | 336,120 | 40,102,189 |
| 40,000 | 51,040 | 4,953,607 | 3,321,813 | 3,106,478 | 3,111,956 | | |
| 50,000 | 63,800 | 6,632,191 | 4,233,915 | 3,919,435 | 3,928,786 | | |
| 60,000 | 76,560 | 8,750,803 | 5,201,503 | 4,748,512 | 4,761,111 | | |
| 67,500 | 86,130 | 10,838,574 | | | | | |
| 70,000 | 89,320 | | 6,249,845 | 5,595,490 | 5,609,175 | | |
| 80,000 | 102,080 | | 7,423,624 | 6,463,029 | 6,473,477 | | |
| 90,000 | 114,840 | | 8,811,003 | 7,354,945 | 7,354,866 | | |
| 100,000 | 127,600 | | 10,612,590 | 8,276,598 | 8,254,655 | | |
| 110,000 | 140,360 | | 13,379,722 | 9,235,480 | 9,174,797 | | |
| 120,000 | 153,120 | | | 10,242,194 | 10,118,139 | | |
| 130,000 | 165,880 | | | 11,312,186 | 11,088,813 | | |
| 140,000 | 178,640 | | | 12,468,987 | 12,092,857 | | |
| 150,000 | 191,400 | | | 13,750,672 | 13,139,211 | | |
| 160,000 | 204,160 | | | 15,223,465 | 14,241,375 | | |
| 170,000 | 216,920 | | | 17,012,744 | 15,420,231 | | |
| 180,000 | 229,680 | | | 19,381,403 | 16,709,004 | | |

^a assumed weighted occupancy rate of 1.276, 92% cars at 1.3 persons/car and 8% trucks at 1.0 persons/truck
^b assumed weighted occupancy rate of 11.204, 92% vans at 8.7 persons/van and 8% buses at 40.0 persons/bus

TABLE A7
 Yearly Marginal User Costs per Vehicle for a
 6-Lane Urban Freeway (1975 Prices, 1 Mile Length)

| ADT | Marginal Running Costs | Marginal Cycling Costs | Marginal Operating Costs | Marginal Time Costs | Marginal Accident Costs | Marginal User Costs |
|---------|------------------------|------------------------|--------------------------|---------------------|-------------------------|---------------------|
| 0 | \$36.94 | \$0.14 | \$37.08 | \$36.06 | \$1.71 | \$74.85 |
| 10,000 | 36.94 | 1.54 | 38.48 | 36.06 | 1.71 | 76.25 |
| 20,000 | 36.94 | 2.94 | 39.87 | 36.07 | 1.71 | 77.65 |
| 30,000 | 36.93 | 4.34 | 41.27 | 36.10 | 1.71 | 79.07 |
| 40,000 | 36.91 | 5.73 | 42.65 | 36.18 | 1.71 | 80.53 |
| 50,000 | 36.88 | 7.13 | 44.00 | 36.37 | 1.71 | 82.09 |
| 60,000 | 36.80 | 8.52 | 45.32 | 36.74 | 1.71 | 83.77 |
| 70,000 | 36.68 | 9.90 | 46.57 | 37.39 | 1.71 | 85.67 |
| 80,000 | 36.47 | 11.26 | 47.73 | 38.46 | 1.71 | 87.90 |
| 90,000 | 36.14 | 12.61 | 48.75 | 40.12 | 1.71 | 90.58 |
| 100,000 | 35.64 | 13.92 | 49.56 | 42.62 | 1.71 | 93.88 |
| 110,000 | 34.89 | 15.18 | 50.07 | 46.29 | 1.71 | 98.07 |
| 120,000 | 33.82 | 16.35 | 50.17 | 51.64 | 1.71 | 103.52 |
| 130,000 | 32.29 | 17.41 | 49.69 | 59.45 | 1.71 | 110.86 |
| 140,000 | 30.15 | 18.27 | 48.42 | 70.99 | 1.71 | 121.12 |
| 150,000 | 27.30 | 18.80 | 46.10 | 88.46 | 1.71 | 136.28 |
| 160,000 | 23.73 | 18.79 | 42.53 | 116.03 | 1.71 | 160.26 |
| 170,000 | 19.93 | 17.75 | 37.68 | 162.28 | 1.71 | 201.67 |
| 180,000 | 17.74 | 14.54 | 32.29 | 247.55 | 1.71 | 281.54 |

TABLE A8
 Comparison of Yearly Marginal Costs per Person
 (1975 Prices, 1 Mile Length)

| ADT | Contra-flow Lane | 6-Lane Urban Urban City Street with 35 mph Speed Limit | 4-Lane Rural Divided Highway | 6-Lane Urban Free-way | Metered 6-Lane Urban Freeway |
|---------|------------------|--|------------------------------|-----------------------|------------------------------|
| 0 | \$73.43 | \$85.88 | \$61.27 | \$58.66 | \$58.51 |
| 10,000 | 75.55 | 88.57 | 63.02 | 59.76 | 59.75 |
| 20,000 | 103.93 | 94.35 | 64.88 | 60.85 | 60.98 |
| 30,000 | 496.11 | 104.07 | 67.03 | 61.97 | 62.20 |
| 40,000 | | 119.74 | 69.75 | 63.11 | 63.41 |
| 50,000 | | 145.62 | 73.41 | 64.32 | 64.62 |
| 60,000 | | 190.99 | 78.57 | 65.65 | 65.84 |
| 67,500 | | 250.56 | | | |
| 70,000 | | | 86.30 | 67.14 | 67.09 |
| 80,000 | | | 98.75 | 68.89 | 68.39 |
| 90,000 | | | 121.09 | 70.98 | 69.77 |
| 100,000 | | | 167.54 | 73.57 | 71.28 |
| 110,000 | | | 287.09 | 76.86 | 72.98 |
| 120,000 | | | | 81.13 | 74.94 |
| 130,000 | | | | 86.88 | 77.28 |
| 140,000 | | | | 94.92 | 80.20 |
| 150,000 | | | | 106.80 | 83.93 |
| 160,000 | | | | 125.60 | 89.05 |
| 180,000 | | | | 220.64 | 106.54 |

TABLE A9
 Approximation of Marginal Cost Function
 for a 6-Lane Urban Freeway

| <u>ADT</u> | <u>Actual</u> | <u>Approximate</u> |
|------------|---------------|--------------------|
| 0 | \$74.85 | \$74.85 |
| 10,000 | 76.25 | 85.85 |
| 20,000 | 77.65 | 76.96 |
| 30,000 | 79.07 | 78.20 |
| 40,000 | 80.53 | 79.60 |
| 50,000 | 82.09 | 81.20 |
| 60,000 | 83.77 | 83.03 |
| 70,000 | 85.67 | 85.14 |
| 80,000 | 87.90 | 87.63 |
| 90,000 | 90.58 | 90.58 |
| 100,000 | 93.88 | 94.15 |
| 110,000 | 98.07 | 98.54 |
| 120,000 | 103.52 | 104.09 |
| 130,000 | 110.86 | 111.31 |
| 140,000 | 121.12 | 121.10 |
| 150,000 | 136.28 | 135.15 |
| 160,000 | 160.26 | 156.95 |
| 170,000 | 201.67 | 195.43 |
| 180,000 | 281.54 | 281.54 |

APPENDIX B

The marginal user cost allocation method involves equating the marginal cost for each corridor route. The marginal cost functions are sufficiently complex that an iteration technique is required. The iteration must be performed for each year during the projection period. Therefore, the following approximations were developed to allocate traffic between n highways without any iterations necessary.

The following approximation to the marginal cost functions are discussed in the main body of the report, and for n highways consist of,

$$\begin{aligned} \frac{1}{x_1(i)-a_1} &= b_1+c_1y_1(i) \\ \cdot & \\ \cdot & \\ \cdot & \\ \cdot & \\ \cdot & \\ \frac{1}{x_n(i)-a_n} &= b_n+c_ny_n(i) \end{aligned}$$

where i = 1 when ADT = 0
i = 3 when ADT = route capacity
x = marginal cost
y = ADT

Set the first highway such that

$$x_1(1) \leq \text{all other } x(1)\text{'s}$$

For each of the other highways, j = 2,...,n

if $x_1(1) = x_j(1)$, then $\alpha_j = 0$

If $x_1(1) < x_j(1)$, then

$$\alpha_j = \frac{b_j - b_1 [1+b_j(a_1-a_j)]}{c_1[1 + b_j(a_1 - a_j)]}$$

If $x_1(3) = x_j(3)$, then

$$\beta_j = \frac{y_1(3) - \alpha_j}{y_j(3)}$$

If $x_1(3) > x_j(3)$, then

$$y_1 = \frac{b_j + c_j y_j(3) - b_1 [1 + (a_1 - a_j)(b_j + c_j y_j(3))]}{c_1 [1 + (a_1 - a_j)(b_j + c_j y_j(3))]}$$

$$\beta_j = \frac{y_1 - \alpha_j}{y_j(3)}$$

If $x_1(3) < x_j(3)$, then

$$y_j = \frac{b_1 + c_1 y_1(3) - b_j [1 + (a_j - a_1)(b_1 + c_1 y_1(3))]}{c_j [1 + (a_j - a_1)(b_1 + c_1 y_1(3))]}$$

$$\beta_j = \frac{y_1(3) - \alpha_j}{y_j}$$

These calculations derive the coefficients for the following set of equations,

$$y_1 = \alpha_j + \beta_j y_j \text{ for all } j = 2, \dots, n$$

ADT for the first route is a linear function of each of the other routes. To solve the equations, the corridor traffic constraint is required,

$$y_1 + y_2 + \dots + y_n = T$$

where T = total corridor traffic

This gives a set of simultaneous equations which can be solved for the desired y_1, y_2, \dots, y_n with a given T .

$$y_1 = \frac{\sum_{j=2}^n (\alpha_j \prod_{i=2, i \neq j}^n \beta_i) + T (\prod_{i=2}^n \beta_i)}{\sum_{j=2}^n (\prod_{i=2, i \neq j}^n \beta_i) + \prod_{i=2}^n \beta_i}$$

$$y_j = \frac{y_1 - \alpha_j}{\beta_j} \text{ for all } j = 2, \dots, n$$

For example when $n = 2$,

$$y_1 = \frac{\alpha_2 + \beta_2 T}{1 + \beta_2}$$

$$y_2 = \frac{y_1 - \alpha_2}{\beta_2}$$

when $n = 3$,

$$y_1 = \frac{\alpha_2 \beta_3 + \alpha_3 \beta_2 + T \beta_2 \beta_3}{\beta_2 + \beta_3 + \beta_2 \beta_3}$$

$$y_2 = \frac{y_1 - \alpha_2}{\beta_2}$$

$$y_3 = \frac{y_1 - \alpha_3}{\beta_3}$$

Recommended HEEM Program Changes

1. Substitute proposed demand subroutine, including HMC subroutine, for the current demand subroutine. A flow chart of the proposed demand subroutine and the HMC subroutine are contained in this appendix.
2. Make the appropriate changes to the cost calculation subroutine CALC03.
 - a. Take one lane of capacity out of existing highway when contraflow lane constructed.
 - b. Incorporate occupancy rates into value of time calculations. This also requires that the values of time on card 1 of the input data be in terms of value of time per person rather than volume of time per vehicle.
 - c. Incorporate occupancy rates into accident cost calculations.

Between program lines 11900 and 11910 the following should be inserted,

```
IF(ICTF.NE.1) GOTO 12
IF(L1.NE.1) GOTO 12
IF(L.NE.1) GOTO 12
IF(Y.EQ.ICYR) GOTO 12
DO 50 K1=1,11
CTFSTR(K1) = TABLE (K1,X)
50 CONTINUE
TABLE (1,X) = TABLE (1,X)-30000.
TABLE (6,X) = 9866.906/TABLE(1,X)
```

```

TABLE (7,X) = 5.4897/TABLE (1,X)
IF(HSW(1).EQ.29..OR.HSW(1).EQ.30..OR.HSW(1).EQ.31..OR.HSW
(1).EQ.32..OR.HSW(1).EQ.33..OR.HSW(1).EQ.38..OR.HSW(1).EQ.
39.) GOTO 14
TABLE (2,X) = TABLE (2,X)-18750.
TABLE (9,X) = 3.2-(TABLE (1,X)/300000.)
GOTO 12
14 TABLE (2,X) = TABLE (2,X)-20000.
TABLE (9,X) = 2.88-(TABLE(1,X)/329670.)

```

Between program lines 12470 and 12480, the following should be inserted,

```

IF(L2.EQ.2) GOTO 27
XVT(L2)=XT(L2)*ASSUMP(L2+1)*OCCPC(L1)*(1.+ASSUMP(4))**(Y-1)
GOTO 21

```

Between program lines 13560 and 13570, the following should be inserted,

```

DO 60 K2=1,11

```

```

TABLE (K2,HSW(1))=CTFSTR(K2)

```

```

60 CONTINUE

```

The following program lines should be changed,

```

11910      12 IF(L.NE.1) GOTO 31
12310      1HSW(L1).EQ.32..OR.HSW(L1).EQ.33..OR.HSW (L1).EQ.
          38..OR.HSW(L1).EQ.39) GOTO 40
12480      27 XVT(L2)=XT(L2)*ASSUMP(L2+1)*OCCPT(L1)*(1.+ASSUMP
          (4))**(Y-1)
12840      ACCOST=TABLE (8,X)*( .414*OCCP(L1)+.47)*ACCNO*(1.+
          ASSUMP(4))**(Y-1)

```

3. Add HOV highway types in Table 1 to Highway Specification Table.
 - a. Add table data between program lines 580 and 590
 - b. Add highway type names in program line 840.
 - c. Assign index values between program lines 6050 and 6060.
 - d. Set urban, rural switch program line 6260.
 - e. Change the dimension of Table, program lines 40, 60, 600, 8890, 9700, 11600, 13600, 13950, and 14370.
4. Read in additional values for the proposed highway, card 4, and expansion of proposed highway, card 5, between program lines 5130 and 5140, and change GOTO in line 5100, if these values are different from the initial assumptions on card 1.
 - a. Card columns 44-47, percent trucks, ASMHOV(1).
 - b. Card Columns 49-52, value car time, ASMHOV(2).
 - c. Card columns 54-57, value truck time, ASMHOV(3).
 - d. Card columns 59-62, car occupancy rate, OCHOV(1).
 - e. Card columns 64-67, truck occupancy rate, OCHOV(2).

Include these variables in the common arrays for each subroutine

If the proposed highway is an HOV project, then default factors must be provided in the event they are not specified on the input cards.

Recommended Values

$$\text{ASMHOV}(1) = \text{ASSUMP}(1)$$

$$\text{ASMHOV}(3) = 2.6 * \text{ASSUMP}(2)$$

$$\text{OCHOV}(2) = 40.0$$

If the HOV is a contraflow lane (UIT), set the contraflow switch, ICTF, equal to one, then

$$\text{ASMHOV}(2) = 2.6 * \text{ASSUMP}(2)$$

$$\text{OCHOV}(1) = 8.7$$

If the HOV is not a contraflow lane, then

$$\text{ASMHOV}(2) = 2.1 * \text{ASSUMP}(2)$$

$$\text{OCHOV}(1) = 3.7$$

Print out the values used in the model for HOV projects and convert ASMHOV(1) to decimal form.

5. Check buildover switch, program lines 5090-5110, it must be equal to zero if the proposed highway is an HOV project.
6. If the proposed highway is an HOV project, then change printout to reflect the person allocation between the build and no-build alternatives in addition to the vehicle allocation.
 - a. Put the title "Vehicle Demand" above the lines printed in line 7430.
 - b. Put a separate "Total" for the do-nothing demand and if construct demand, since they may be different for an HOV project. The title is in program line 7430 and the numbers in lines 7460-7480.
 - c. Printout the person allocation similar to the vehicle allocation, including a title and the demand for every 5th year.
7. Include in the common array for each subroutine the following additional variables,
 - a. The car occupancy rate for each highway, OCCPC(4)
 - b. The truck occupancy rate for each highway, OCCPT(4)
 - c. The person demand for each highway, DEMAND(6,40,2)
 - d. The contraflow switch, ICTF.

Variable Dictionary

| | |
|-----------|--|
| AAMC(1-3) | intercept term for the linear relationship between highway types in allocating traffic. AAMC(1-2) for 3 highway allocation, AAMC(3) for 2 highway allocation |
| AC | marginal accident cost |
| ADAT | variable used in calculation of slope for linear relationships between highway types in allocating traffic |
| ADT | variable indicating person demand for each loop of marginal cost calculations |
| AF | intercept term in approximation fo speed/volume relationship |
| ALL(1-3) | variable to indicate the highways available for allocation |
| AMC(1-3) | calculated variable for each highway type. Used in marginal cost approximation |
| AO | variable used in marginal cost calculation |
| ASMHOV(1) | percent trucks (buses) for HOV lane(s) |
| ASMHOV(2) | time cost (\$/min) for cars (vans) per person for HOV lane(s) |
| ASMHOV(3) | time cost (\$/min) for trucks (buses) per person for HOV lane(s) |
| BBMC(1-3) | slope term for the linear relationships between highway types in allocating traffic. BBMC(1-2) for 3 highway allocation, BBMC(3) for 2 highway allocation |
| BF | slope term in approximation of speed-volume relationship |
| BMC(1-3) | calculated variable for each highway type, used in marginal cost approximation |
| CMC(1-3) | calculated variable for each highway type, used in marginal cost approximation |
| CY | marginal cycling costs |
| CY1 | variable used in marginal cycling cost calculation |

CY2 variable used in marginal cycling cost calculation

DEMAND(1) person demand on existing road

DEMAND(2) person demand on proposed road

DEMAND(3) person demand on diversion road

DEMAND(4) person demand on alternate road

DEMAND(1,Y,L) vehicle demand on existing road

DEMAND(2,Y,L) vehicle demand on proposed road

DEMAND(3,Y,L) vehicle demand on diversion road

DEMAND(4,Y,L) vehicle demand on alternate road

F1 variable used in approximating number of cycles for a metered freeway

FY speed (mph) on a particular highway type given a vehicle demand

FY1 first derivative of FY, used in marginal cost calculation

G1 variable used in approximating number of cycles for a metered freeway

HMC(KX,KY) highway marginal cost per person for highway KX and ADT index KY

IC index used in calculation of marginal cost approximations for 3 highway allocation. IC=1 calculations performed for highway ALL(1), IC=2 calculations performed for highway ALL(2), IC=3 calculations performed for highway ALL(3)

ICS variable to hold highway type in calculation of variables for marginal cost approximations in 3 highway allocation

ICTF swich indicating if proposed highway is a contraflow lane, ICTF=1 if proposed route is contraflow, ICTF=0 if not

IH index for adjusting percent trucks, and occupancy rates for HOV highway types

| | |
|----------|--|
| IJ | index for highway type in conversion of allocated person demand into vehicle demand |
| IR | index used to indicate the number of highways which require marginal cost calculations |
| ISW(1-3) | variable to indicate the order of allocation ISW(3)=highway with lowest initial marginal cost, first to receive traffic allocation |
| J1 | working variable used in linear relationships between highway costs |
| J3 | working variable used in linear relationships between highway costs |
| JA | index used in calculation of marginal cost approximations for 2 highway allocation. JA=1, calculations performed for highway ALL(1), JA=2, calculations performed for highway ALL(2) |
| JASW | JASW=1 if capacity marginal cost for highway ALL(2) is less than initial marginal cost for highway ALL(1) in 2 highway allocation, JASW=0 otherwise |
| JB | index to calculate linear relationships between the highway types. JB=1 will calculate $ISW(3) = \alpha_1 + \beta_1 (ISW(1))$, JB=2 will calculate $ISW(3) = \alpha_2 + \beta_2 (ISW(2))$ |
| JBSW | JBSW=1 if capacity marginal cost for highway ALL(1) is less than initial marginal cost for highway ALL (1) in 2 highway allocation, JBSW=0 otherwise |
| JSWC | variable to hold highway type in calculation of variables for marginal cost approximations of 2 highway allocation |
| JW1 | index for highway type with higher initial marginal cost in two highway allocation |
| JW2 | index for highway type with lower initial marginal cost in two highway allocation |
| K1 | index to adjust table for reduced number of lanes on existing road for contraflow lane project |
| KX | index to indicate highway type in marginal cost calculation |

KY index which indicates the proportion of highway capacity to be used in marginal cost calculation. KY=1 at 0, KY=2 at 1/2 capacity, KY=3 at capacity

L index indicating run type, 1=do nothing, 2=construct

LSW switch to indicate if variables to allocate traffic involving 3 highways have to be calculated. LSW=1 if the variables must be calculated initially or any change occurs such that they must be recalculated. LSW=0 otherwise

LSWC switch to indicate if variables to allocate traffic involving 2 highways have to be calculated. LSWC=0 if the variables must be calculated initially or any change occurs such that they must be recalculated. LSWC=1 otherwise

N03 variable used to hold minimum range at demand calculation; in regular run N03 always equals 1, in optimum N03 equals 1 once and 2 several times

N04 variable used to hold maximum range of demand calculation: In regular run N04 always equals 2, in optimum N04 equals 1 once and 2 several times

OCCP(1-4) weighted average occupancy rate for each highway type

OCCPC(1-4) car(van) occupancy rate for each highway type, will equal 1.3 unless highway is HOV

OCCPT(1-4) truck (bus) occupancy rate for each highway type, will equal 1.0 unless highway is HOV

OCHOV(1) car (van) occupancy rate for HOV highway

OCHOV(2) truck (bus) occupancy rate for HOV highway

P1 variable used in calculation of marginal accident costs

PADT(1-4) person capacity of each highway type adjusted for technical performance factor

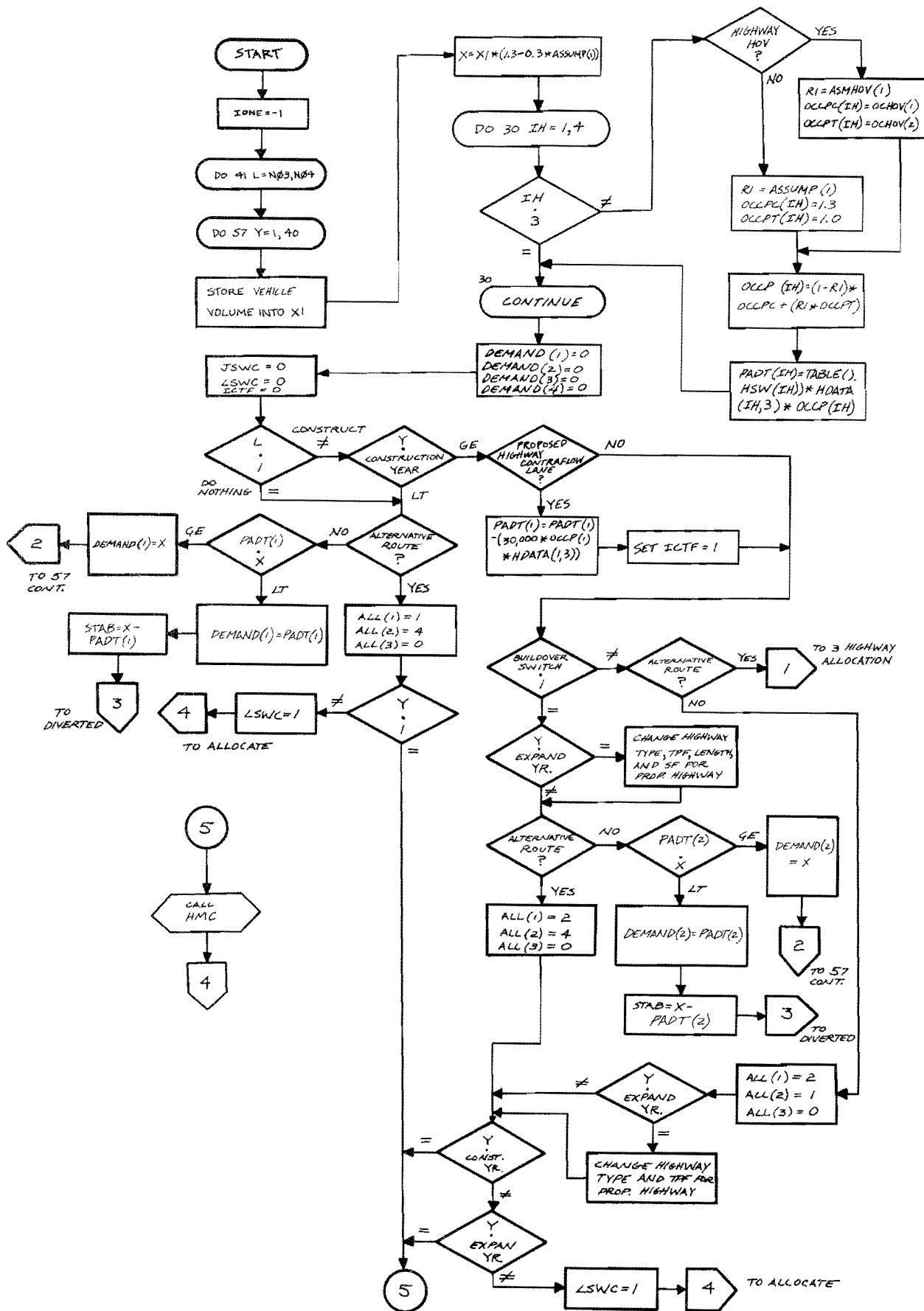
P0 variable used in marginal time cost

R1 percent trucks, will equal assumption 1 unless highway is HOV

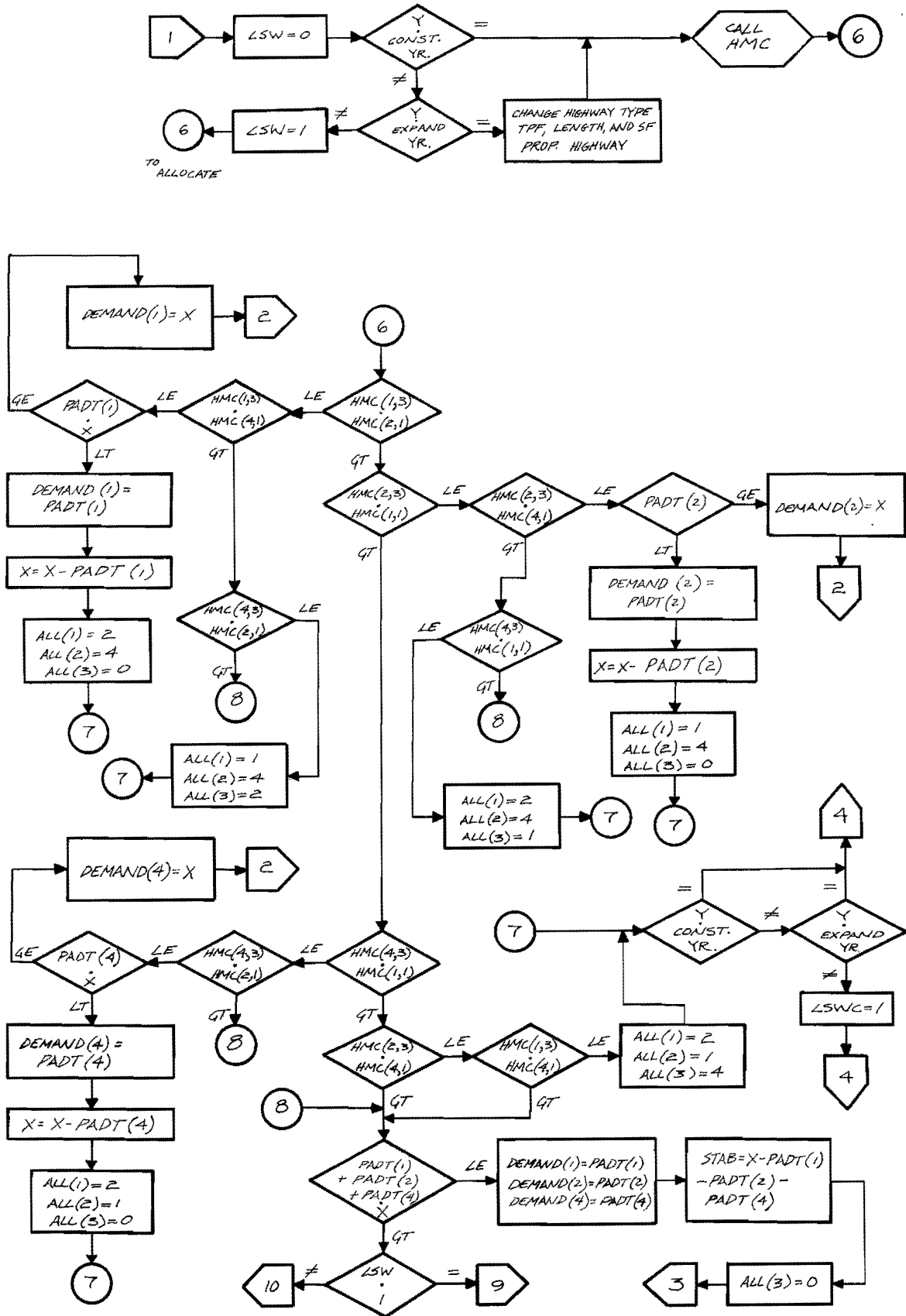
R2 percent cars $R2=1-R1$

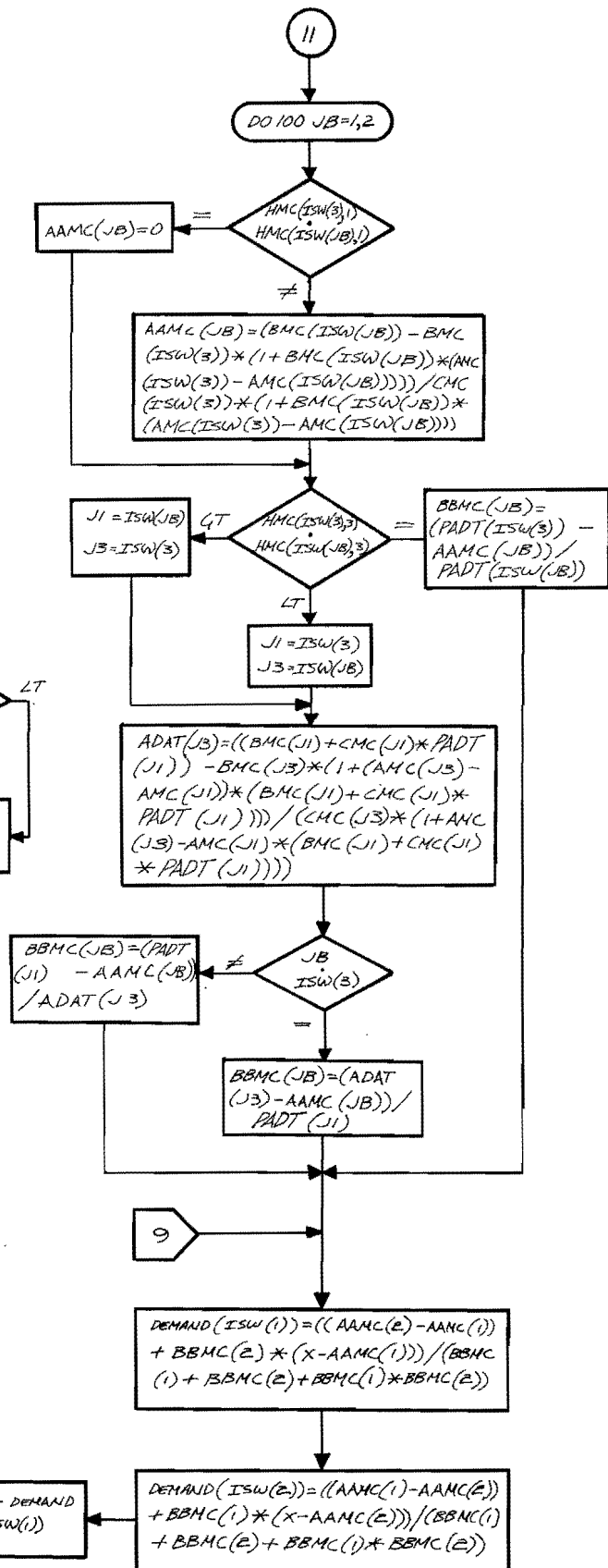
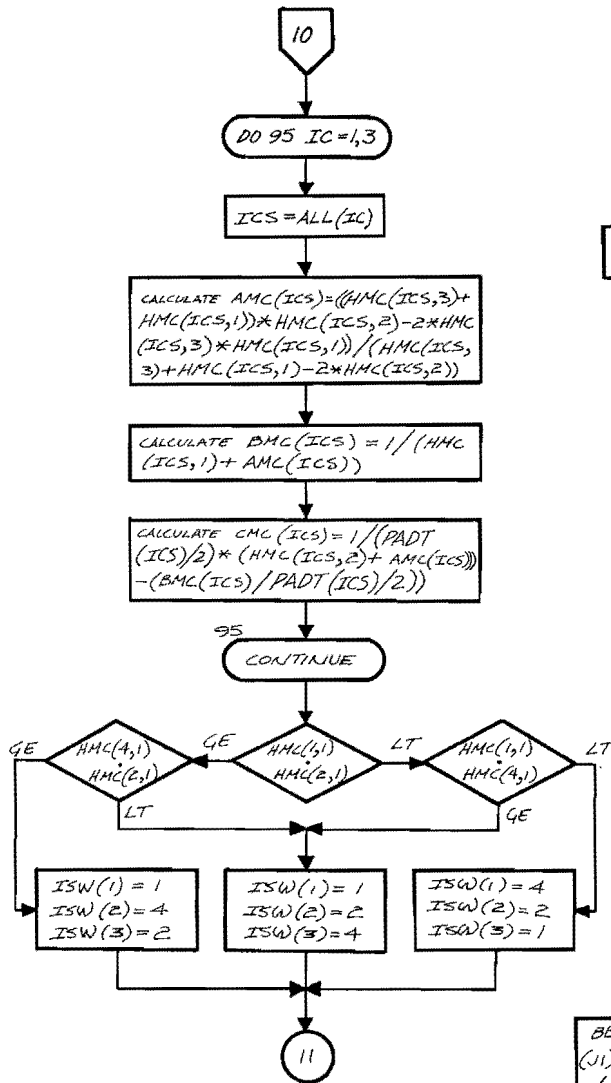
| | |
|-------------|---|
| RN | marginal running cost |
| STAB | traffic to be allocated to diverted route, or in allocations with a proposed, existing, and alternate route, traffic to be allocated to one after the other two have reached capacity |
| TBLE(1,IX) | person capacity of highway IX |
| TBLE(2,IX) | person breakpoint of highway IX |
| TBLE(3,IX) | beginning speed of highway IX |
| TBLE(4,IX) | breakpoint speed of highway IX |
| TBLE(5,IX) | capacity speed of highway IX |
| TBLE(6,IX) | intercept for number of cycles of highway IX |
| TBLE(7,IX) | slope for number of cycles of highway IX |
| TBLE(8,IX) | mean accident cost for highway IX |
| TBLE(9,IX) | intercept for number of accidents of highway IX |
| TBLE(10,IX) | slope for number of accidents of highway IX |
| TBLE(11,IX) | average maintenance cost/mile of highway IX |
| TC | car (van) time cost, used in marginal cost calculations |
| TPF | technical performance factor/100 |
| TT | truck (bus) time cost, used in marginal cost calculations |
| VT | marginal time cost |
| X | variable containing the amount of person traffic volume (by year) available for allocation |
| X1 | variable containing the amount of expanded vehicle traffic volume (by year) available for allocation |
| Y | index indicating year (1-40) |
| Y1 | variable to indicate person demand for each loop of marginal cost calculation |

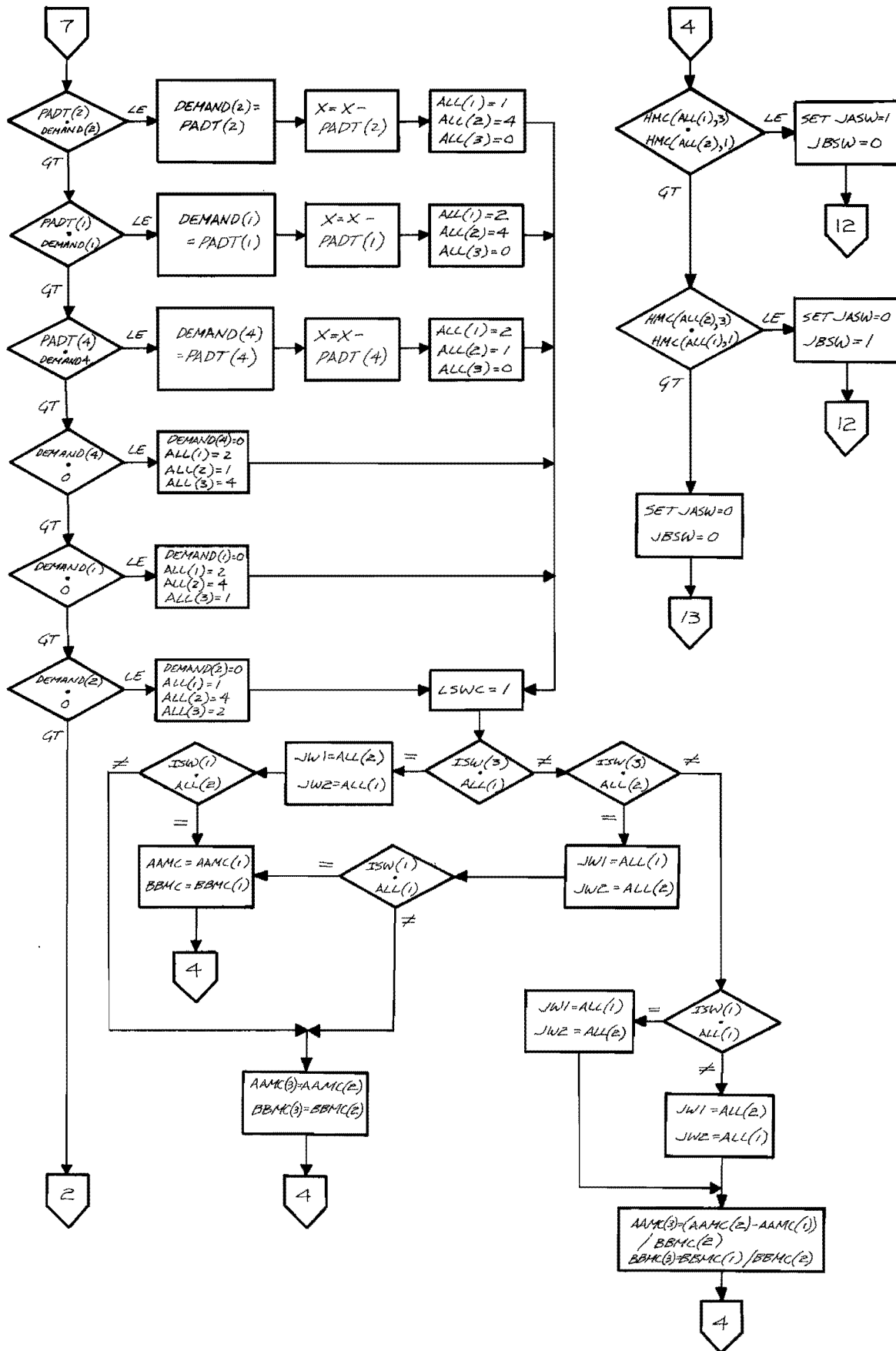
PROPOSED DEMAND SUBROUTINE

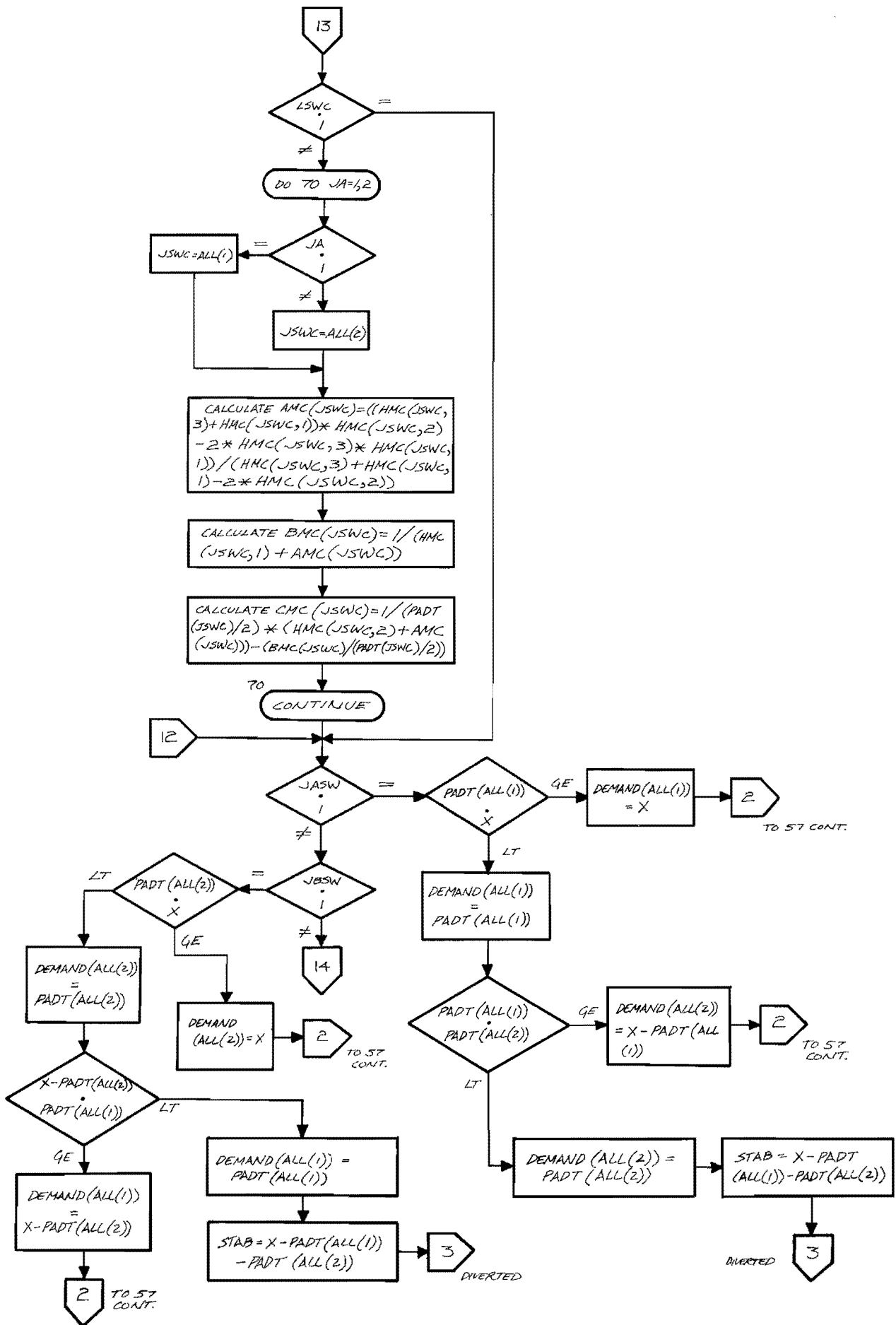


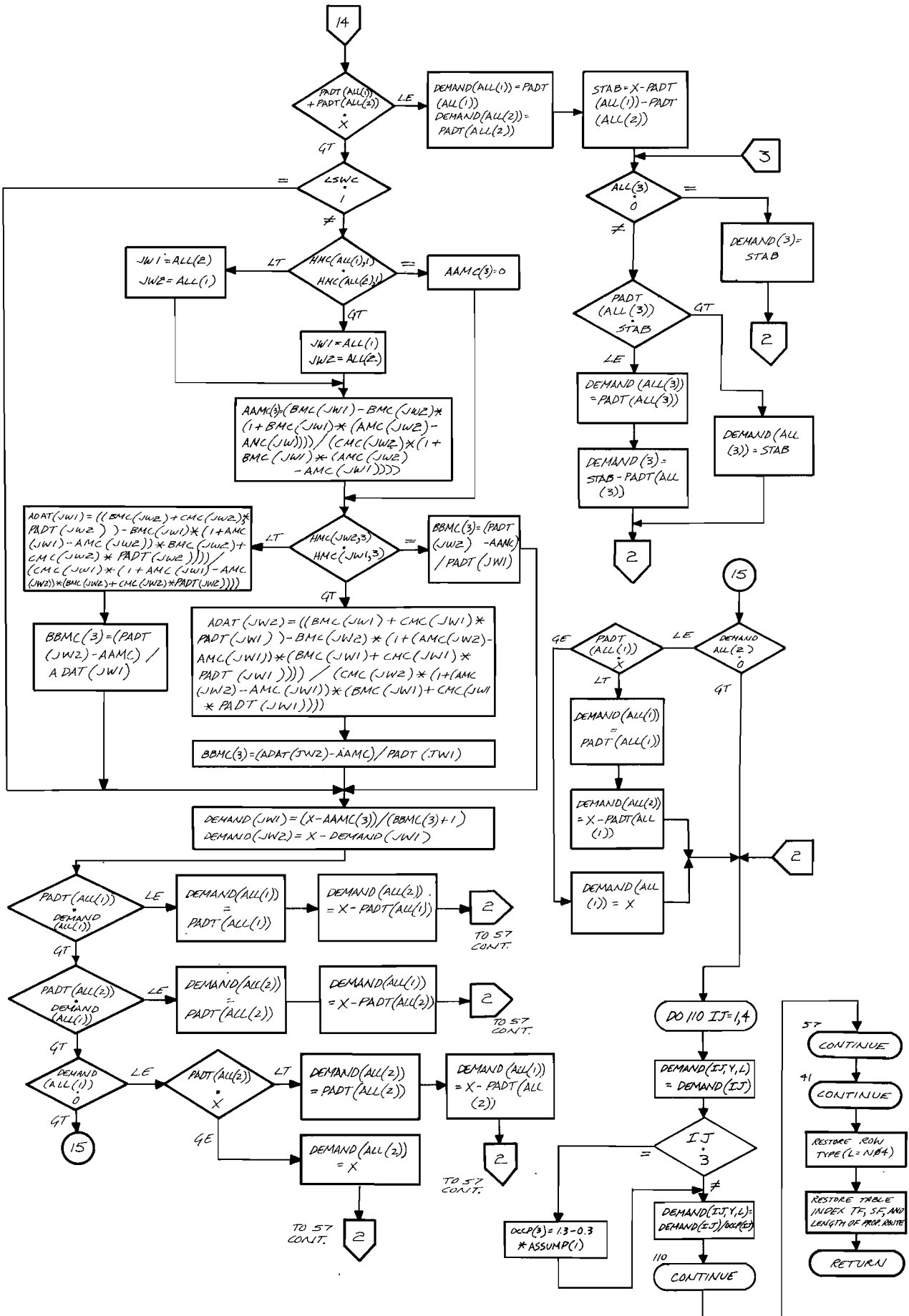
THREE HIGHWAY ALLOCATION



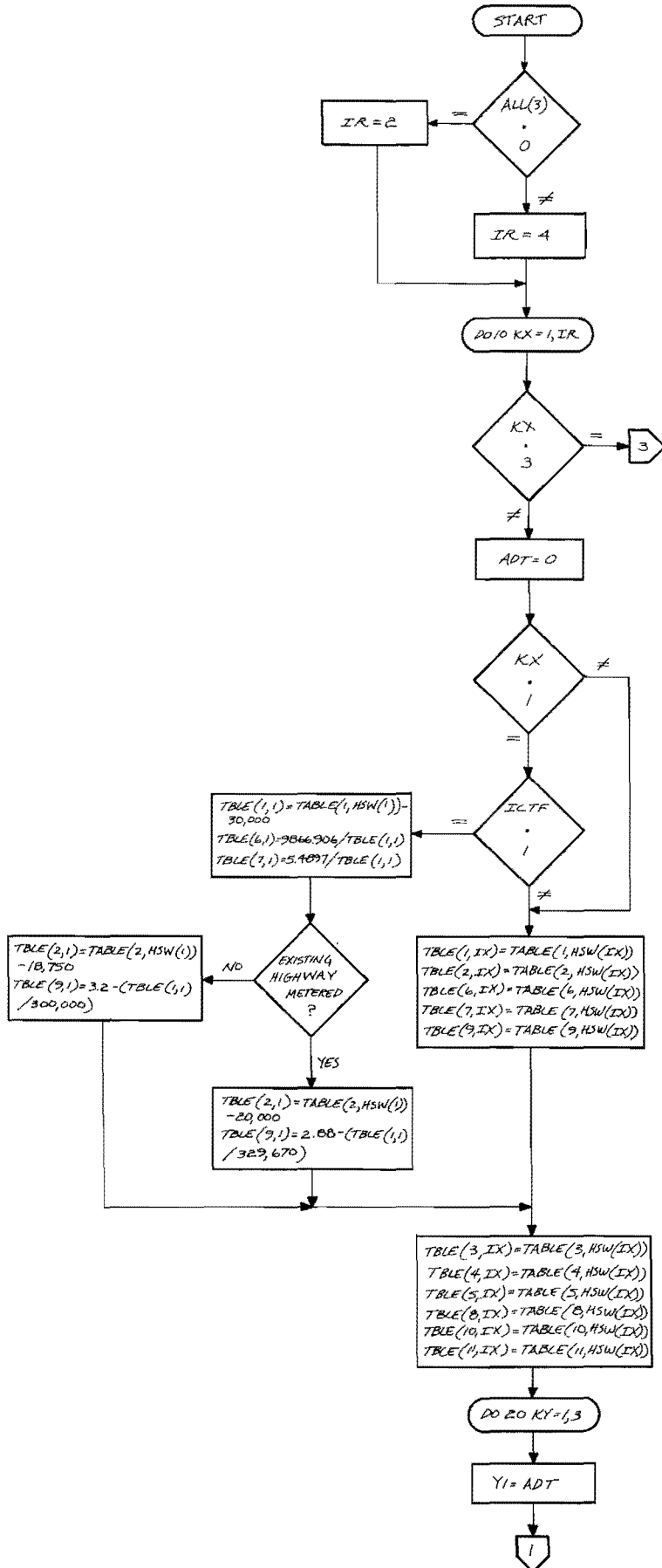




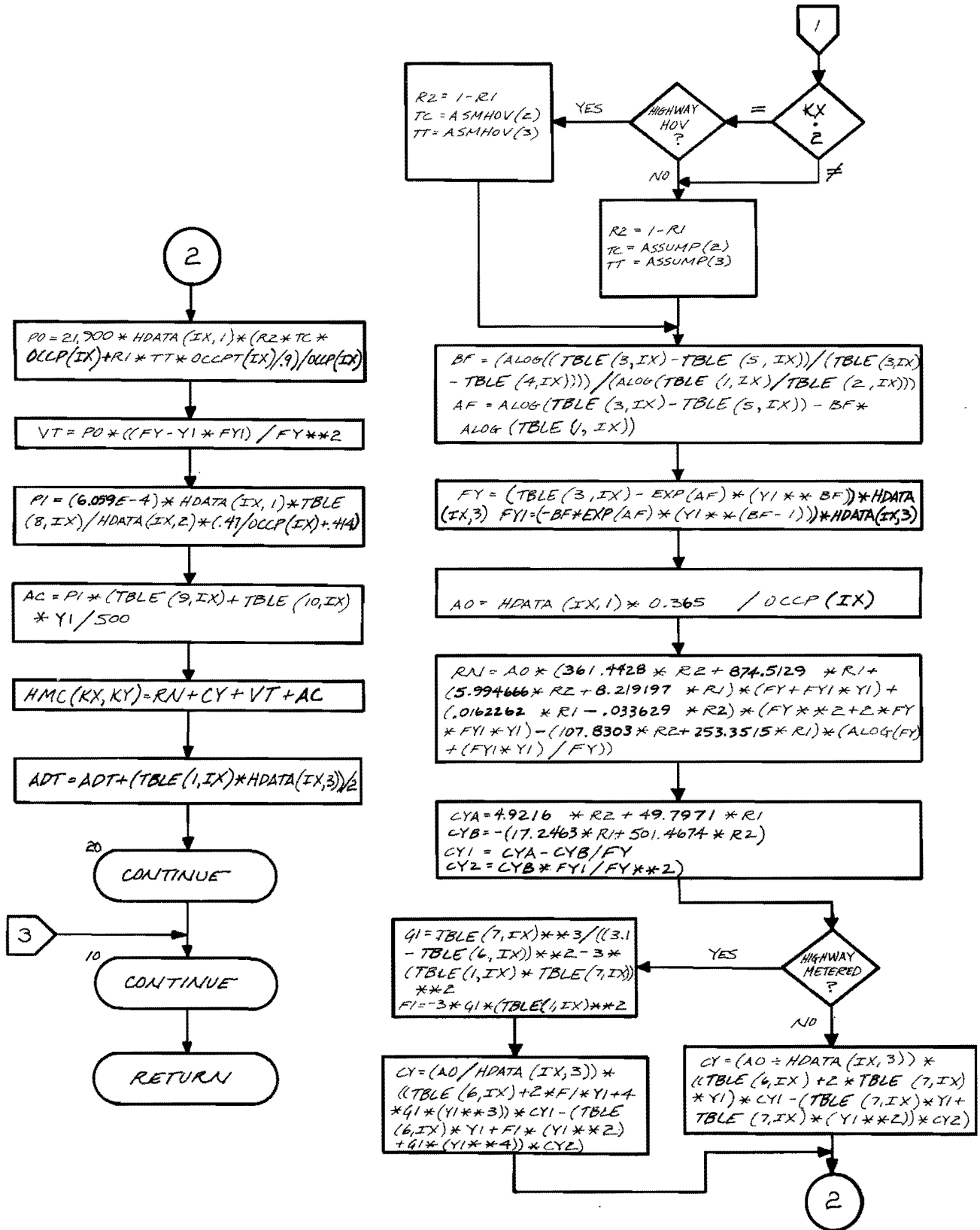




Subroutine for HMC (Highway Marginal Cost)



Subroutine for HMC (Highway Marginal Cost)



Proposed Input Cards

Card 4: Proposed Highway

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|----|---|
| 1 | Problem No.* |
| 2 | Segment No.* |
| 3 | Card Type* |
| 4 | Highway Type* |
| 5 | Length* (Miles) |
| 6 | Safety Factor* (Base = 100) |
| 7 | Technical Factor* (Base=100) |
| 8 | Speed Limit (mph) |
| 9 | Construction Year* |
| 10 | Construction Cost* (\$1,000,000) |
| 11 | Bulldover |
| 12 | Percent Trucks (Buses) |
| 13 | Value Car (van) Time per person (\$/min.) |
| 14 | Value Truck Time per person (\$/min.) |
| 15 | Car (van) Occupancy Rate per Vehicle |
| 16 | Truck (bus) Occupancy Rate per Vehicle |
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Card 5: Expansion of Proposed Highway

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| 1 | Problem No.* |
| 2 | Segment No.* |
| 3 | Card Type* |
| 4 | Highway Type* |
| 5 | Length* (Miles) |
| 6 | Safety Factor* (Base = 100) |
| 7 | Technical Factor* (Base=100) |
| 8 | Speed Limit (mph) |
| 9 | Expansion Year* |
| 10 | Construction Cost* (\$1,000,000) |
| 11 | Percent Trucks (Buses) |
| 12 | Value Car (van) Time per person (\$/min.) |
| 13 | Value Truck Time per person (\$/min.) |
| 14 | Car (van) Occupancy Rate per Vehicle |
| 15 | Truck (bus) Occupancy Rate per Vehicle |
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Card 6: Alternative Route

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|----|------------------------------|
| 1 | Problem No.* |
| 2 | Segment No.* |
| 3 | Card Type* |
| 4 | Highway Type* |
| 5 | Length* (Miles) |
| 6 | Safety Factor* (Base = 100) |
| 7 | Technical Factor* (Base=100) |
| 8 | Speed Limit (mph) |
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