APPLICATIONS MANUAL FOR LOGIT MODELS OF EXPRESS BUS-FRINGE PARKING CHOICES

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

Manual computations and computerized applications of logit models are described. The models demonstrated reflect travel behavior concerning express bus-fringe parking transit. The specific travel issues addressed include the basic automobile vs. express bus transit choice, model transferability between two study areas, submodal split, and n-dimensional choice modeling. A series of curves derived from the mathematical models are presented in the appendices to simplify computations. A FORTRAN subroutine for using these models within the UTPS battery of computer programs for transportation planning is provided.

PREFACE

This report is one of two which describe the implementation portion of a three-phased study concerning planning procedures for express bus-fringe parking subarea transit. The first two phases concerned the analysis of the application of existing techniques and the development of design guidelines and choice models, respectively.

The implementation of logit models of travel choice behavior estimated in the preceding phase of this study program are the focus of this report. Both manual and computer applications are considered, with emphasis on the former. Another report which was prepared simultaneously with this one describes a planning process wherein these choice models are used. The companion document is titled "A Procedural Method for Express Bus-Fringe Parking Planning" and is available from the Virginia Highway and Transportation Research Council.

The author acknowledges those colleagues who provided significant contributions to this report. Jerry L. Korf, research engineer, developed the FORTRAN subroutine and descriptive information given in Appendix E. Larry Caldwell, graduate assistant, developed the figures given in Appendices A through D, and assisted in preparing the example problems.

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INTRODUCTION

The purpose of this manual is to demonstrate hand computations and potential computerized uses of logit models of express bus-fringe parking choice behavior that were calibrated in a previous study.[1] A series of plots of the mathematical functions are given in the appendices to simplify use of the models. The implementation of these logit choice models in a practical planning context is demonstrated in another report.[2]

The specific models described in the text and shown in the appendices are:

1. A binary auto-transit choice model stratified by residential zone accessibility to the fringe lot;

2. binary auto-transit choice models from two study areas (unstratified);

3. park'n ride vs. kiss 'n ride submodal split model; and

4. an n-dimensional choice model (auto to CBD vs. park 'n ride vs. kiss 'n ride).

MANUAL APPLICATIONS

Direct Application: Auto vs. Transit Choice

The mathematical form of the logistic model is stated by equation (1) for the binary choice case.*

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*The binary choice is a special case of an n-dimensional set of choices (any number) where the computations are less complex than for the general case. An n-dimensional choice model which considers the automobile, bus (park 'n ride) and bus (kiss 'n ride) is described in a subsequent section.

$$P_b = \frac{e^{G_i(X)}}{1 + e^{G_i(X)}} \qquad (1)$$

or, alternatively, if the numerator and denominator are divided by $G_i(X)$,

$$P_b = \frac{1}{1 + e^{-G_i(X)}} \qquad (2)$$

where

P_b = the probability of choosing the express bus,

i = a model stratification index, and

$G_i(X)$ = a linear function of explanatory variables

specifically,

$$G_i(X) = b_0 + b_1X_1 + b_2X_2 \dots + b_nX_n. \qquad (3)$$

Calibration of this model requires that values be estimated for the "b" coefficients, which can be done for the logistic model as conveniently as for a linear regression model by using the ULOGIT program in the Urban Transportation Planning System (UTPS) of computer models.

This report focuses on the application of previously calibrated models within the transit planning process. The development of the models used here is described elsewhere.(1) Accordingly, selected models are chosen from reference 1 to show example applications in the forecasting or prediction mode.

A typical set of binary choice models is given in Table 1 for 4 stratification levels relative to zonal accessibility to the fringe lot. The variables and respective strata are defined in Table 2. The $G_i(X)$ for the relative values model* defined in Table 1 are expressed by equations (4) through (7).

*The term "relative values model" refers to the manner by which the alternative model characteristics are specified, i.e., the travel time or cost of a certain mode divided by the average of the automobile and bus times or costs for the journey.

$$G_0(X) = 2.7839 + 1.0883X_2 - 3.5738X_3 + 6.6795X_4 + 3.3517X_5 \quad (4)$$

$$G_1(X) = 2.3732 - 1.3416X_1 + 1.1430X_2 - 2.3536X_3 + 4.2932X_4 + 3.3990X_5 \quad (5)$$

$$G_2(X) = 4.3230 - 1.3092X - 3.9319X_3 + 10.8990X_4 + 4.7533X_5 \quad (6)$$

$$G_3(X) = 1.4384X_2 - 4.7783X_3 + 8.5377X_4 + 4.7783X_5 \quad (7)$$

Table 1

Relative Values Model
(Binary Case)

Estimated Model Coefficients

Independent* Variable	Accessibility Group 1	Accessibility Group 2	Accessibility Group 3	All Data
X_1	-1.3416	-1.3092	-0.8207**	-0.5294**
X_2	1.1430	0.3443**	1.4384	1.0883
X_3	-2.3536	-3.9319	-4.7517	-3.5738
X_4	4.2932	10.8990	8.5377	6.6795
X_5	3.3990	4.7533	4.7783	3.5717
Constant	2.3732	4.3230	2.0465**	2.7839

Evaluative Measures

X^2	30.05	33.03	36.20	94.8
e_1	0.21%	0.22%	0.24%	0.88%
P_b at zero diff.	0.554	0.532	0.236	0.451
e^2	—	—	—	2.22%

*Variables are defined in Table 2.

**Indicates variable or constant was found to be nonsignificant at the 0.05 level.

Table 2

Variables Used

Independent Variable	Symbol
Sex 0 = female; 1 = male	X_1
Age 0 = (25-44); 1 = otherwise	X_2
$\frac{\text{No. household autos}}{\text{No. licensed drivers}}$	X_3
Total time difference divided by average total time	$X_4 = \frac{T_a - T_b}{(T_a + T_b)/2}$
Total cost difference divided by average total cost	$X_5 = \frac{C_a - C_b}{(C_a + C_b)/2}$

Accessibility Groups

Group 1. Trips from zones adjacent to zone where lot is located.

Group 2. Trips from zones whose minimum time route to the CBD passes through the area where the lot is located.

Group 3. Trips from zones whose minimum time routes to the CBS are out of the way from the lot.

Dependent Variable

Calibration: P_b = 0 for auto trips

P_b = 1 for bus trips

Application: P_b = probability of bus choice

Note: a = auto measure; b = express bus measure.

An examination of the relationship between Table 1 and equations (4) through (7) clarifies how the tabular form of the models as given in reference 1 represents the $G_i(X)$ for input into equations (1) or (2). The value of $G_i(X)$ by itself is meaningless; it must be used in conjunction with equation (1) to provide a value for the real dependent variable, P_b.

Example Estimates with Desk Calculator

The following example demonstrates estimates of transit choice probabilities that are obtained from logistic models using a hand calculator with an exponential function.

Example 1. Stratified binary choice model

The model used here is that given in Table 1. The three socioeconomic variables (X_1, X_2, X_3) and accessibility strata permit the specification of a variety of tripmaker groups. The following travel group is specified for the model:

Relative location	:	Accessibility Group 2
Sex	:	Male
Age	:	25-44
Household $\left[\frac{\text{Automobile}}{\text{Drivers}}\right]$	:	0.5

For accessibility group 2, equation (6) applies. For the given values of $X_1 = 1$, $X_2 = 0$, and $X_3 = 0.5$, equation (6) becomes

$$G_2(X) = 4.3230 - 1.3092(1) - 3.9319(.5) +$$

$$10.8990X_4 + 4.7533X_5 =$$

$$1.0478 + 10.8990X_4 + 4.7533X_5. \qquad (1.1)$$

Equation (1.1) accounts for all variables except the time and cost characteristics of the respective mode choices. Let us further specify that for a certain residential zone, lot location, and bus service conditions that the travel time for the automobile and bus modes are 20 minutes and 30 minutes, respectively. With these data, X_4 becomes

$$X_4 = \frac{T_a - T_b}{(T_a + T_b)/2} = \frac{20 - 30}{(20 + 30)/2} = -0.4. \quad (1.2)$$

Equation (1.1) now is reduced to

$$G_2(X) = 1.0478 + 10.8990\ (-0.4) + 4.7533X_5 =$$

$$- 3.311880 + 4.7533X_5. \quad (1.3)$$

The final measure to be considered relates to the relative costs of the competing modes, whereby inputting a specified value for this term gives an estimate of the probability of bus choice. For example, if the cost by automobile is estimated to be \$1.25 while the expense incurred via bus is \$0.50,

$$X_5 = \frac{C_a - C_b}{(C_a + C_b)/2} = \frac{1.25 - 0.50}{(1.25 + 0.50)/2} = \frac{0.75}{0.875} = 0.857. \quad (1.4)$$

Under these cost conditions which give X_5 a value of 0.8571, the value of $G_2(X)$ is

$$G_2(X) = - 3.3118 + 4.7533\ (0.8571) = 0.7622. \quad (1.5)$$

Now the value given by equation (1.5) is inserted into equation (1) to provide an estimate of the probability that male travelers between the ages of 25 and 44 who reside in households with 1 car for 2 licensed drivers select a fringe parking-express bus service which takes 30 minutes while auto takes 20 minutes and costs \$0.50, where the automobile trip is estimated to cost \$1.25.

$$P_b = \frac{e^{G_2(X)}}{1 + e^{G_2(X)}} = \frac{e^{0.7622}}{1 + e^{0.7622}} = 0.68 \quad (1.6)$$

Thus, the probability of transit choice for the aforementioned circumstances is computed to be 0.68.

Table 3 shows the results of a series of calculations from equation (1.3) for different values of ΔC. The computations for Example 1 are underlined. A plot of this curve is given in Figure 1. If Figure 1 (A/D = 0.5, ΔT = -10) is entered for ΔC = 0.75, P_b is directly obtained as 0.68 as in Example 1. Appendix A provides a set of similar curves (P_b vs. AC) for variations of the model for accessibility group 2 that result from changes in the explanatory variables. In practice, the planner can use these curves or develop his own as required. Example 2 and subsequent examples demonstrate the direct use of the graphs provided in the Appendices. Each appendix contains a definition of the figures contained therein.

Table 3

Data for Plot of Model Derived in Example 1

$$P_b = \frac{e^{-3.3118 + 4.7533X_5}}{1 + e^{-3.3118 + 4.7533X_5}}$$

C_a	C_b	D_c	X_5*	$G_2(X)$	P_b
2.00	0.50	1.50	1.200	2.3922	0.916
1.75	0.50	1.26	1.111	1.9691	0.878
1.50	0.50	1.00	1.000	1.4415	0.809
1.25	0.50	0.75	0.857	0.7618	0.682
1.00	0.50	0.50	0.667	-0.1413	0.465
0.75	0.50	0.25	0.400	-1.4105	0.199
0.50	0.50	.00	0.000	-3.3118	0.018
0.25	0.50	-0.25	-0.667	-6.4822	0.002
0.00	0.50	-0.50	-2.000	-12.8180	—

$$^*X_5 = \frac{C_a - C_b}{(C_a + C_b)/2}$$

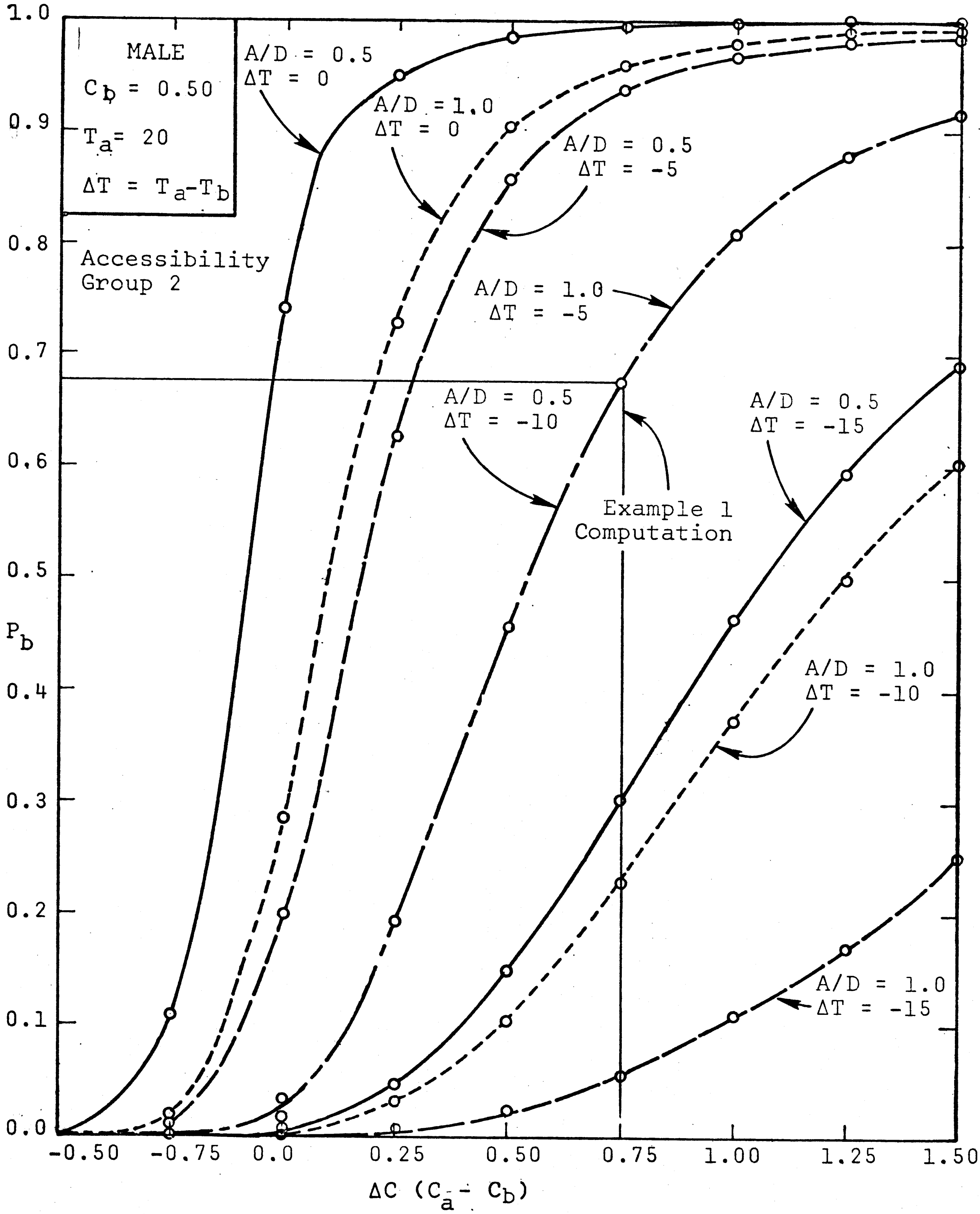

Figure 1. Example binary choice curve.

Example 2. Stratified binary choice model

a. Given: Male tripmaker, Auto/Drivers = 1
Automobile cost = \$1.25
Bus cost = \$0.50
Automobile travel time = 20 minutes
Bus travel time = 30 minutes

Find the percentage using the express bus for the stated conditions.

Solution: For T_a = 20, C_b = \$0.50 use Figure A.3
choose curve for A/D = 1, ΔT = -10
for ΔC = \$0.75, obtain P_b = 0.23

b. What percentage of the travel group defined in part(a) would choose the bus if the bus travel time were reduced to 20 minutes (ΔT = 0)?

Solution: Use Figure A.3, ΔT = 0, A/D = 1
For ΔC = 0.75, P_b = .96

c. Given: Female tripmaker, A/D = 0.5
Automobile cost = \$1.25
Bus cost = \$1.00
Automobile travel time = 20 minutes
Bus travel time = 25 minutes

Find the percentage using the express bus for the stated conditions.

Solution: For T_a = 20, C_b = 1.00 use Figure A.6.

Choose curve for A/D = 0.5, ΔT = -5
For ΔC = .25, P_b = .73

Model Transferability: Unstratified Binary Choice Models

The models to be presented here are mathematically similar to those given in the previous section, except that they are calculated with the entire data set, disregarding accessibility stratifications. The particular significance of this application is the contrast between the predictions obtained from the models calibrated in different cities. Accordingly, the analyst must be careful in selecting a model which relates to conditions similar to those in his study area and is, hence, transferable. Example 3 demonstrates a case in which two different models can be applied to separate sections of one city.

In this case the Richmond model was derived for travel from a homogeneous high income area to the central city. The Virginia Beach model was associated with travel from a diverse suburban area to a secondary employment center. The Richmond corridor experiences a high volume of CBD destined traffic, while only a small portion of the vehicles on the Virginia Beach-Norfolk corridor were actually destined for the Norfolk CBD, the destination of the express bus. Using this information as a guideline, it is therefore advisable to apply the Richmond model to situations which experience relatively large volumes of trips from a high income residential area to a dominant employment center. The Virginia Beach model is most applicable in cases where there are multiple employment centers.

In this case, the model given by equation (4) applies for Richmond and the counterpart model for the Virginia Beach-Norfolk area is stated by equation (8). Appendix B provides selected graphs of these models.

$$G_0(X) = 1.1625 - 3.2198X_3 + 2.9728X_4 + 1.9312X_5, \quad (8)$$

where X_3, X_4, X_5 are defined in Table 2.

Example 3. Unstratified binary choice model (alternate models available)

a. Given: Automobiles/Drivers = 0.5
Automobile cost = $1.00
Bus cost = $0.50
Automobile travel time = 20 minutes
Bus travel time = 30 minutes
Subarea characteristics: High income, concentrated employment center

Number of CBD work trips generated = 1000
Number workers between ages 25 and 44 = 450
Number workers other ages = 550

Find the number of expected express bus users.

Solution: For A/D = 0.5, T_b = 30, T_a = 20, C_b = $0.50
Use Figure B3. Use "Richmond" curves for a high income area with a concentrated employment center.

For ages 25-44 and AC = 0.50 } P_b = 0.67

For others and AC = 0.50 } P_b = 0.857

$$\text{Expected number of bus users} = P_b^{25-44} N^{25-44} + P_b^{other} N^{other}$$

$$= .67 \times 450 + .857 \times 550$$

$$= 302 + 471 = 773$$

b. Given: Auto/Drivers = 0.7
Automobile cost = $0.76
Bus cost = $0.50
Automobile travel time = 30 minutes
Bus travel time = 30 minutes
Subarea characteristics: Dispersed employment areas

Find number of expected express bus users for a distribution of 450 workers between the ages of 25 and 44 and 550 workers of others ages destined for the area served by the express bus.

Solution: Figures B7 and B8 apply. Select Virginia Beach model for dispersed employment centers. Interpolating for A/D = 0.7, the model predicts 43.5%, or 435, trips by bus. Note that the age distribution is not reflected be the Virginia Beach model and is, hence, irrelevant data.

Submodel Split Models

Estimates of express bus patronage are not in themselves sufficient for the design of a fringe lot and the related traffic facilities. The actual means by which the users access the service will determine many design requirements. Accordingly, models of the access mode choice can be used to determine the needed parking spaces, pick-up and drop-off lanes, and bicycle storage areas.

The majority of the users of the Parham Express in Richmond arrived by either the park 'n ride or kiss 'n ride mode. Hence the data were sufficient to develop only a binary choice model for the two automobile based modes. This model is given by equation (9) and plotted in Appendix C.

$$P_d = -2.2231 + 5.5835X_3 \qquad (9)$$

Where

P_d = The probability of a bus user parking their car at the lot, and

X_3 = Automobiles/Drivers.

Example 4. Submodal split.

a. How many of the 773 bus riders in part(a) of example 3 can be expected to park their cars at the lot?

A/D = 0.5
From Figure C.1, P_d = 0.395 which projects 305 riders

b. How many of the 435 bus travelers in part(b) of example 3 would access the service via the kiss 'n ride mode?

From Figure C.1, P_k = .66 or 287 riders.

Multimodal Choice Models

In this section an n-dimensional choice model which simultaneously considers the basic automobile-transit and transit access decisions is introduced. This model performs a function similar to that which previously had been shown to be accomplished by two binary choice models. Similar models can be calibrated with the ULOGIT program in the UTPS system. Since it is the purpose of this report to demonstrate application, no specific model strategy (i.e., 2 binary models vs. the n-dimensional model) is recommended at this time.

The model applied here is a generalization of the basic logistic model as stated by equation (1). The computations proceed as follows with the variables defined by Table 2. First compute equations (10), (11), and (12) using the linear functions defined in equations (13) and (14).

$$P_d = \frac{1}{1 + e^{G_a(X)} + e^{G_k(X)}} \qquad (10)$$

$$P_a = \frac{e^{G_a(X)}}{1 + e^{G_a(X)} + e^{G_k(X)}} \tag{11}$$

$$P_k = 1 - P_d - P_a \tag{12}$$

$$G_a(X) = 1.8503 - 0.8776X_1 - 1.9550X_2 -$$

$$3.8446X_4 - 4.9552X_5 \tag{13}$$

$$G_k(X) = 2.1623 - 2.0600X_1 - 1.9700X_2 - 3.6987X_3 \tag{14}$$

where

d refers to the park 'n ride access mode and express bus,
k refers to the kiss 'n ride access mode and express bus,
a refers to an automobile trip to the CBD, and
P_i is the probability of selecting mode i.

A fully competitive modification as described in reference 1 is next used to refine the choice probability estimates.

$$Y_d = P_d\ (1 + Qu_d) \tag{15}$$

$$Y_k = P_r\ (1 + Qu_k) \tag{16}$$

$$Y_a = P_a\ (1 + Qu_a) \tag{17}$$

Where

$Q = 1/3$,

$u_i = P_i - \sum_{j=1}^{M} P_j^2$,

$i, j = 1,2,3$, and

$M = 3$.

Example 5 shows how direct estimates of the number of trip-makers using each of these alternative travel strategies are obtained with an n-dimensional logit model. Curves developed for this model are given in Appendix D.

Example 5.. n-dimensional logit model (automobile to CBD vs. Express Bus as accessed by park 'n ride or kiss 'n ride)

a. Given: Population = 500 females
Age = 25-44
Automobile/Driver = 0.85
Automobile travel cost = \$1.25
Bus travel cost = \$0.50
Auto travel time = 22 minutes
Bus travel time = 30 minutes

Find the number of this subgroup using each modal strategy.

Solution: For female, Age = 25-44, C_a = \$1.25 C_b = \$0.50, T_b = 30 use figures D.26 and D.27 (must interpolate from A/D = .5 and A/D = 1.0 for A/D = 0.85).

The values of the P_i obtained from Figures D.26 and D.27 for $\Delta T = -8$ and the interpolated values for A/D = 0.85 are shown in Table 4. The following volumes are obtained for each mode.

Park 'n ride = N_d = 0.593 X 500 = 297

Kiss 'n ride = N_k = 0.248 X 500 = 124

Automobile to CBD = N_a = 0.158 X 500 = 79

TOTAL 500

b. Given: Population = 500 males
Age = 25-44
Automobile/Driver = 0.35
Automobile travel cost = \$1.35
Bus travel cost = \$0.50
Automobile travel time = 20 minutes
Bus travel time = 30 minutes

Find the number of this subgroup using each modal strategy.

Solution: For male, age = 25-44, T_a = 20, T_b = 30, C_b = \$0.50. Use Figures D.10 and D.11 for A/D = 0 and 0.5.

The values obtained for the P_i from Figures D.10 and D.11 for ΔC = \$0.85 are shown in Table 5. The following volumes are predicted for each mode.

Park 'n ride = N_d = 0.946 X 500 = 473

Kiss 'n ride = N_k = 0.042 X 500 = 22

Automobile to CBD = N_a = 0.010 X 500 = 5

TOTAL = 500

C. Given: Population = 500 males, Age = 25-44
Automobile/Driver = 0.35
Automobile travel cost = \$1.35
Bus travel cost = \$0.50
Automobile travel time = 24 minutes
Bus travel time = 30 minutes

Find the number using each of the three modes.

Solution: In order to use the figures in Appendix D, we must first interpolate for A/D and then for T_a. This is accomplished by using the results from part b (Table 5) and generating Table 6 from figures D.22 and D.23. Interpolating between Tables 5 and 6 gives the values required for this problem which are shown in Table 7. The following volumes are estimated for each mode.

Park 'n ride = N_d = 0.95 X 500 = 475

Kiss 'n ride = N_k = 0.042 X 500 = 21

Automobile to CBD = N_a = 0.007 X 500 = 4

TOTAL =500

Table 4

Values of P_i for Example 5a

Automobile/Driver Model Choice Probabilities	0.5 (Fig. D.26)	0.85	1.0 (Fig. D.27)
P_d	0.368	0.593	0.690
P_k	0.529	0.248	0.127
P_a	0.105	0.158	0.180

Table 5

Values of P_i for Example 5b

Automobile/Driver Model Choice Probabilities	0 (Fig. D.10)	0.35	0.5 (Fig. D.11)
P_d	0.885	0.946	0.972
P_k	0.104	0.042	0.015
P_a	0.010	0.010	0.010

Table 6

Values of P_i for T_a = 24 for Example 5c

Automobile/Driver Model Choice Probabilities	0 (Fig. 0.22)	0.35	0.5 (Fig. 0.23)
P_d	0.893	0.9555	0.981
P_k	0.163	0.042	0.016
P_a	0.004	0.003	0.002

Table 7

Final Values of P_i for Example 5c

T_a / Model Choice Probabilities	20	24	30
P_d	0.946	0.950	0.955
P_k	0.042	0.042	0.042
P_a	0.010	0.007	0.003

COMPUTER APPLICATIONS

Travel demand models (i.e., separate trip generation, distribution and model choice models or combinations thereof) are implemented within the computerized UTPS through the program UMODEL. Although this UMODEL program can perform a variety of functions, the application of concern here involves the framework provided for employing user-furnished models. In this discussion of the application of the choice models it is assumed that the user is familiar with the UTPS programs. On this basis, the details of the UTPS procedures are left to other sources. Accordingly, the discussion here focuses only on the data and FORTRAN subroutine needed to apply the fringe parking choice models within the UTPS system.

Figure 2 shows the data that are processed through a series of UTPS programs for use by demand models. In this case, the dependent variable of interest is the percentage transit (including submodal split). This framework also permits the preparation of trip interchange tables, which when used in conjunction with the choice probabilities produce modal travel volumes between O-D pairs. Figure 3 shows the processing of the trip end and trip interchange data by program UMODEL into modal travel volumes. This problem application is further exemplified by Figure 4.

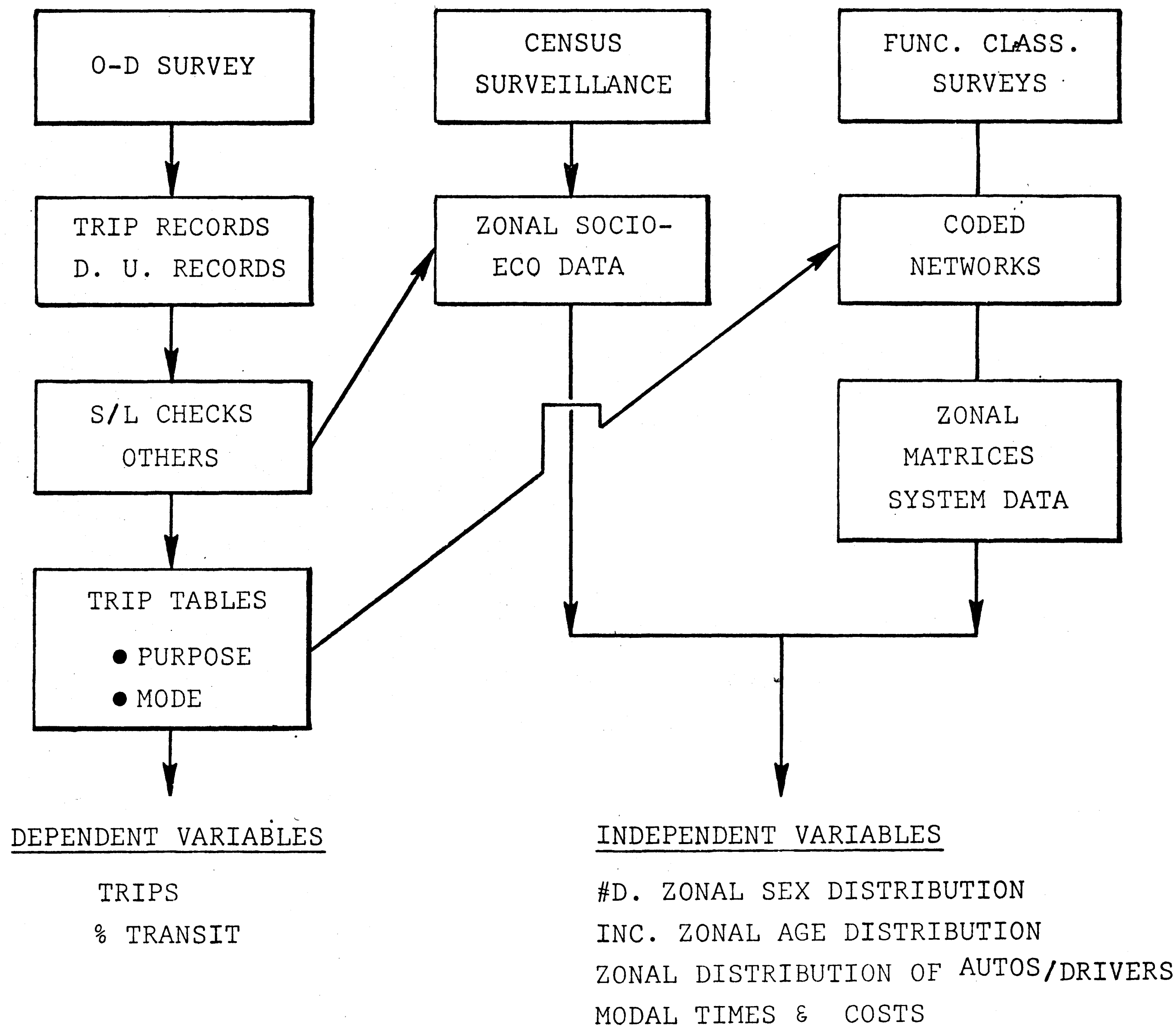

Figure 2. Data for zonal level modeling.
Source: UTPS Training Session Notes, UMTA.

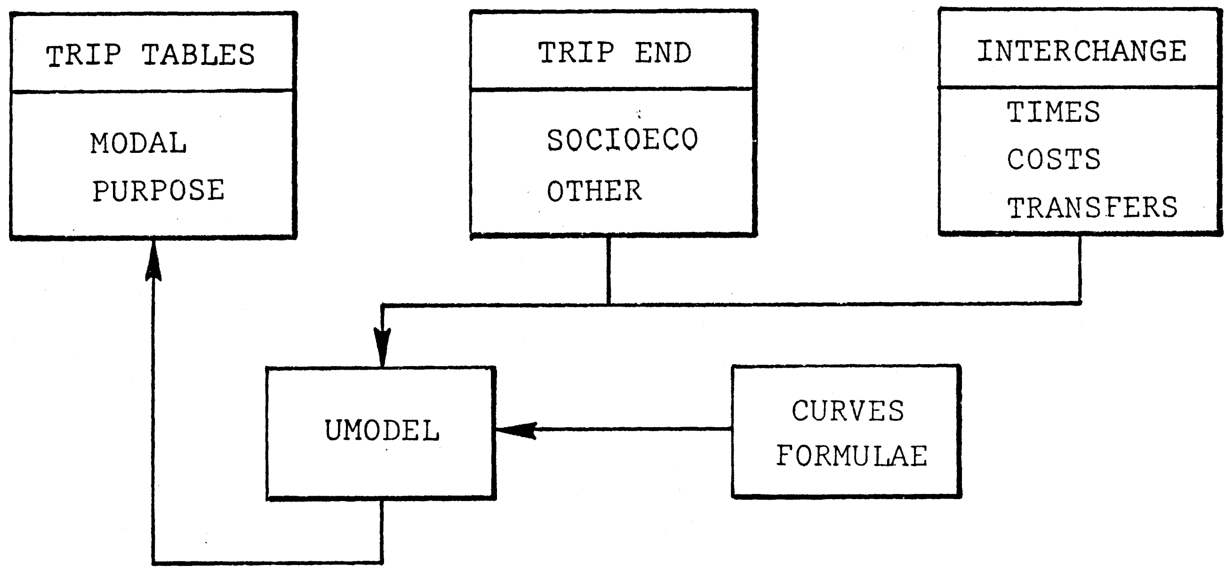

Figure 3. UMODEL-application mode.

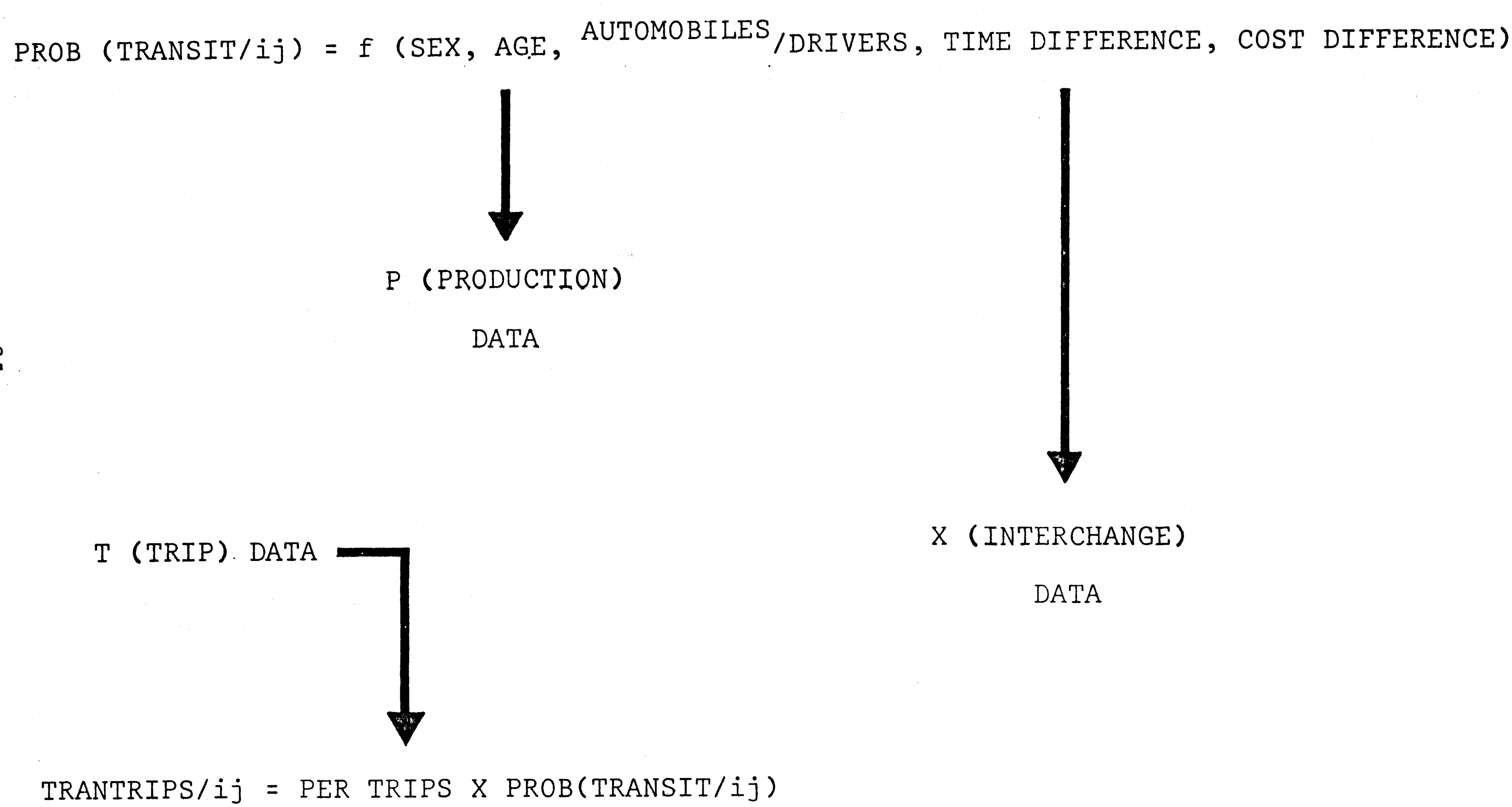

Figure 4. Example problem.

FORTRAN Subroutine

To apply a specific mode choice model within the UTPS package, the user must provide his own FORTRAN program. For this purpose, the user has FORTRAN access to program UMODEL through a user coded subroutine (MODE 13). This subroutine has six entry points, each of which is intended to perform specific tasks. The names of these entry points are MOD13A, MOD13B, MOD13C, MOD13D, MOD13E, and MOD13F. MOD13E applies to the problem of concern here; that is, applying a mode choice model to a trip interchange matrix. The user is referred to the UTPS documentation for details on MOD13E.

An example FORTRAN program which implements the $G_2(X)$ logit model as defined in equation (6) is given in Appendix E. The variable designations and file names used are intended to conform with those used in the UTPS training sessions give by Urban Mass Transportation Administration. It is hoped that this feature will simplify the understanding of the program given to those who have attended the training session.

All of the models that were shown in the manual computations section can be utilized within the computerized UTPS planning package. These computer programs can be adapted to follow the planning procedures developed in reference 2 for express bus-fringe parking subarea transit planning. Planners experienced with the UTPS methodology will intuitively note the significance of this application.

CONCLUSIONS

This report shows the planning practitioner computations with logit models of estimates of express bus-fringe parking travel behavior. The majority of the material covered focuses on manual planning tools, while their use within a procedural planning framework is described in a complementary document.[2]

The emphasis of this report has been on the manual rather than computerized uses of the models in order to convey a straightforward description of the mechanics of models whose theoretical derivations were introduced in an earlier report.[1] Also because computer applications require a working knowledge of the UTPS planning system, it was felt that the general user of this document would best benefit by material on manual applications. However, those with UTPS experience will find the computer program that has been included to be helpful.

This report therefore provides engineers and planners concerned with urban transportation planning a ready reference for interpreting research results concerning logistic models of travel choice behavior. The specific models demonstrated here can be applied during the sketch planning and design phases of fringe parking-express bus services as described in reference 2.

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APPENDIX A

PARHAM EXPRESS BINARY CHOICE MODEL CURVES

Appendix A contains a representative set of curves derived from the logit choice models of auto to CBD vs. express bus choice behavior for the Parham Express in Richmond, Virginia. The purpose of these charts is to provide the planner a means for estimating express bus-fringe parking usage without having to master the mathematics of the model. A representative sample of the curves that can be developed for accessibility group 2 is given. If additional curves are needed (for example, for the other accessibility groups) the procedures given in the text of this report can be easily applied.

The figures provided are first classified according to the primary independent variable, and then according to variations of the variables which specify the constant for the model. For example, if the curve represents the probability of bus choice (P_b) vs. the relative costs of the competing modes (ΔC), then the variables which are assumed constant include sex, age, $\frac{\text{households}}{\text{drivers}}$, and the relative travel times of the two modes. A further assumption regarding each curve is that the value of cost for one mode must also be held constant (e.g. $C_b = 0.50$, C_a varies).

The basic model plotted here is

$$P_b = \frac{e^{G(X)}}{1 + e^{G(X)}} \qquad \text{(A-1)}$$

where

$$G(X) = 4.3230 - 1.3092X_1 - 3.9319X_3 + 10.8990X_4 + 4.7533X_5,$$

$$X_1 = 0, 1 \text{ (male, female)},$$

$$X_3 = A/D = \text{number household autos/ number drivers},$$

$$X_4 = \frac{T_a - T_b}{(T_a + T_b)/2}$$

$$X_5 = \frac{C_a - C_b}{(C_a + C_b)/2}$$

a = auto mode, and

b = bus mode

The curves provided for accessibility group 2 are as follows:

A.1 P_b vs. ΔC (8 curves)

Constants: Male, C_b = \$0.25 T_a = 20

Variables: A/D = 0.5, 1
ΔT = 0, -5, -10, -15 } 2 x 4 = 8 Curves

A.2 Same as A.1 except for females

A.3 Same as A.1 except C_b = \$0.50 (Parham Express Cost)

A.4 Same as A.3 except females

A.5 Same as A.1 except C_b = \$1.00

A.6 Same as A.5 except females

A.7 P_b vs. ΔC (8 curves)

Constants: Male, C_a = \$1.25, T_a = 20

Variables: A/D = 0.5, 1
ΔT = 0, -5, -10, -15 } 2 x 4 = 8 curves

A.8 Same as A.7 except female

A.9 Same as A.7 except C_a = \$2.50

A.10 Same as A.9 except female

A.11 P_b vs. ΔT (4 curves)

Constants: Male, T_b = 20, C_b = \$0.50

Variables: A/D = 0.5, 1
C_a = \$1.25, \$2.50 } 2 x 2 = 4 curves

A.12 Same as A.11 except female

A.13 Same as A.11 except $T_b = 30$

A.14 Same as A.13 except female

A.15 Same as A.11 except $T_b = 40$

A.16 Same as A.15 except female

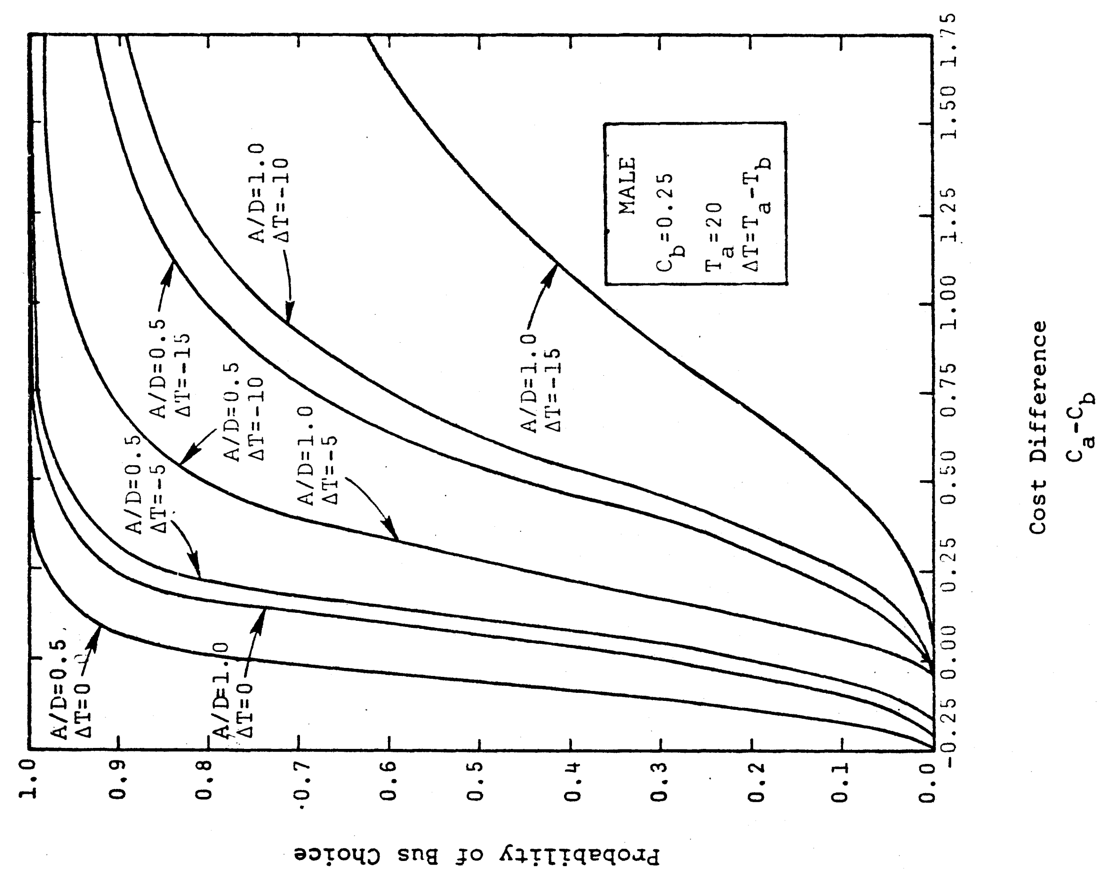


Figure A-1

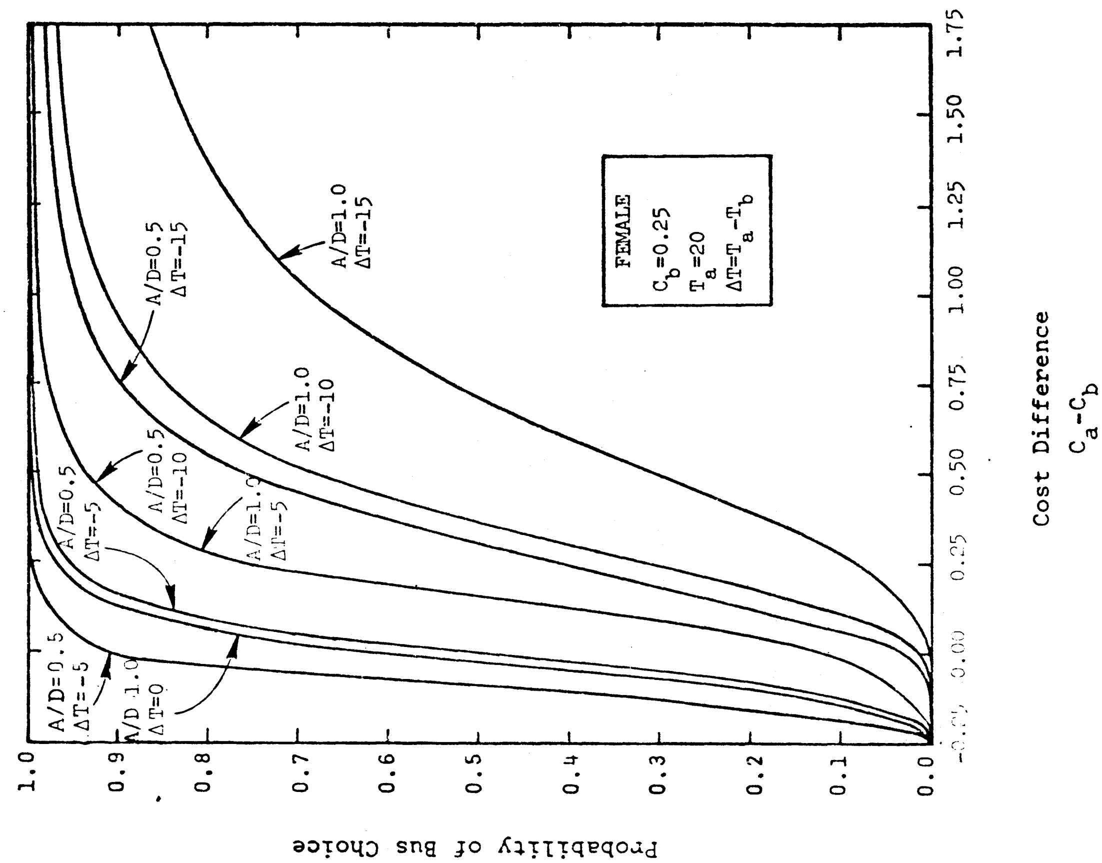
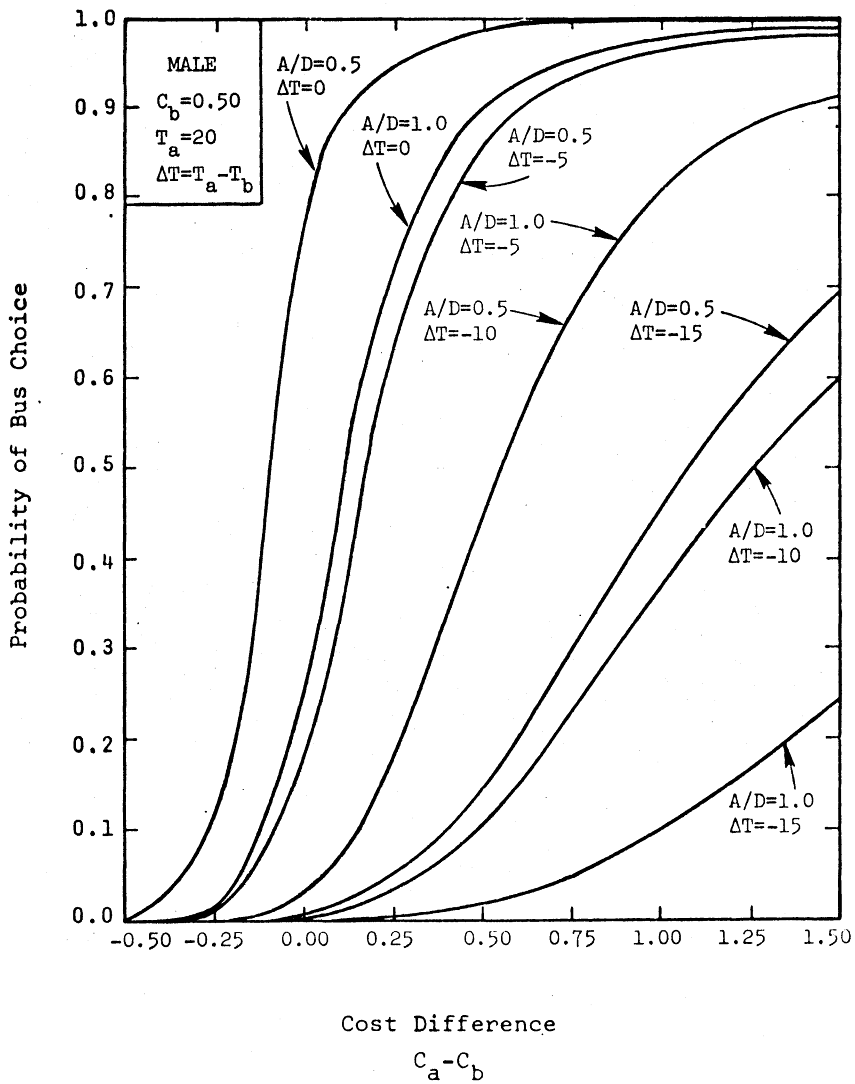


Figure A-2



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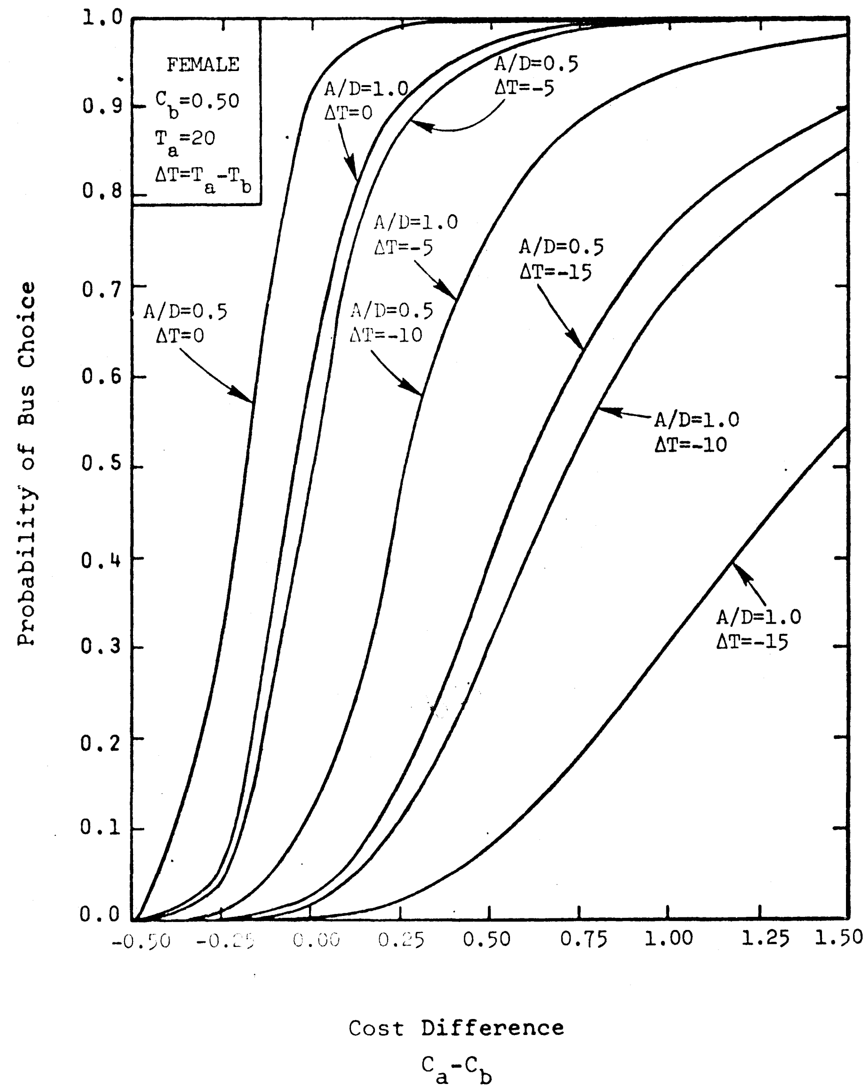

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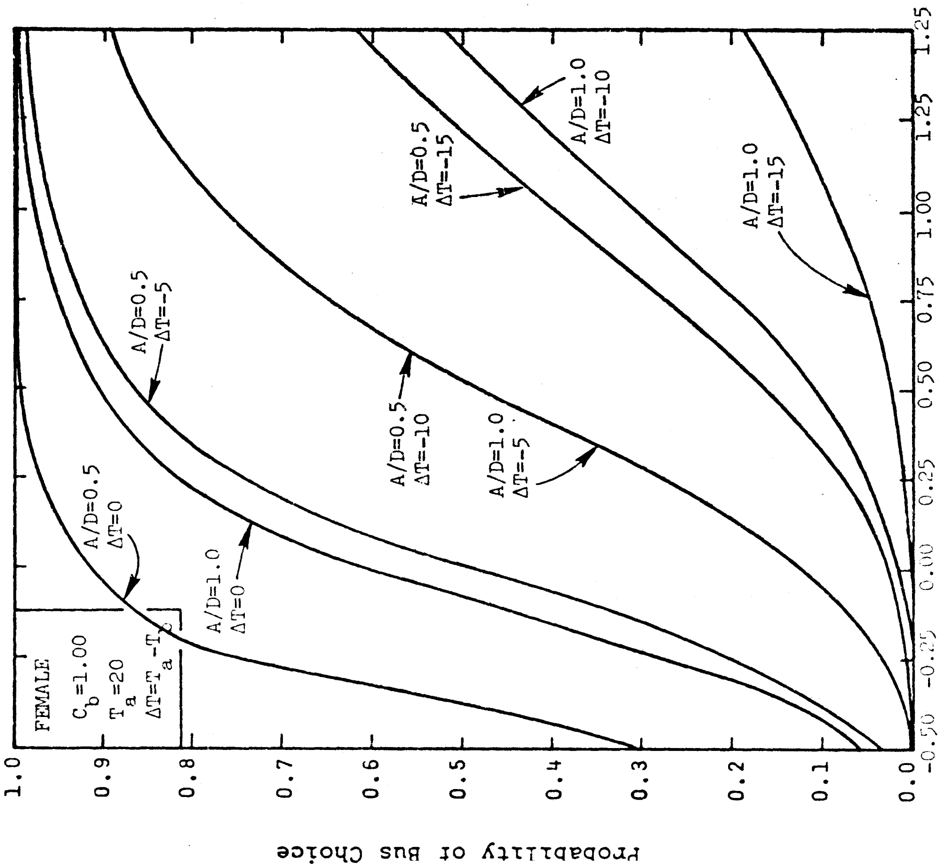
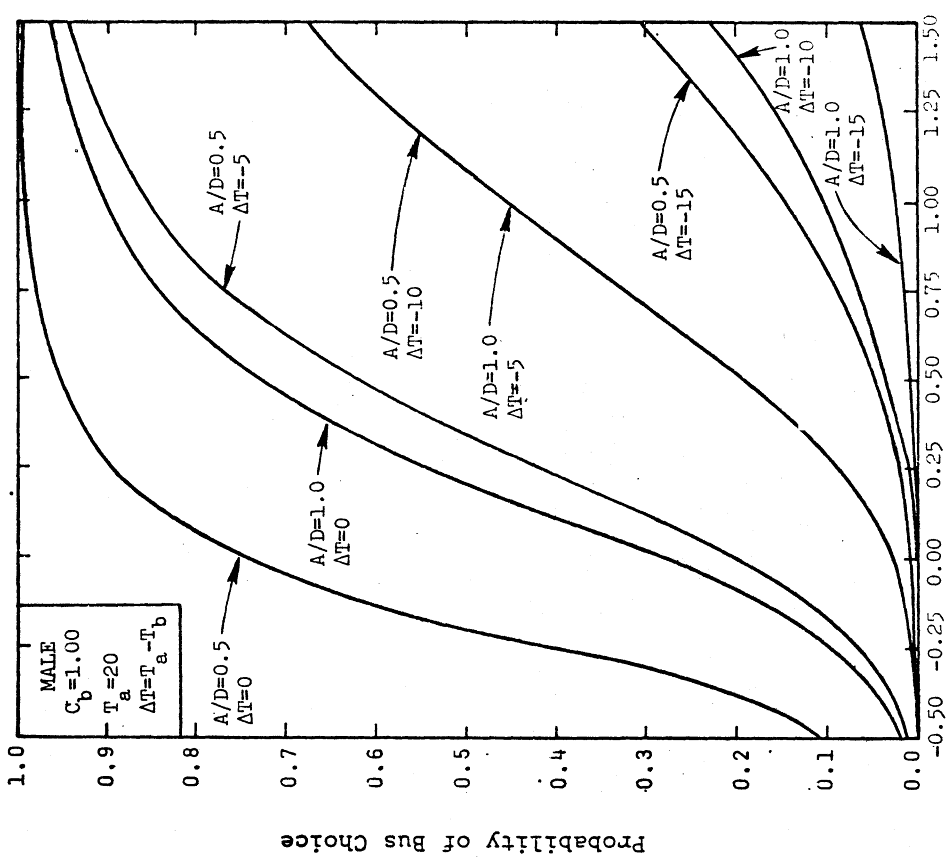


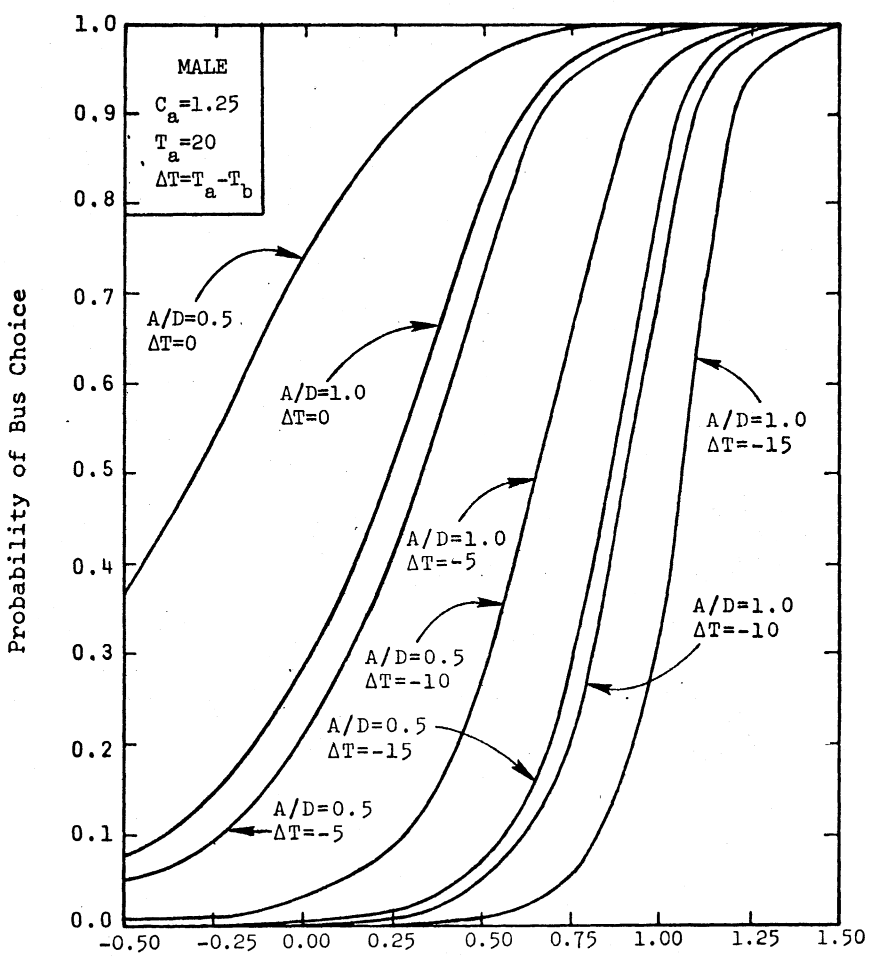
Cost Difference
C_a-C_b

Figure A-6



Cost Difference
C_a-C_b

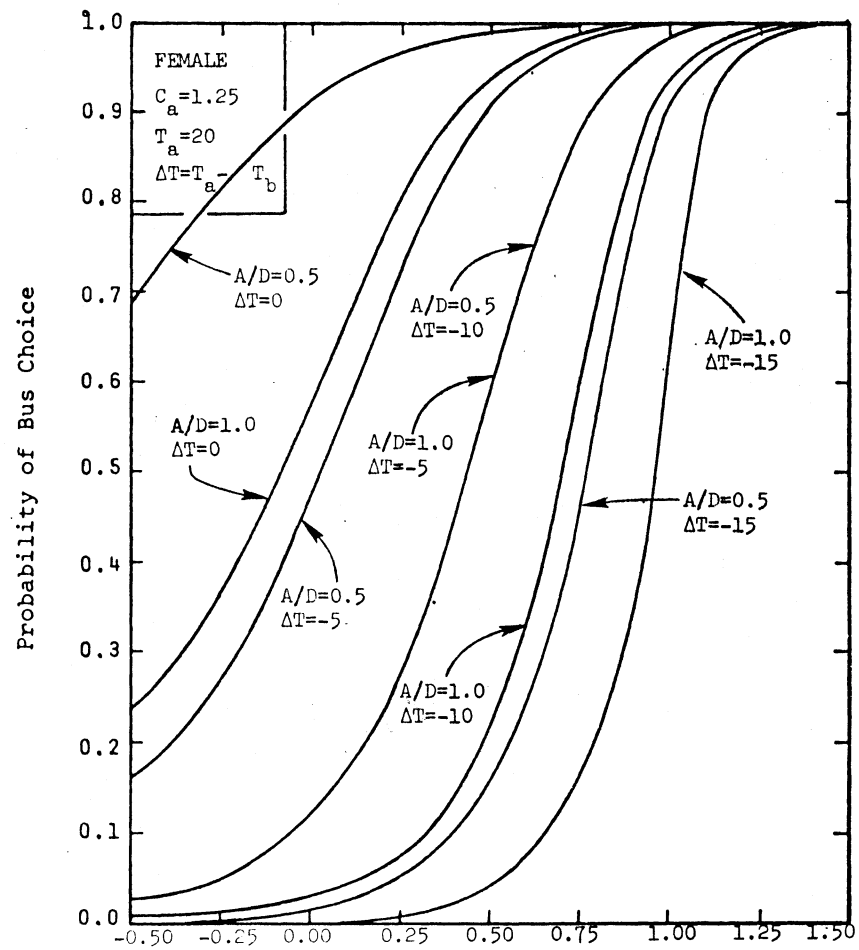
Figure A-5



Cost Difference

C_a-C_b

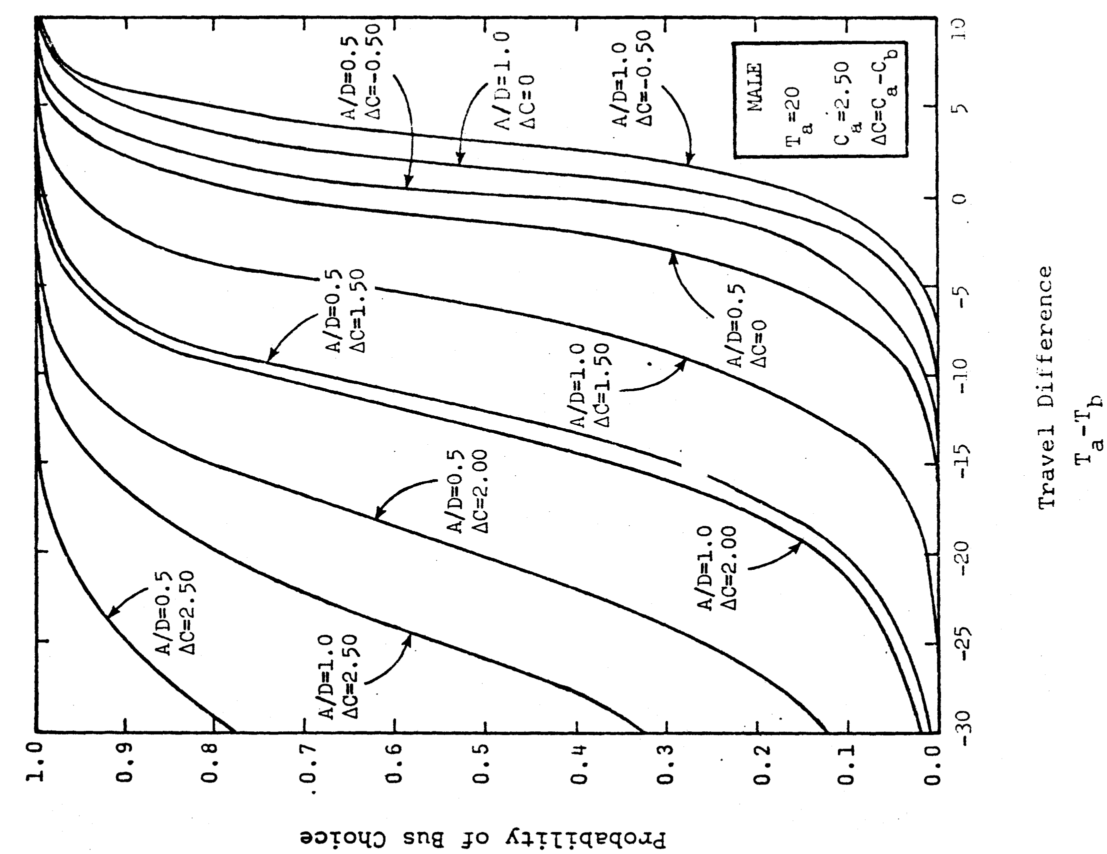
Figure A-7



Cost Difference

C_a-C_b

Figure A-8



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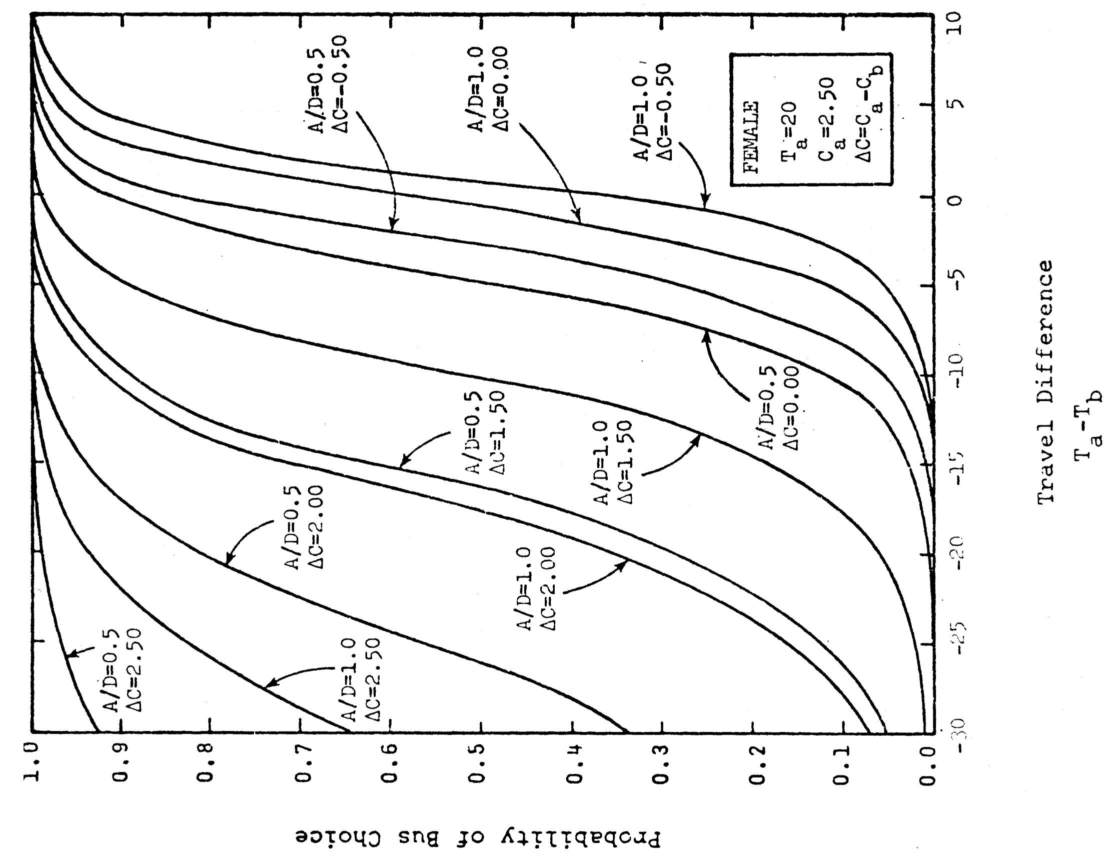
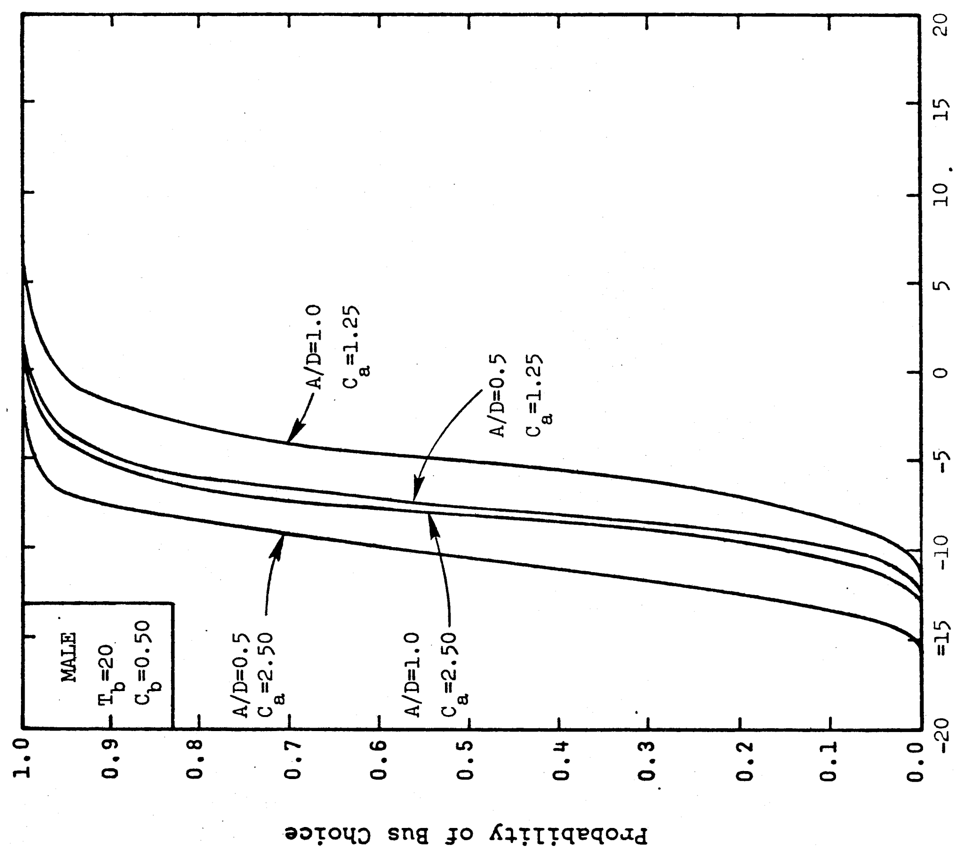


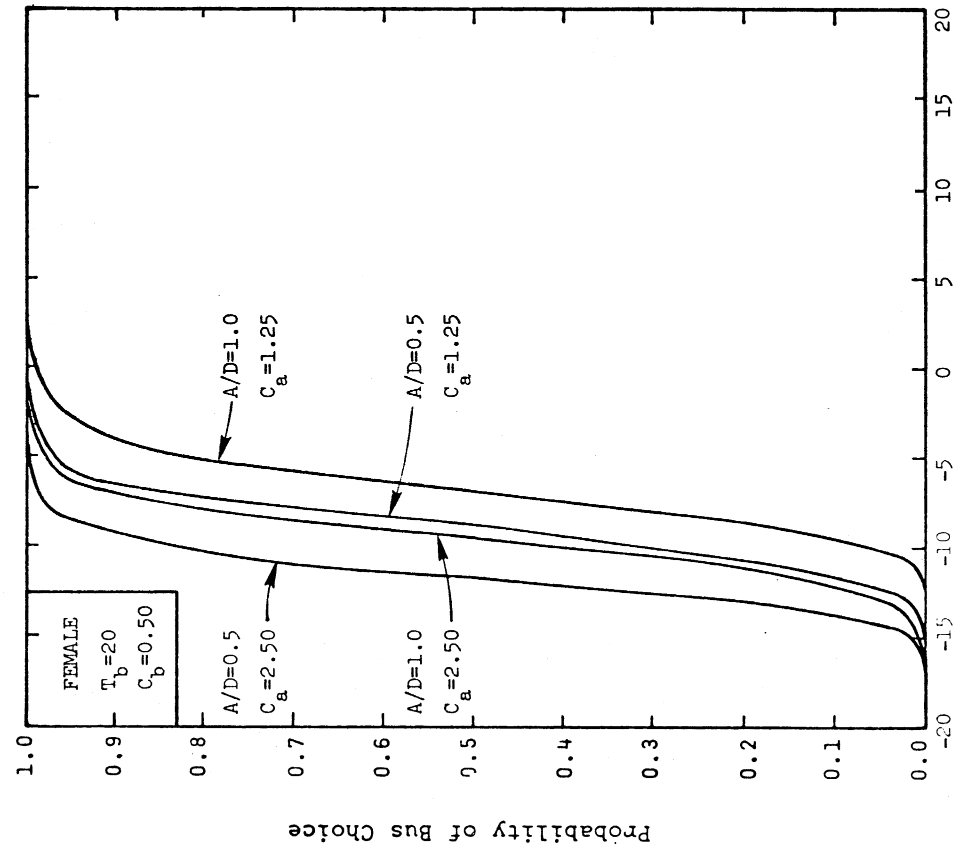
Figure A-10



Travel Difference

T_a-T_b

Figure A-11



Travel Difference

T_a-T_b

Figure A-12

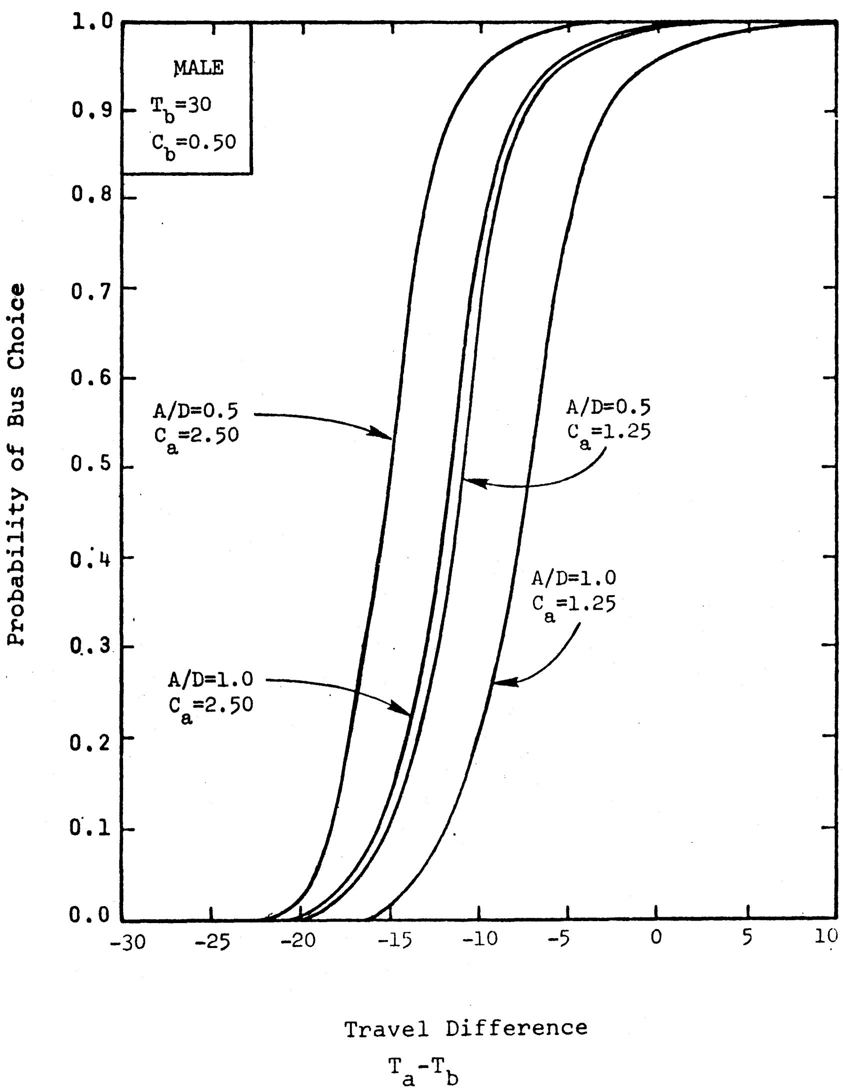
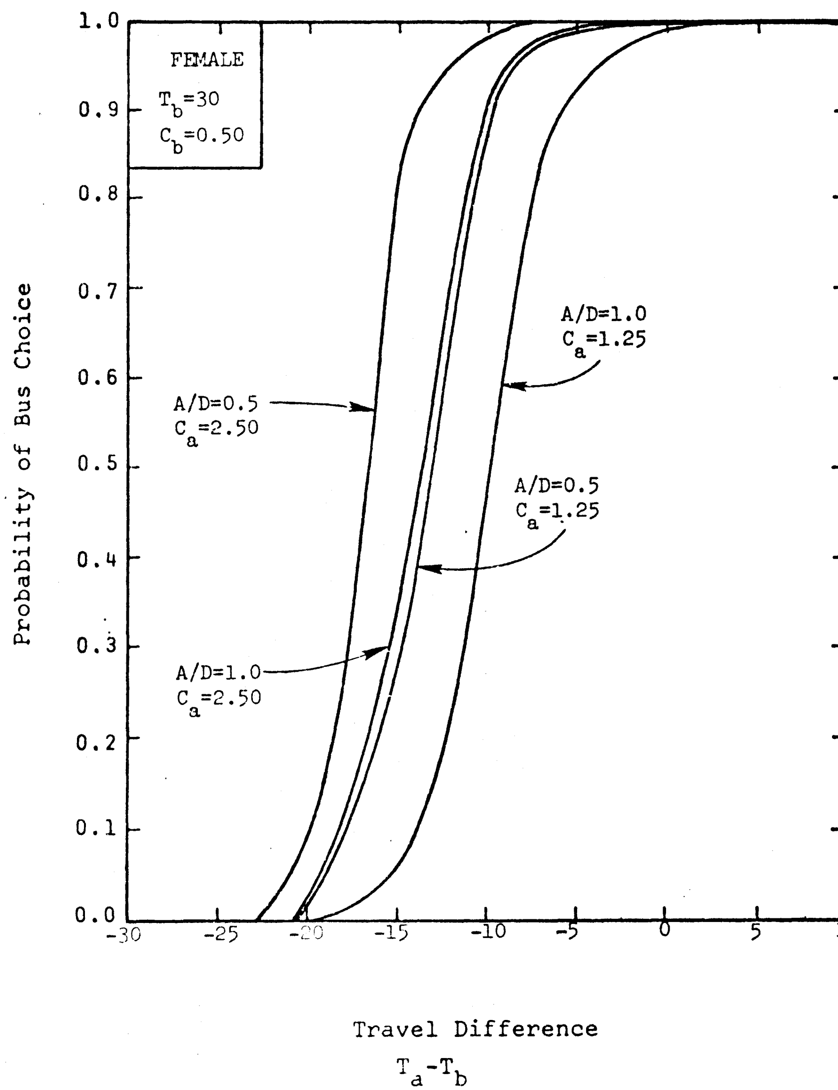


Figure A-13



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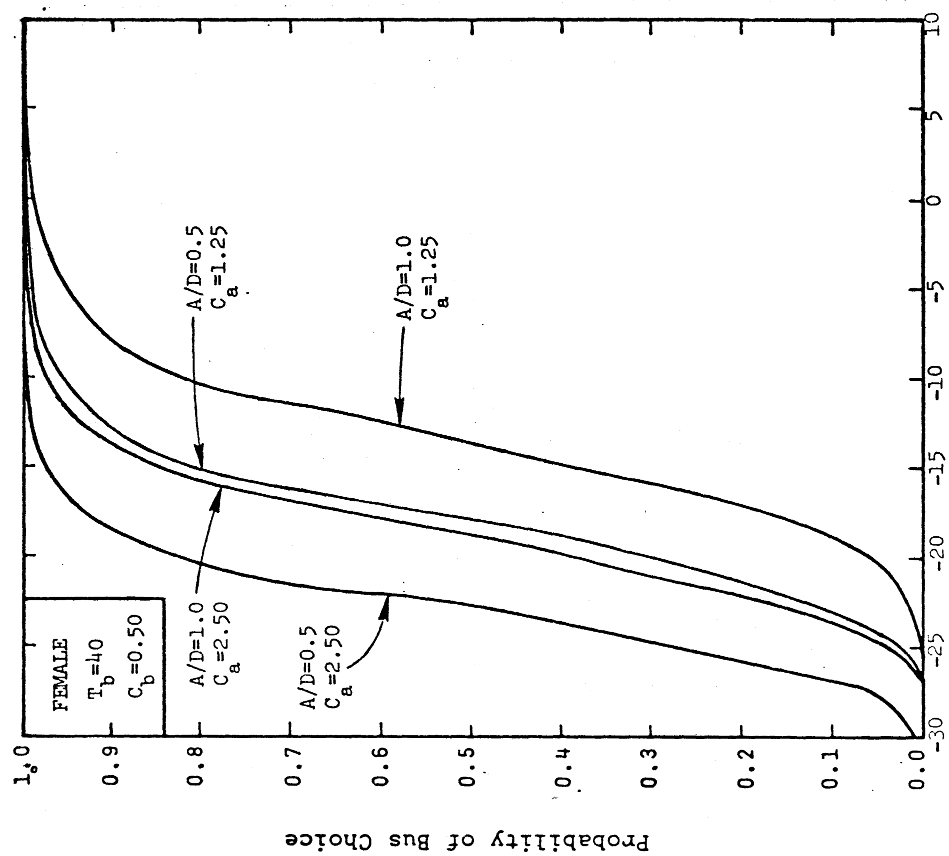
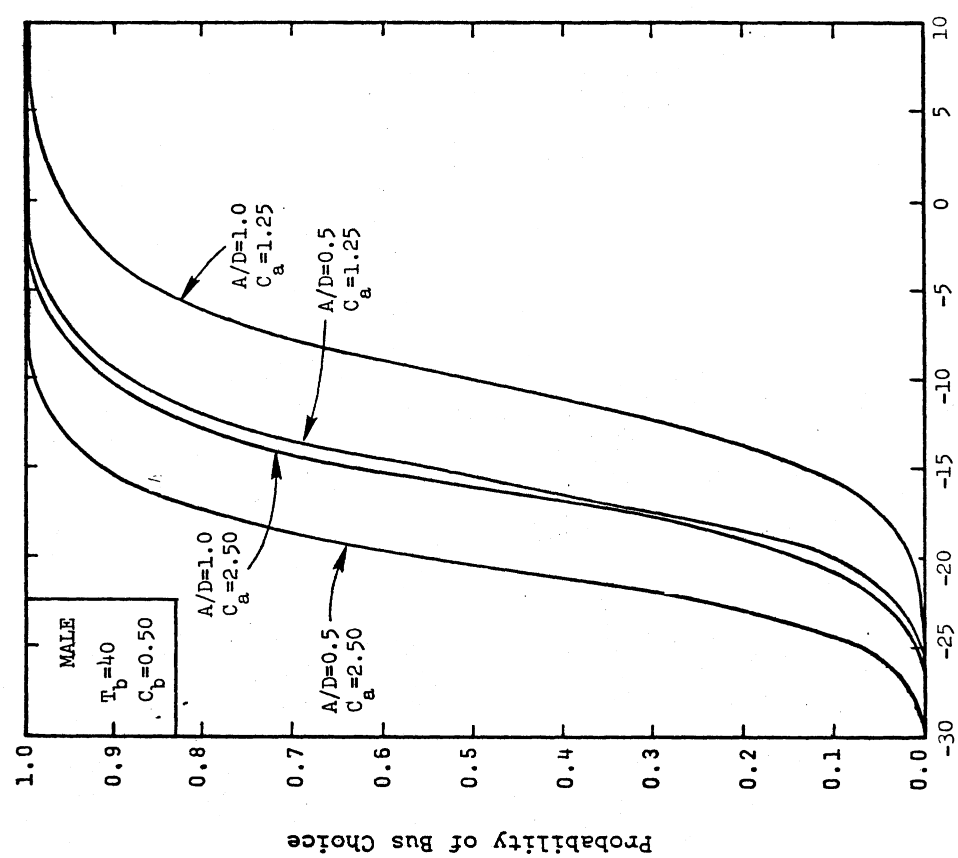


Travel Difference

T_a-T_b

Figure A-16



Travel Difference

T_a-T_b

Figure A-15

APPENDIX B

UNSTRATIFIED BINARY CURVES: RICHMOND AND VIRGINIA BEACH

The curves in Appendix B are derived from logit models calibrated from all automobile and bus trip observations in each of two study areas. The purpose is similar to that stated for the models shown in Appendix A, and the reader is referred to the introductory material of that section.

The curves provided are derived from logistic models with the following linear functions.

Richmond

1. Age = 25-44 years
   $$G_0(X) = 2.7839 - 3.5738X_3 + 6.6795X_4 + 3.5717X_5 \quad \text{(B-1)}$$

2. Age = other
   $$G_0(X) = 1.6956 - 3.5738X_3 + 6.6795X_4 + 3.5717X_5 \quad \text{(B-2)}$$

Virginia Beach

$$G_0(X) = 1.1625 - 3.2198X_3 + 2.9728X_4 + 1.9312X_5 \quad \text{(B-3)}$$

The curves given in this section are identified as follows:

B.1	P_b vs. ΔC (3 curves) Constants: $A/D = 0.5$, $T_b = 30$, $T_a = 15$, $C_b = \$0.50$
B.2	Same as B.1 except A/D = 1
B.3	Same as B.1 except $T_a = 20$
B.4	Same as B.3 except A/D = 1
B.5	Same as B.1 except $T_a = 25$
B.6	Same as B.5 except A/D = 1
B.7	Same as B.1 except $T_a = 30$
B.8	Same as B.7 except A/D = 1

B.9 P_b vs. ΔT (3 curves)
Constants: $A/D = 0.5$, $C_a = 1.25$, $C_b = 0.5$, $T_b = 30$

B.10 Same as B.9 except $A/D = 1$

B.11 Same as B.9 except $C_a = \$2.50$

B.12 Same as B.11 except $A/D = 1$

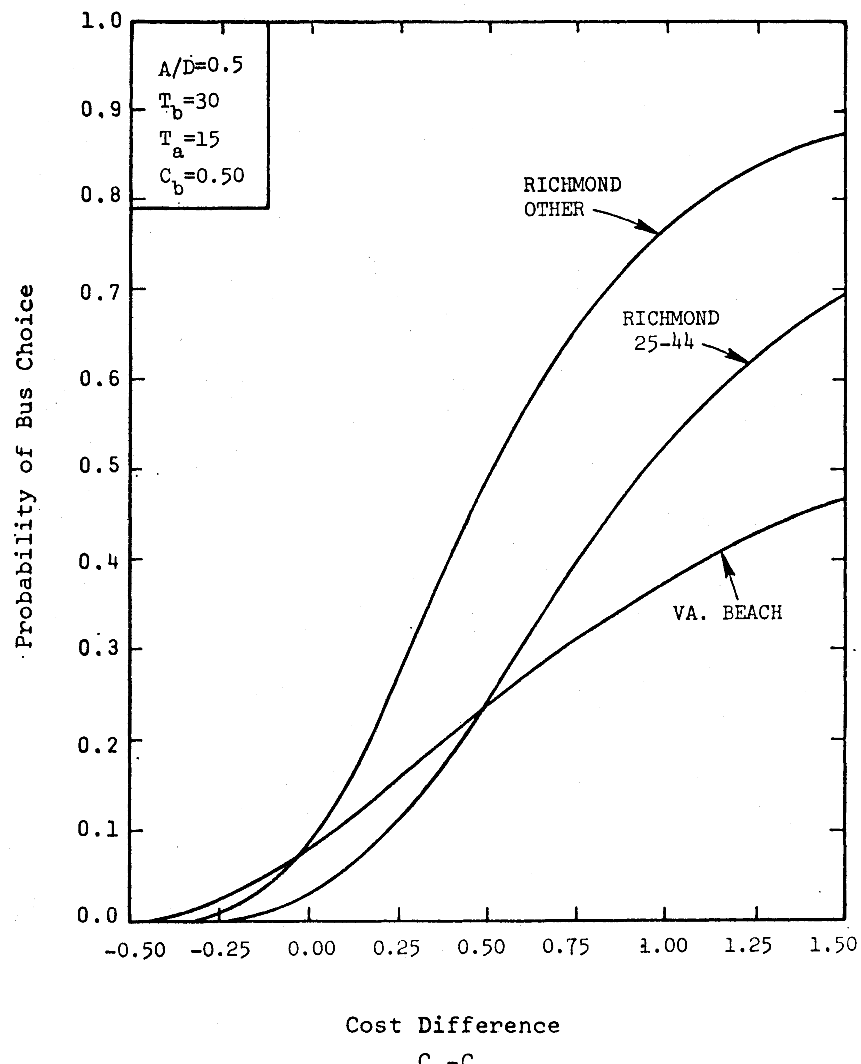


Figure B-1

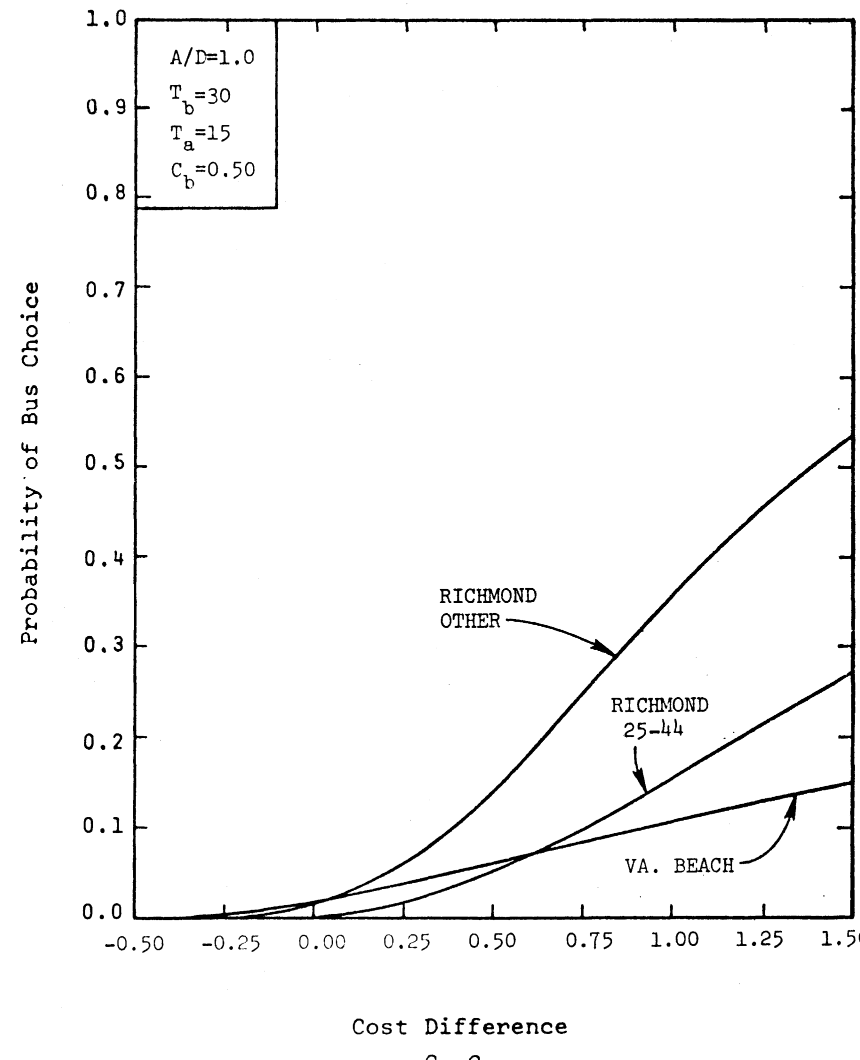


Figure B-2

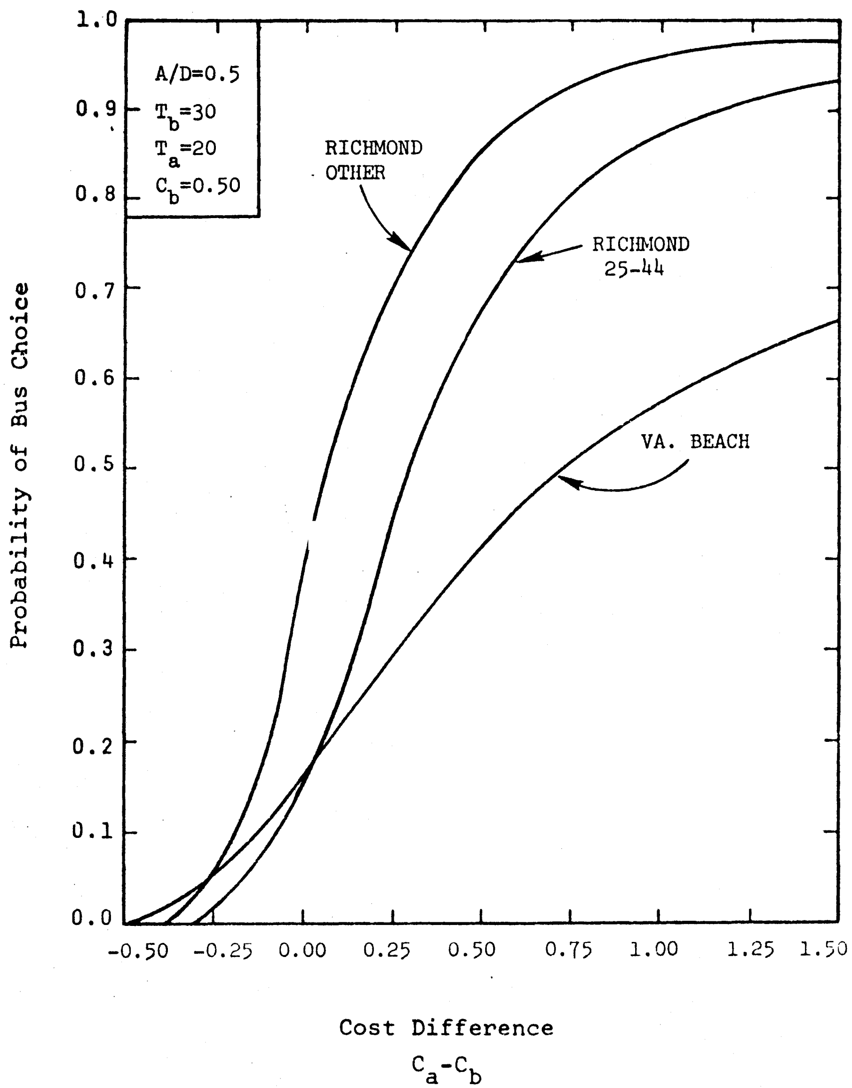


Figure B-3

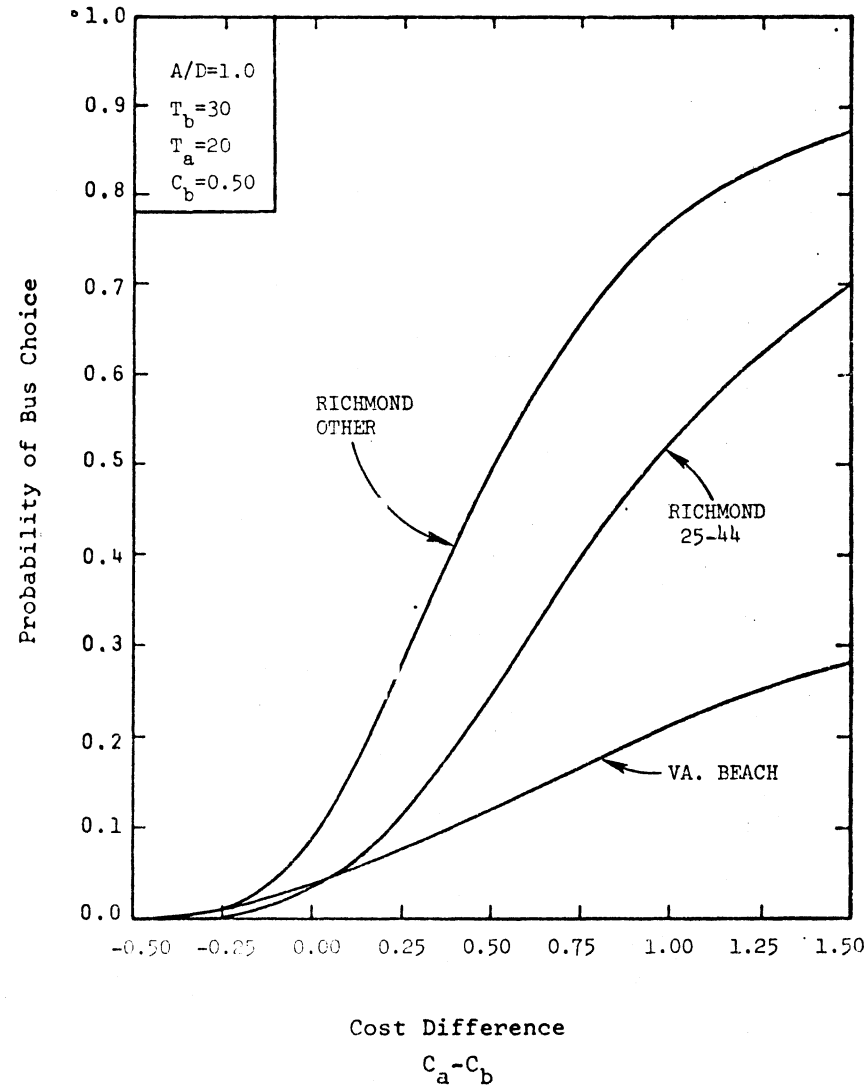
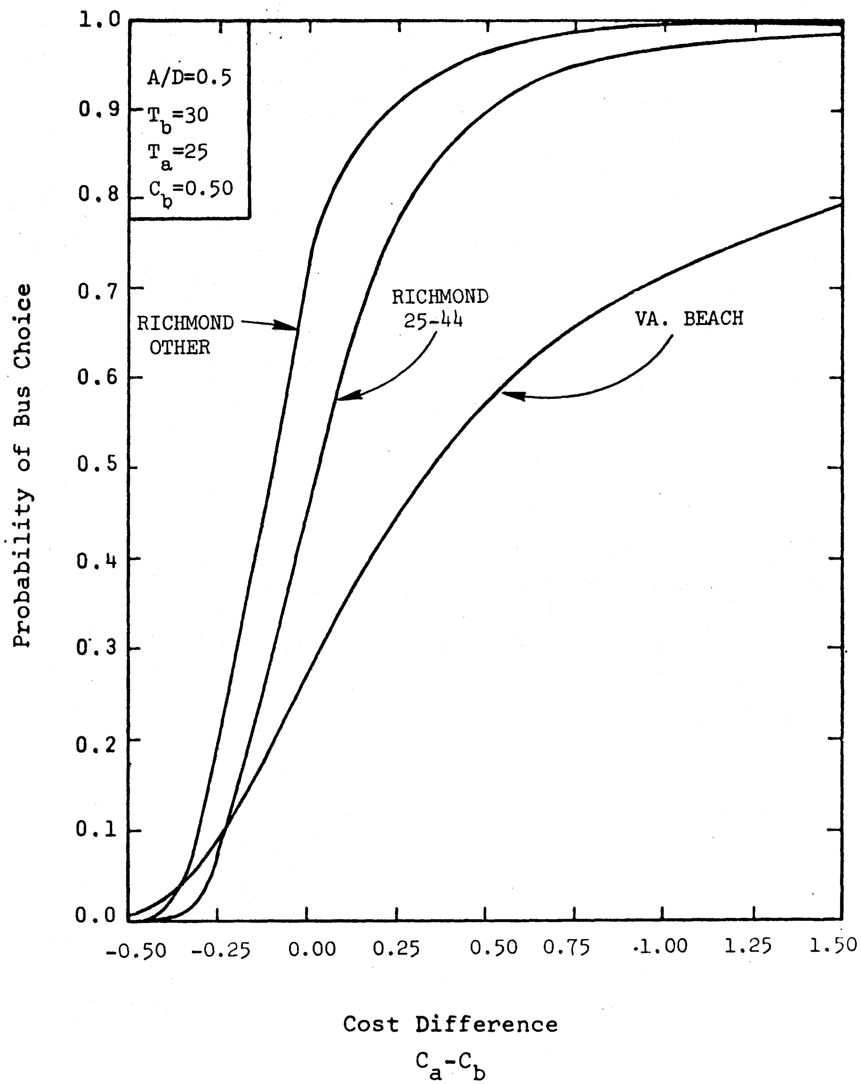


Figure B-4

2090



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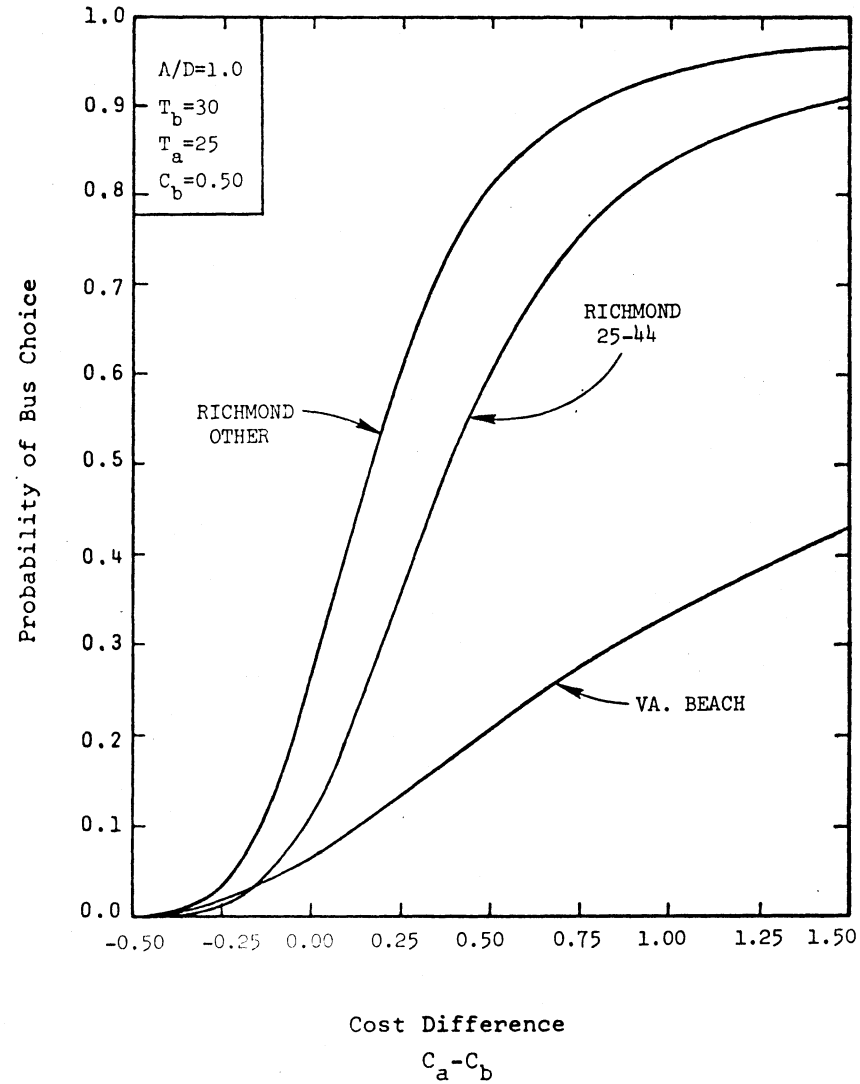

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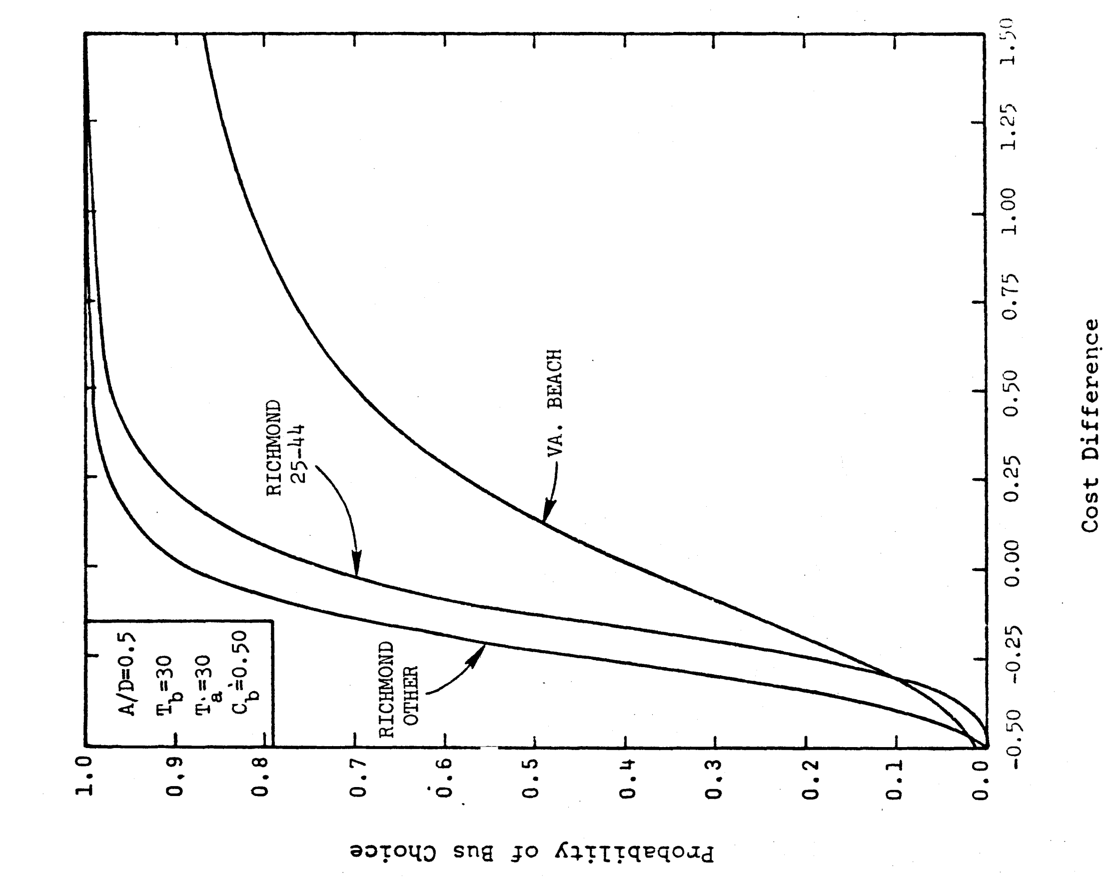
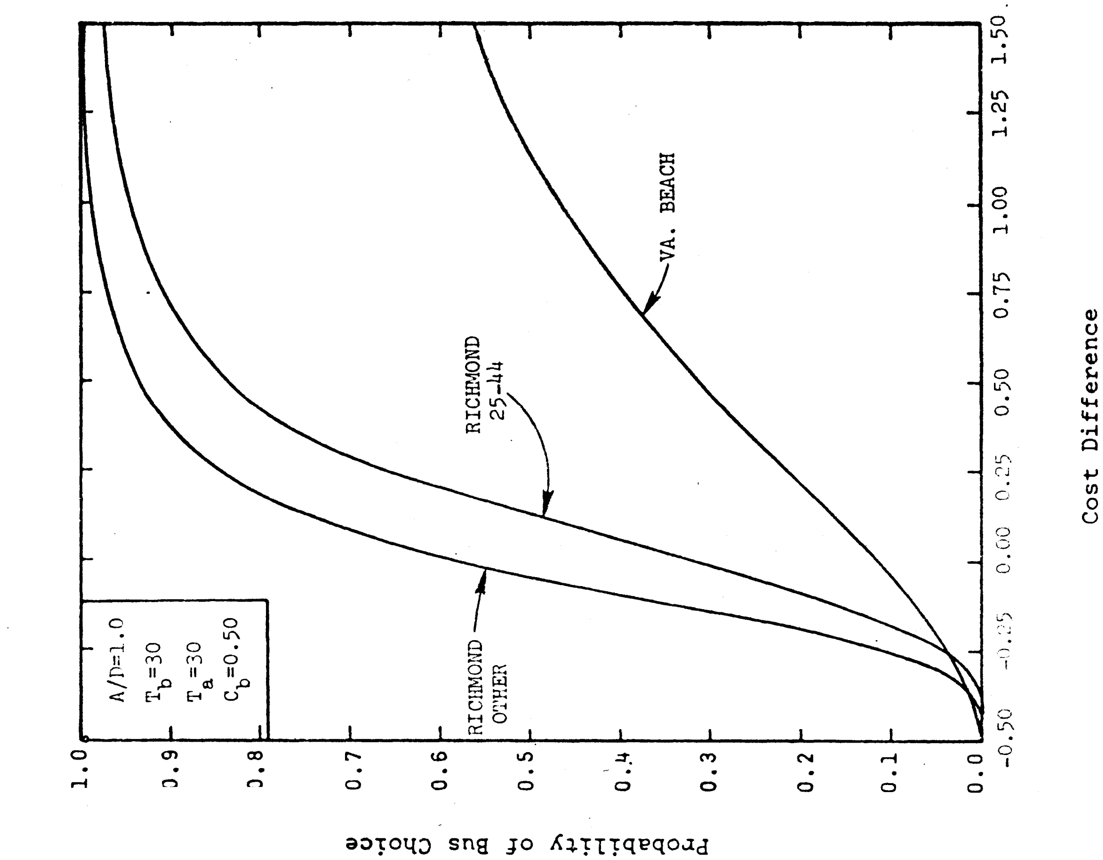


Figure B-7



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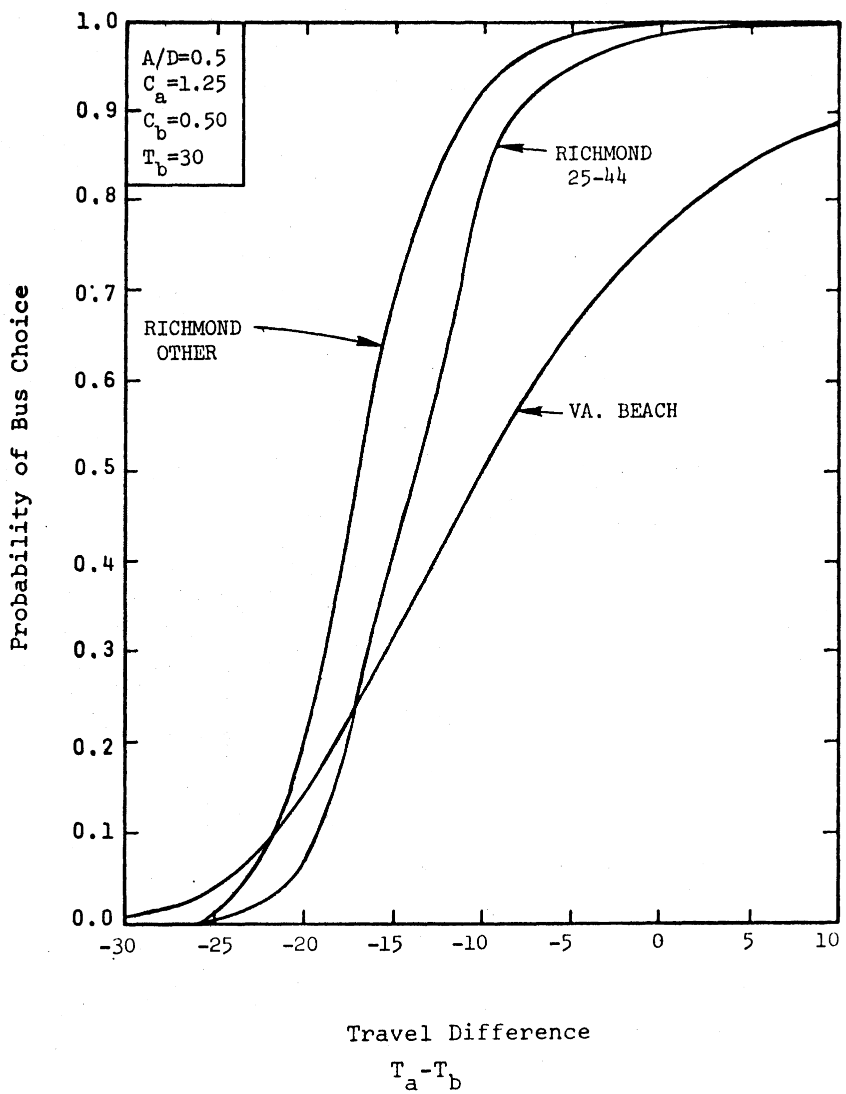


Figure B-9

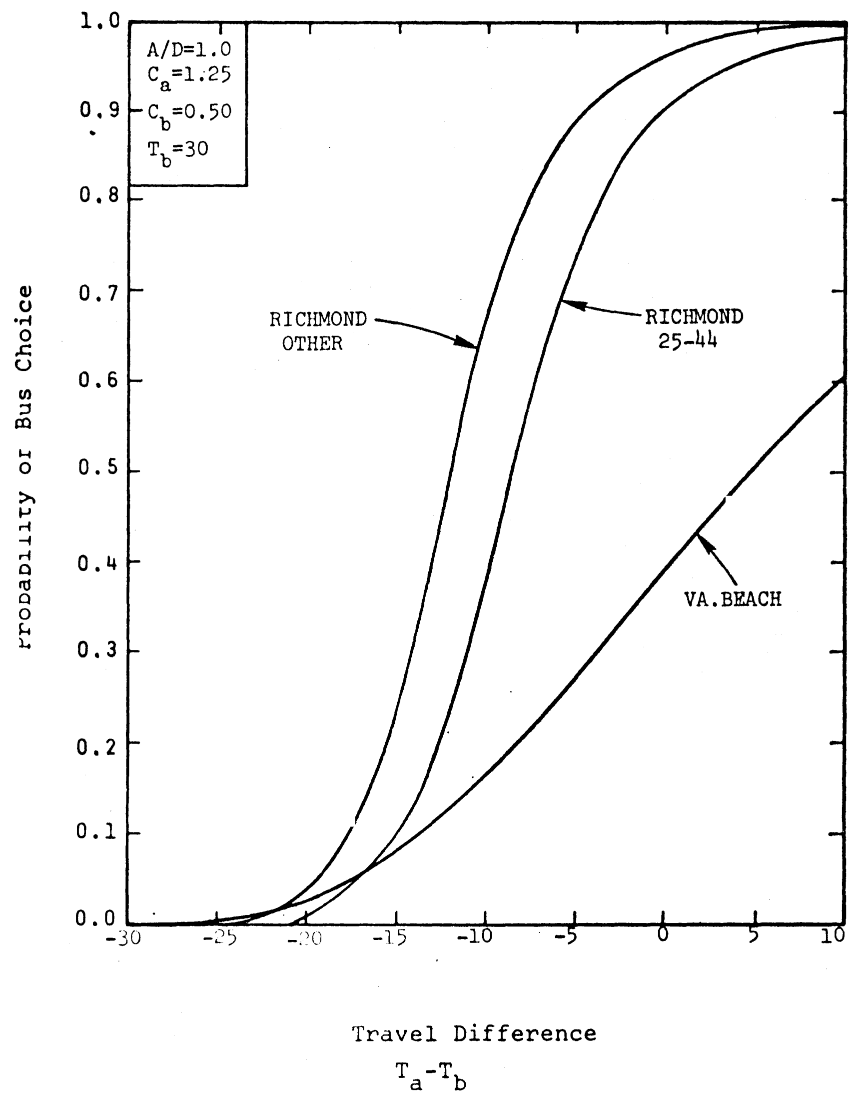
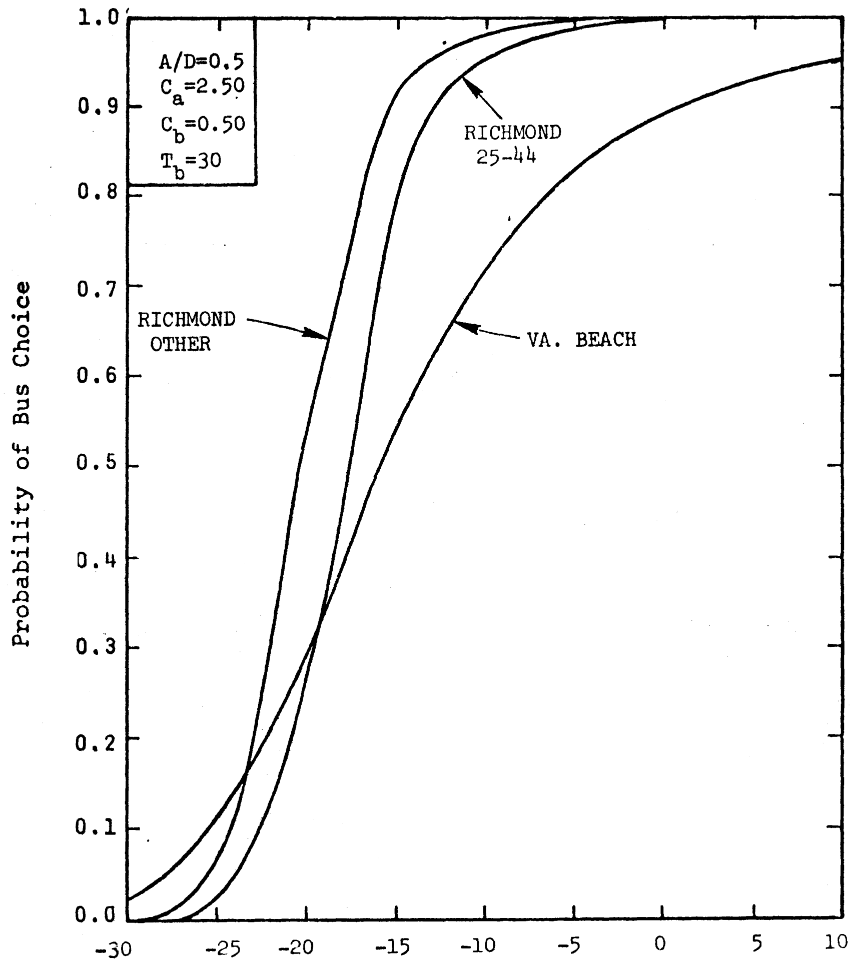


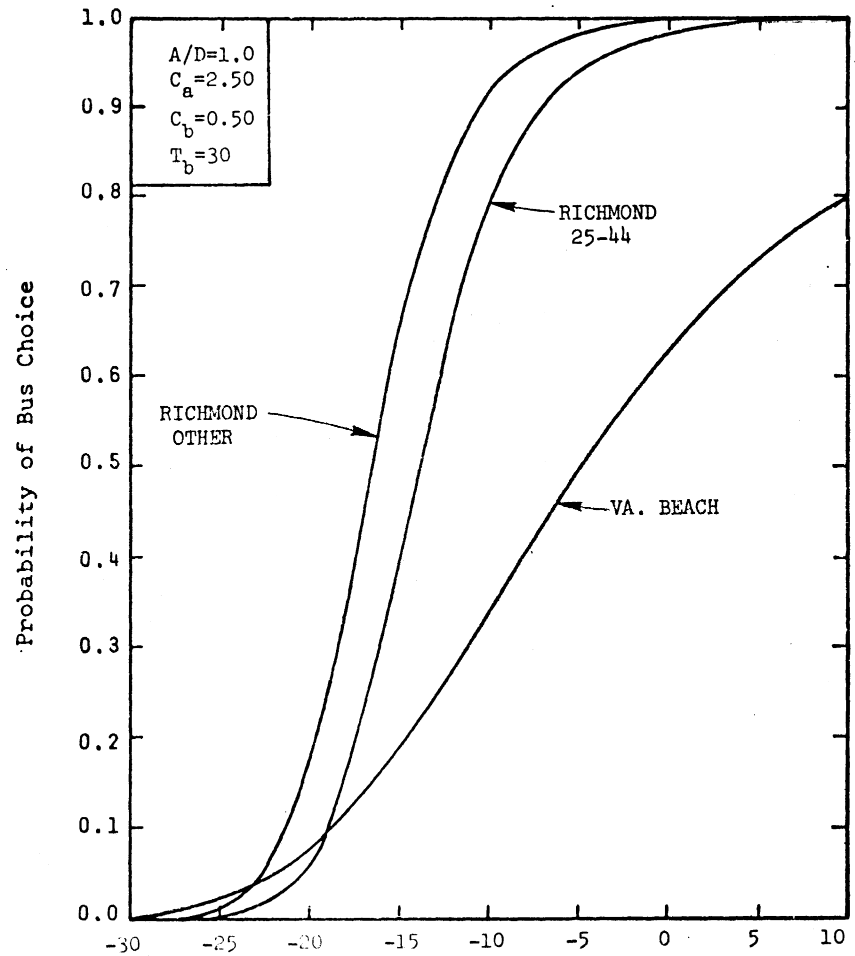
Figure B-10



Cost Difference

C_a-C_b

Figure B-11



Cost Difference

C_a-C_b

Figure B-12

APPENDIX C

SUBMODAL SPLIT CURVES

Appendix C gives a curve for estimating the proportions of express bus users who access the lot by park 'n ride and kiss'n ride. The model was calibrated for the Parham Express in Richmond and uses the ratio of household automobiles to drivers as the only explanatory variable.

$$G_k = 3.2231 - 5.5835X_3\text{, and} \qquad \text{(C-1)}$$

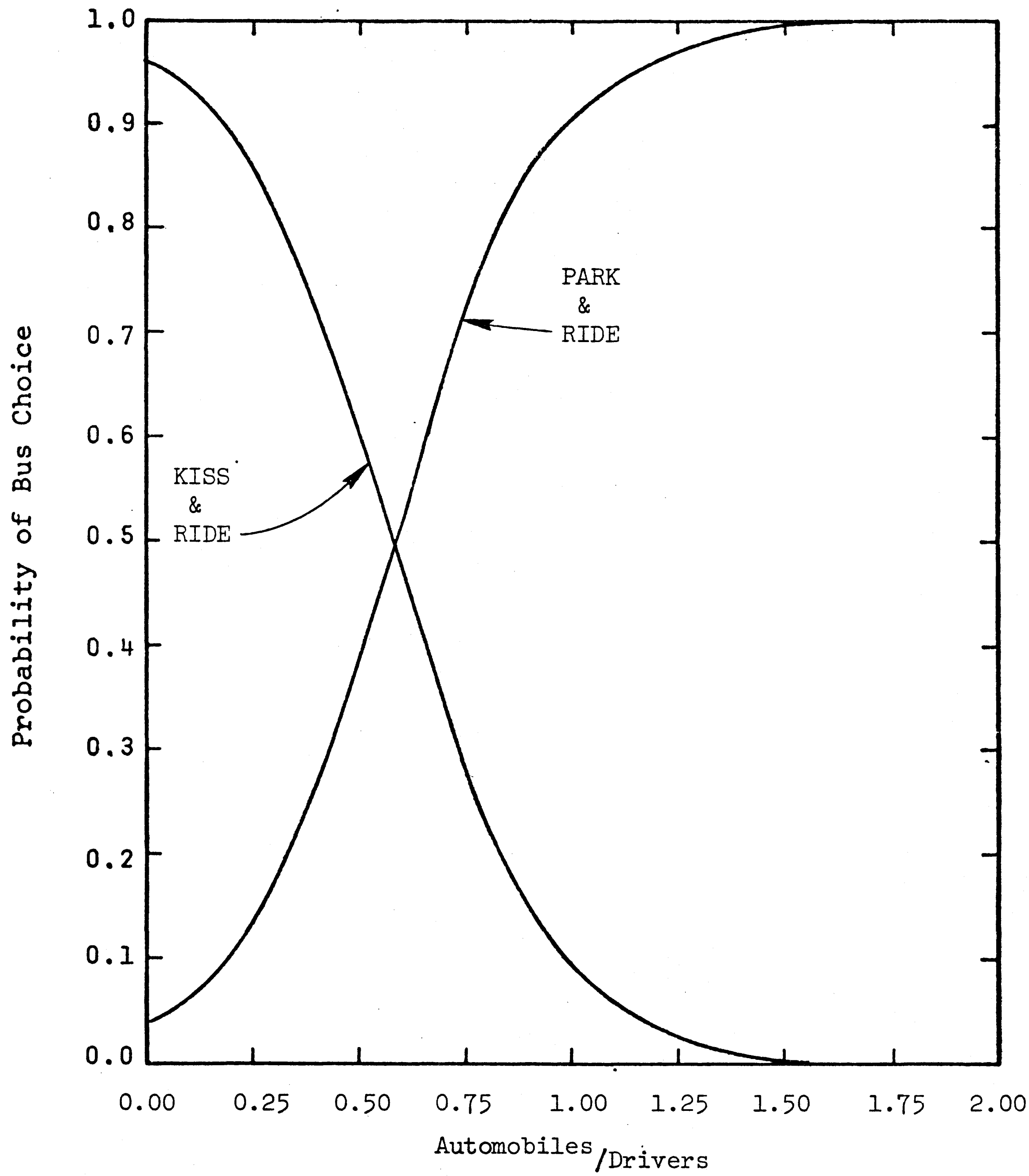
$$G_p = 1 - P_k = -2.2231 + 5.5835X_3 \qquad \text{(C-2)}$$

where,

G_k = Linear function to estimate the probability of kiss 'n ride access, P_a, and

G_p = Linear function to estimate the probability of park 'n ride access, P_p.

X_3 = no. household automobiles/no. drivers in households.



Probability of Bus Choice
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PARK & RIDE
KISS & RIDE
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Automobiles/Drivers

Figure C-1

APPENDIX D

MULTIMODAL CHOICE MODELS

An n-dimensional choice model was calibrated with the Parham Express data which simultaneously computes the probability for either of three modes: automobile to CBD, park 'n ride, and kiss 'n ride. This represents an alternative approach to using the basic binary choice model and the submodal choice model in a sequential manner.

The models which are charted in this Appendix are defined as

$$Y_d = P_d\ (1 + Qu_d) \qquad \text{(D-1)}$$

$$Y_a = P_a\ (1 + Qu_a) \qquad \text{(D-2)}$$

$$Y_k = P_i\ (1 + Qu_k) \qquad \text{(D-3)}$$

where Y_d, Y_a, and Y_k are the estimated probabilities for a fully competitive model for the park 'n ride (d), automobile to CBD (a), and kiss 'n ride (k) modes, respectively.

$$Q = 1/3 \qquad \text{(D-4)}$$

$$u_i = P_i - \sum_{j=1}^{M} P_j^2 \qquad \text{(D-5)}$$

where

$$i, j = 1, 2, \text{ or } 3$$

$$M = 3,$$

$$P_d = \frac{1}{1 + e^{G_a(X)} + e^{G_k(X)}}$$

$$P_a = \frac{e^{G_a(X)}}{1 + e^{G_a(X)} + e^{G_k(X)}}$$

$$P_k = 1 - P_d - P_a$$

where

$G_a(X) = 1.8503 - 0.8776X_1 - 1.9550X_2 - 3.8446X_4 - 4.9552X_5$

$G_k(X) = 2.1623 - 2.0600X_1 - 1.9900X_2 - 3.6907X_3$

X_1 = sex; 0 = female, 1 = male

X_2 = age; 0 = (25-44), 1 other

X_3 = autos/drivers

$X_4 = (T_a - T_b)/(T_a + T_b)/2$

$X_5 = (C_a - C_b)/(C_a + C_b)/2$

The curves provided in this Appendix are as follows:

D.1 P_i vs. ΔC

Constants: Female, Age = 25-44, A/D = 0, T_a = 20, T_b = 30, C_b = 0.50

D.2 Same as D.1 except A/D = 0.5

D.3 Same as D.1 except A/D = 1.0

D.4 Same as D.1 except Age ≠ 25-44

D.5 Same as D.4 except A/D = 0.5

D.6 Same as D.4 except A/D = 1.0

D.7 Same as D.1 except Male

D.8 Same as D.7 except A/D = 0.5

D.9 Same as D.7 except A/D = 1.0

D.10 Same as D.7 except Age ≠ 25-44

D.11 Same as D.10 except A/D = 0.5

D.12 Same as D.10 except A/D = 1.0

D.13 Same as D.1 except T_a = 30

D.14 Same as D.13 except A/D = 0.5

D.15 Same as D.13 except A/D = 1.0

D.16 Same as D.13 except Age ≠ 25-44

D.17 Same as D.16 except A/D = 0.5

D.18 Same as D.16 except A/D = 1.0

D.19 Same as D.13 except Male

D.20 Same as D.19 except A/D = 0.5

D.21 Same as D.19 except A/D = 1.0

D.22 Same as D.19 except Age ≠ 25-44

D.23 Same as D.22 except A/D = 0.5

D.24 Same as D.22 except A/D = 1.0

D.25 P_b vs. ΔT

Constants: Female, Age = 25-44, A/D = 0, C_a = \$1.25, C_b = \$0.50, T_b = 30

D.26 Same as D.25 except A/D = 0.5

D.27 Same as D.25 except A/D = 1.0

D.28 Same as D.25 except Age ≠ 25-44

D.29 Same as D.25 except A/D = 0.5

D.30 Same as D.28 except A/D = 1.0

D.31 Same as D.25 except Male

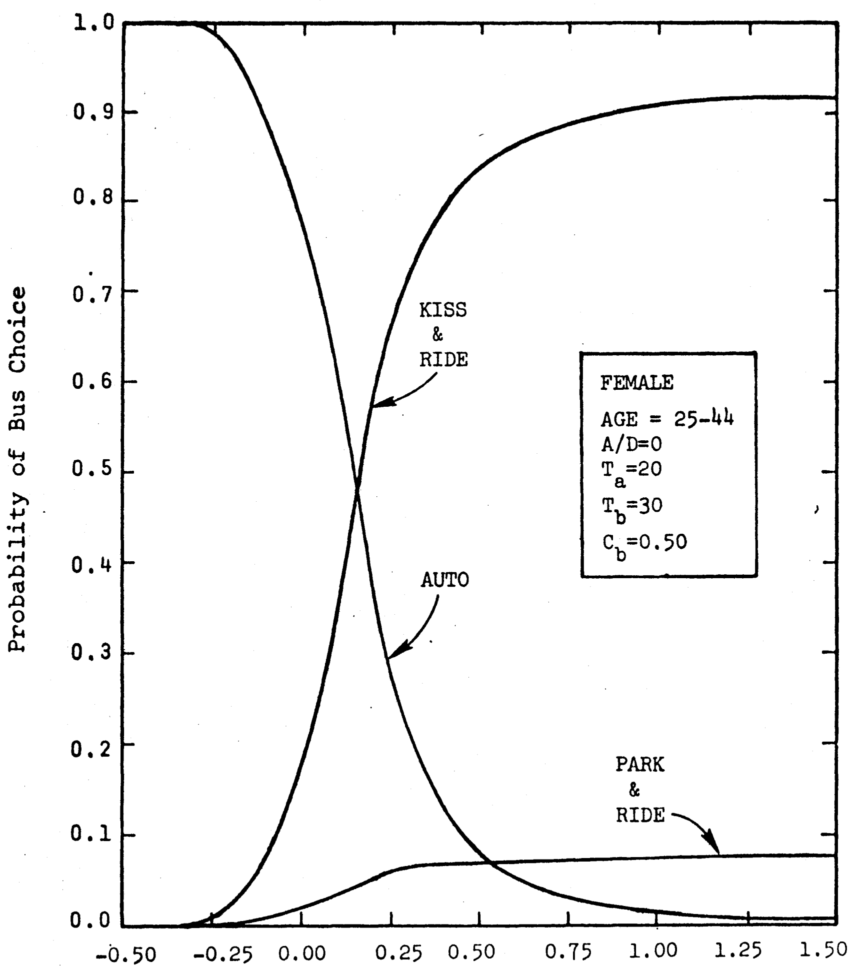
D.32 Same as D.31 except A/D = 0.5

D.33 Same as D.31 except A/D = 1.0

D.34 Same as D.31 except Age ≠ 25-44

D.35 Same as D.34 except A/D = 0.5

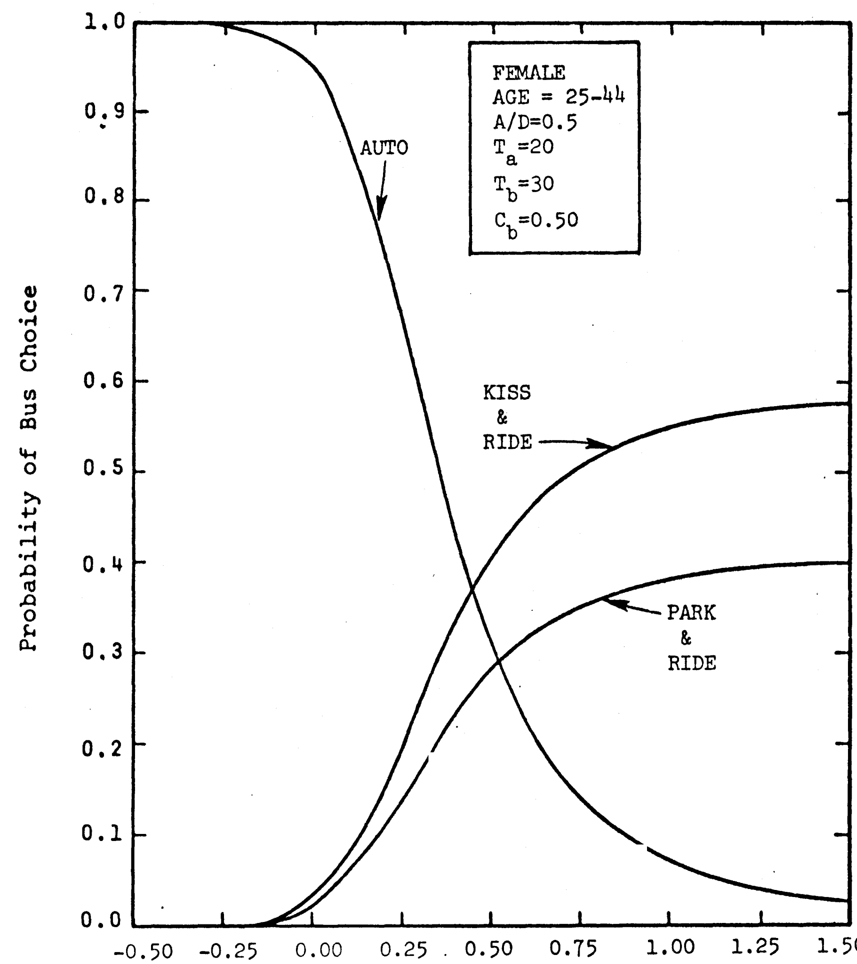
D.36 Same as D.34 except A/D = 1.0



Cost Difference

$C_a - C_b$

Figure D-1



Cost Difference

$C_a - C_b$

Figure D-2

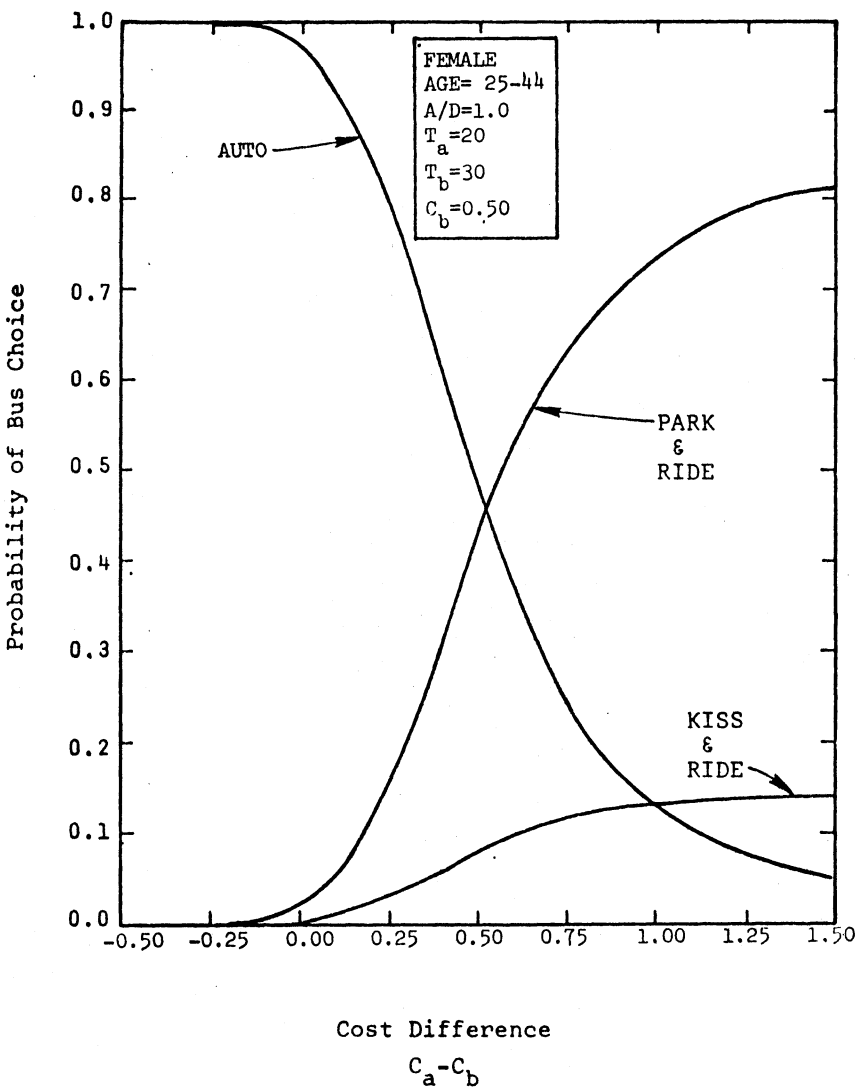


Figure D-3

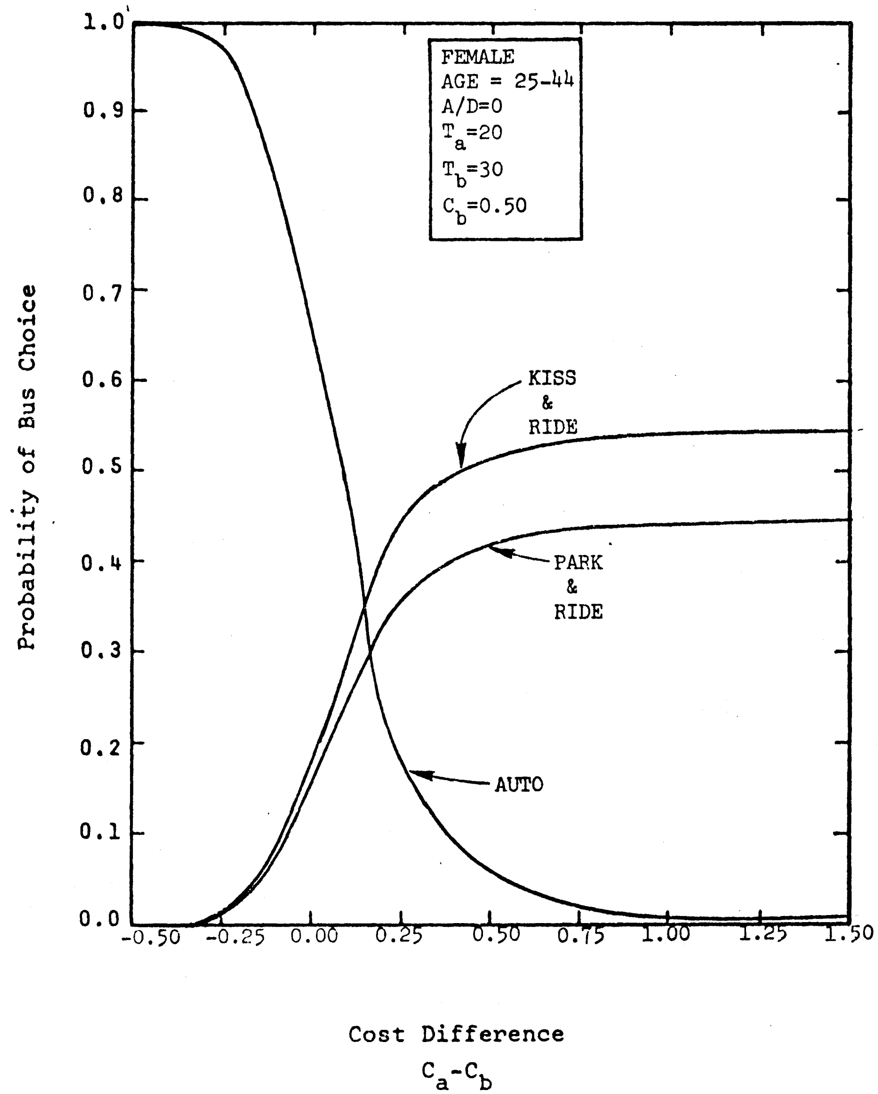


Figure D-4

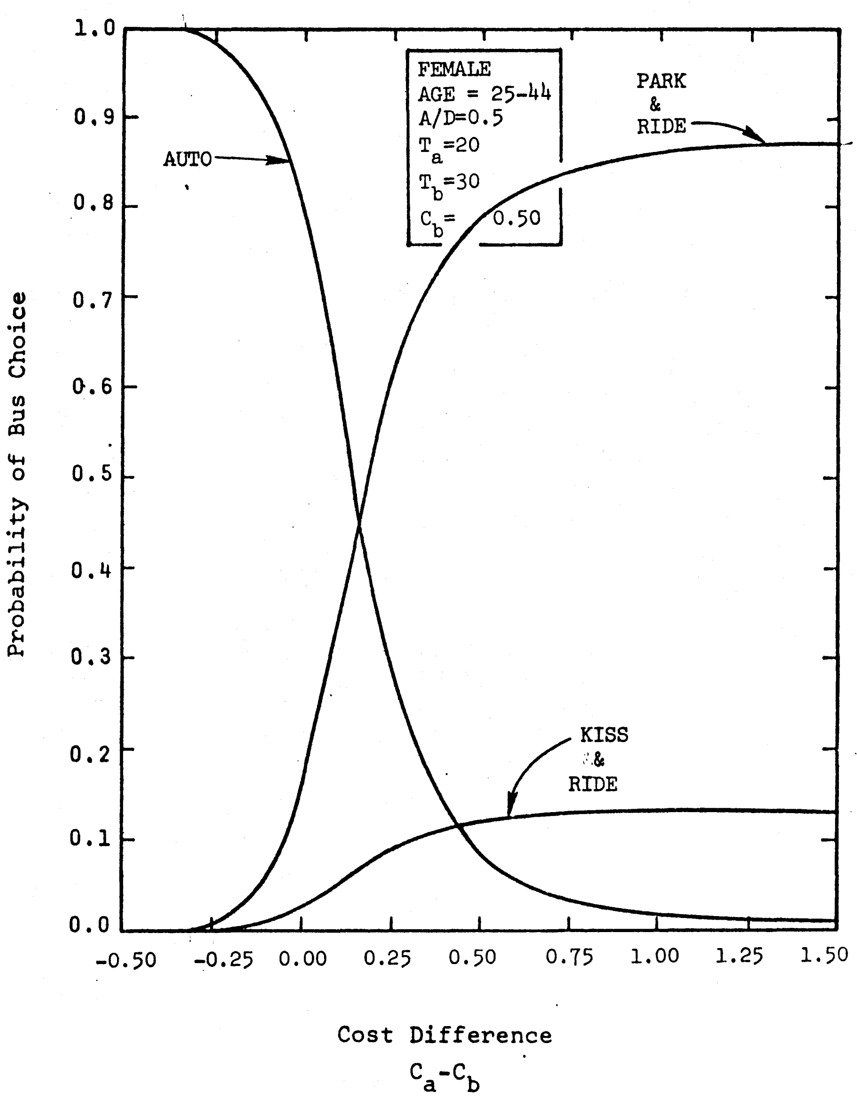


Figure D-5

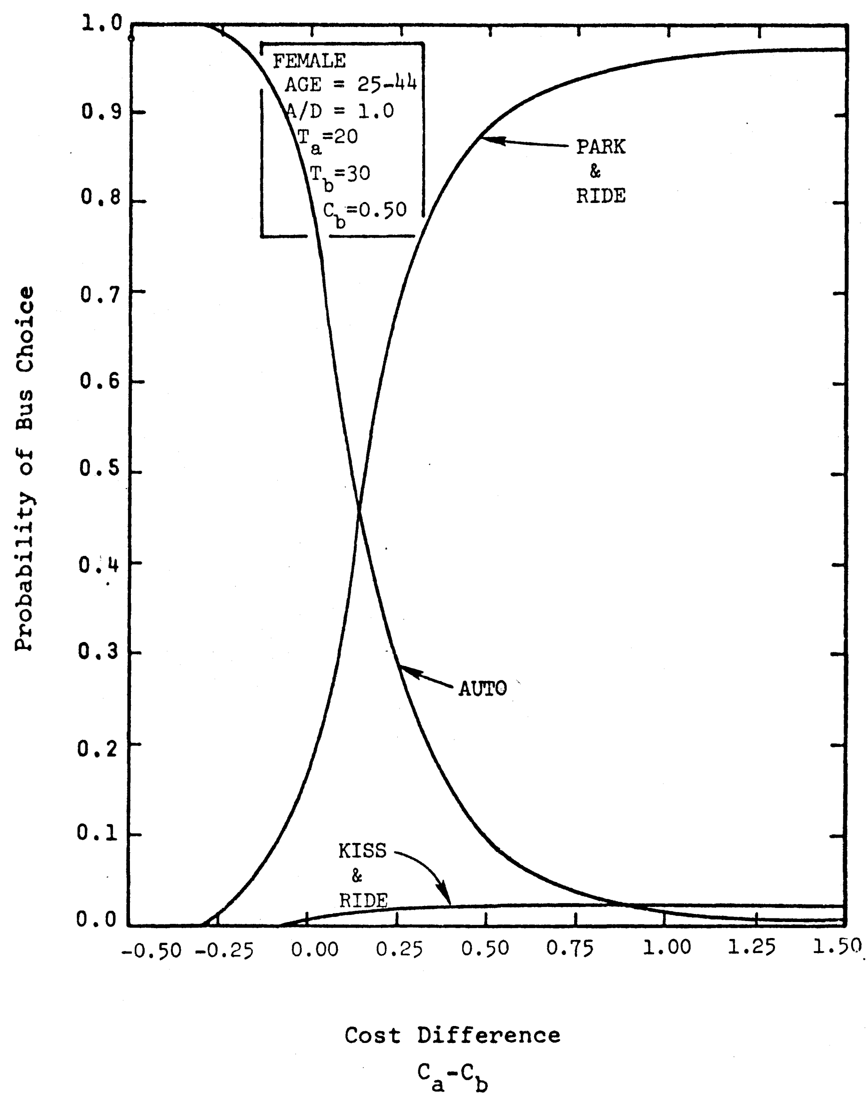
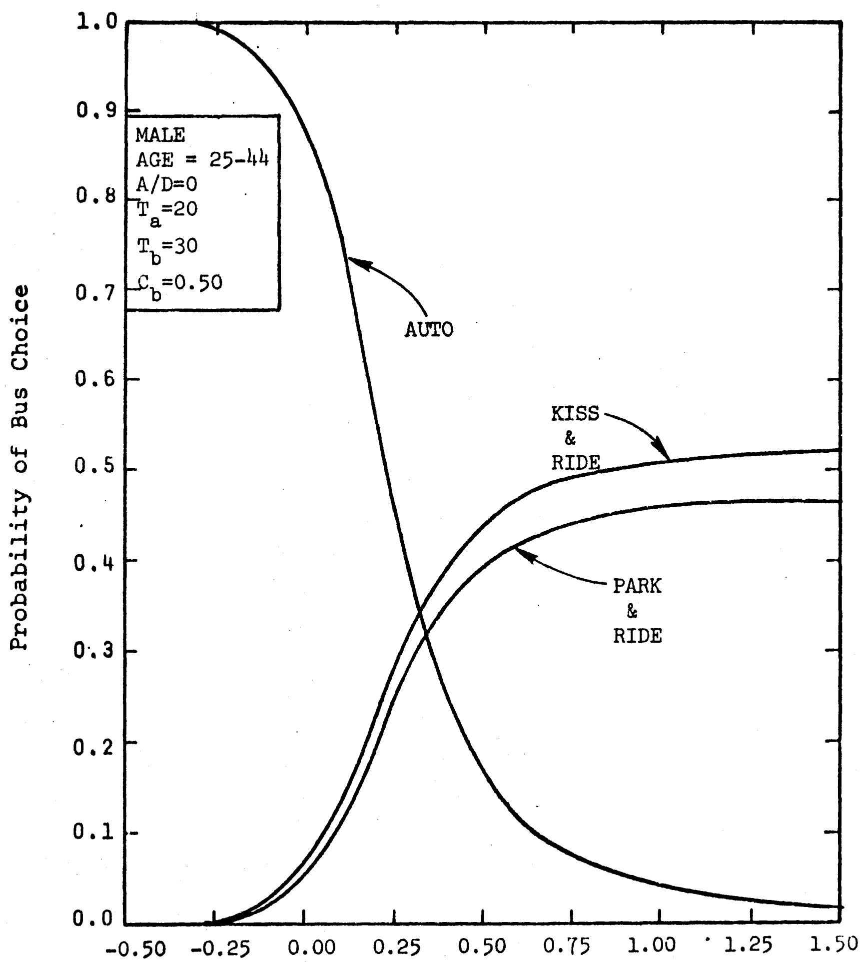


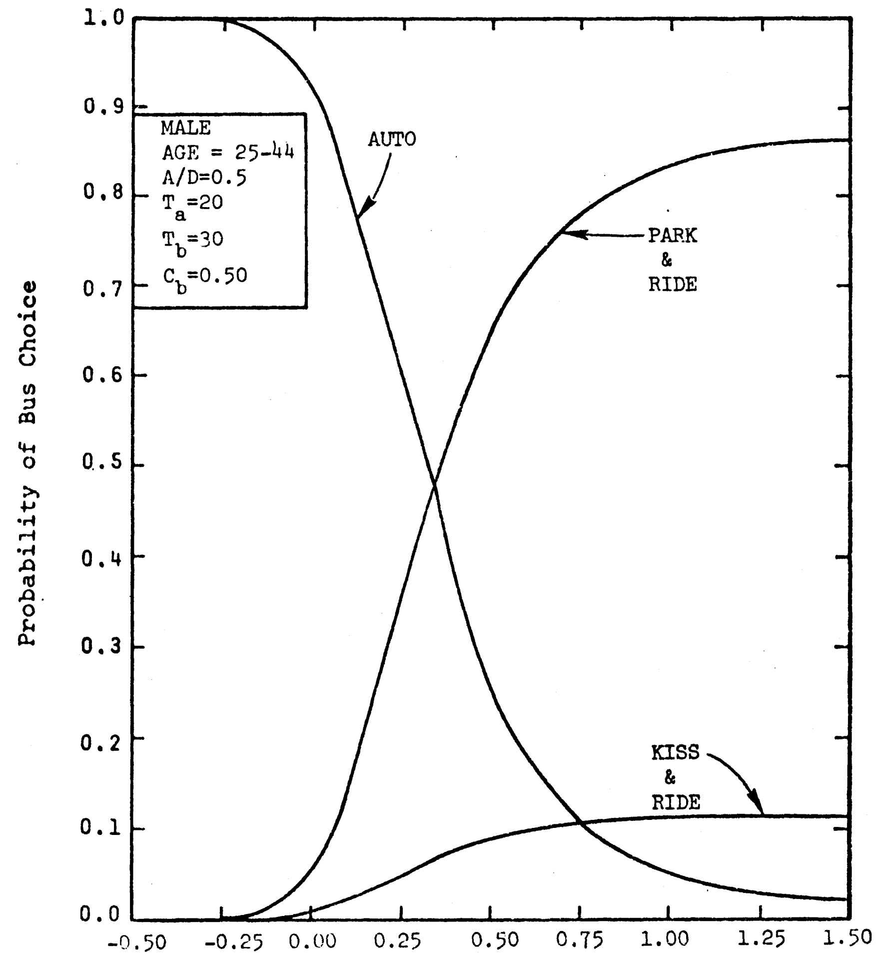
Figure D-6



Cost Difference

C_a-C_b

Figure D-7



Cost Difference

C_a-C_b

Figure D-8

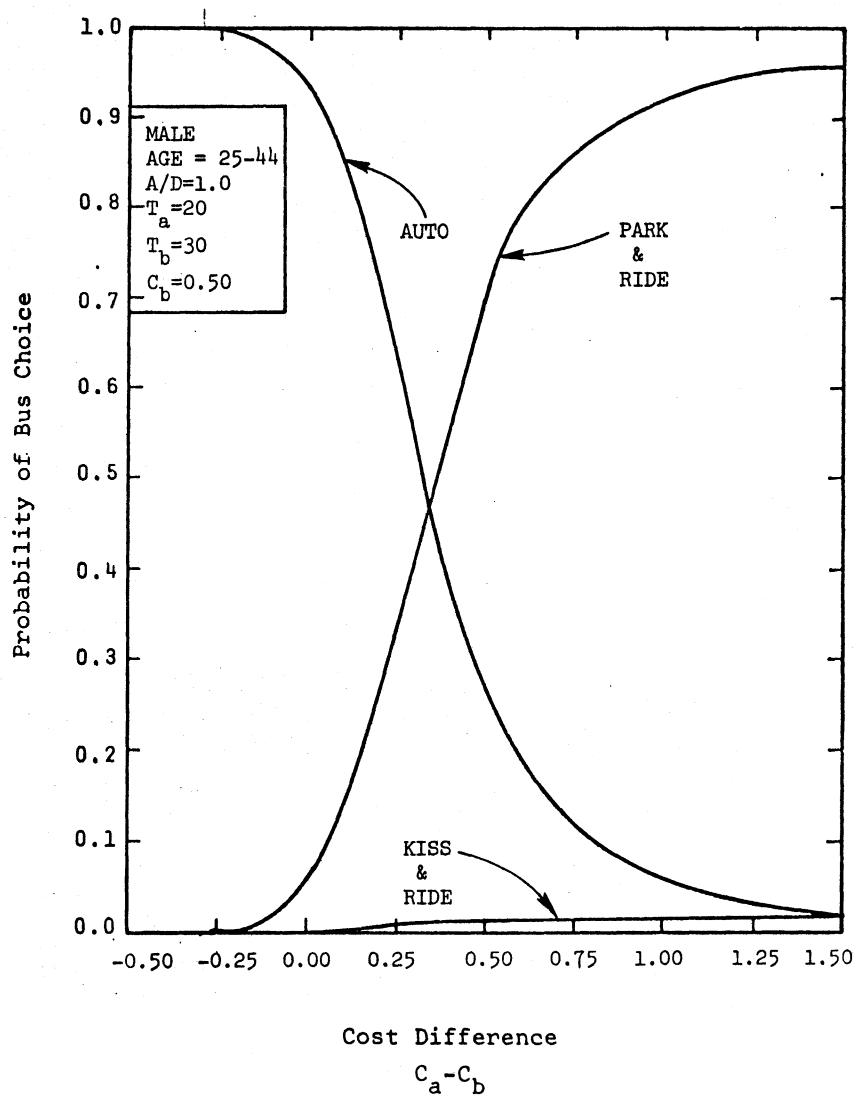


Figure D-9

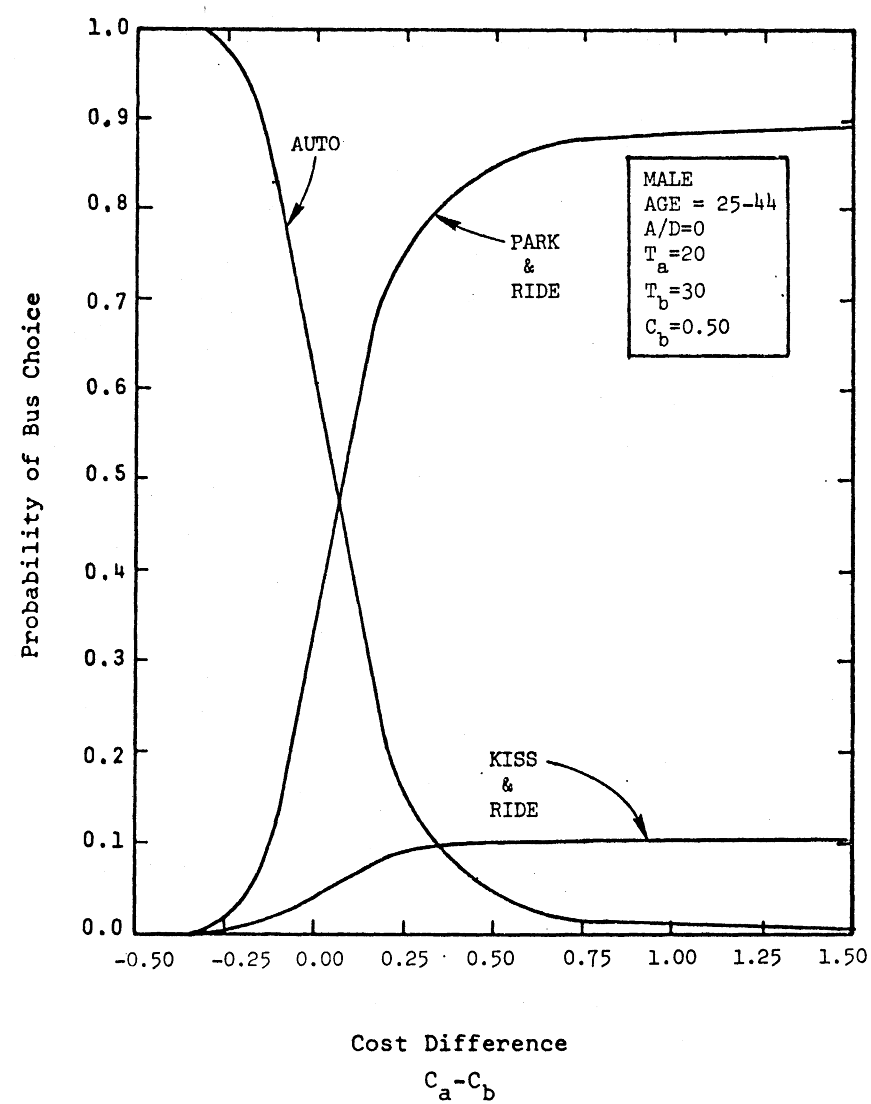
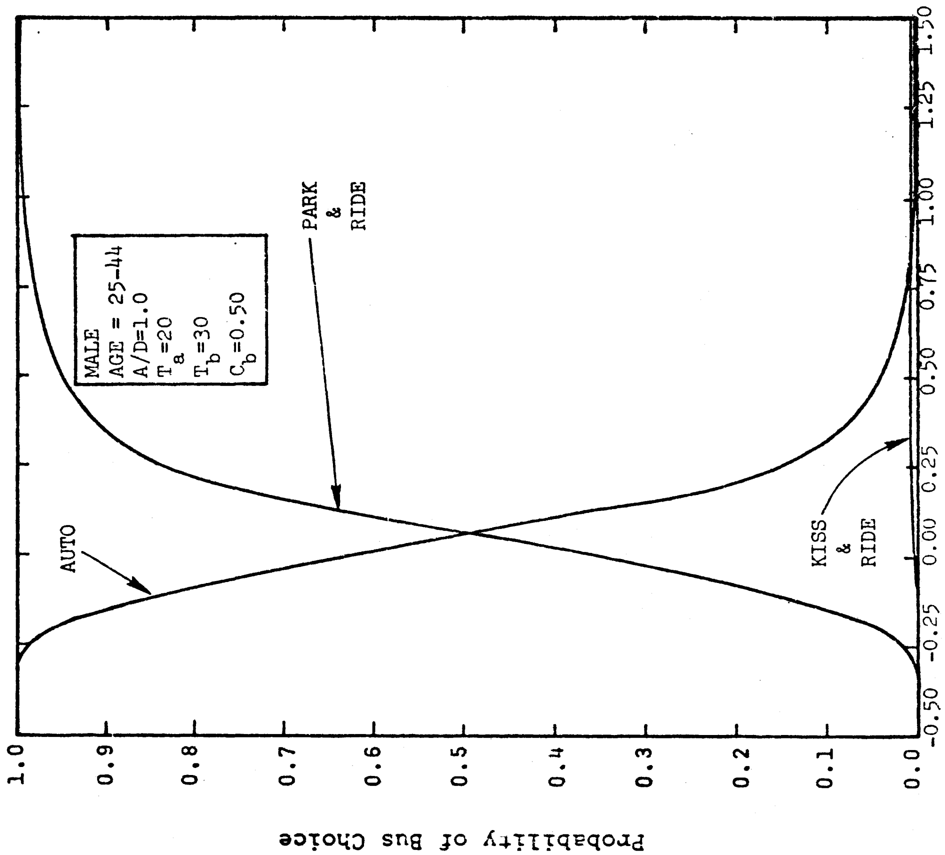


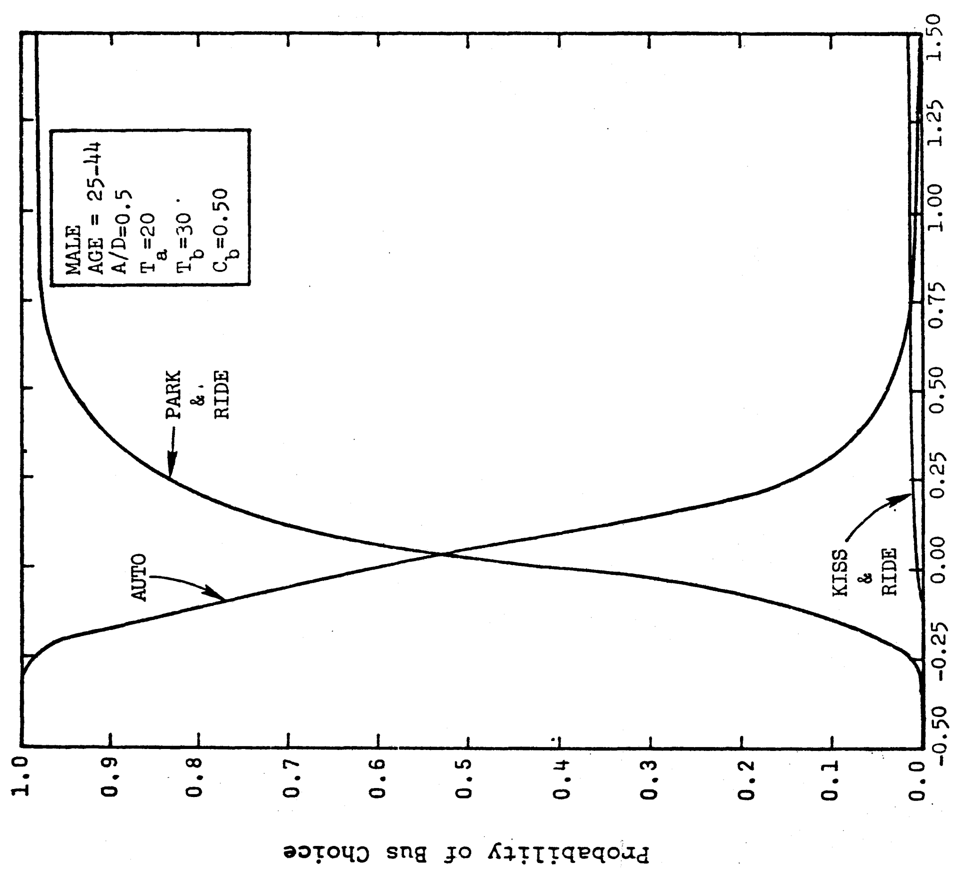
Figure D-10



Cost Difference

C_a-C_b

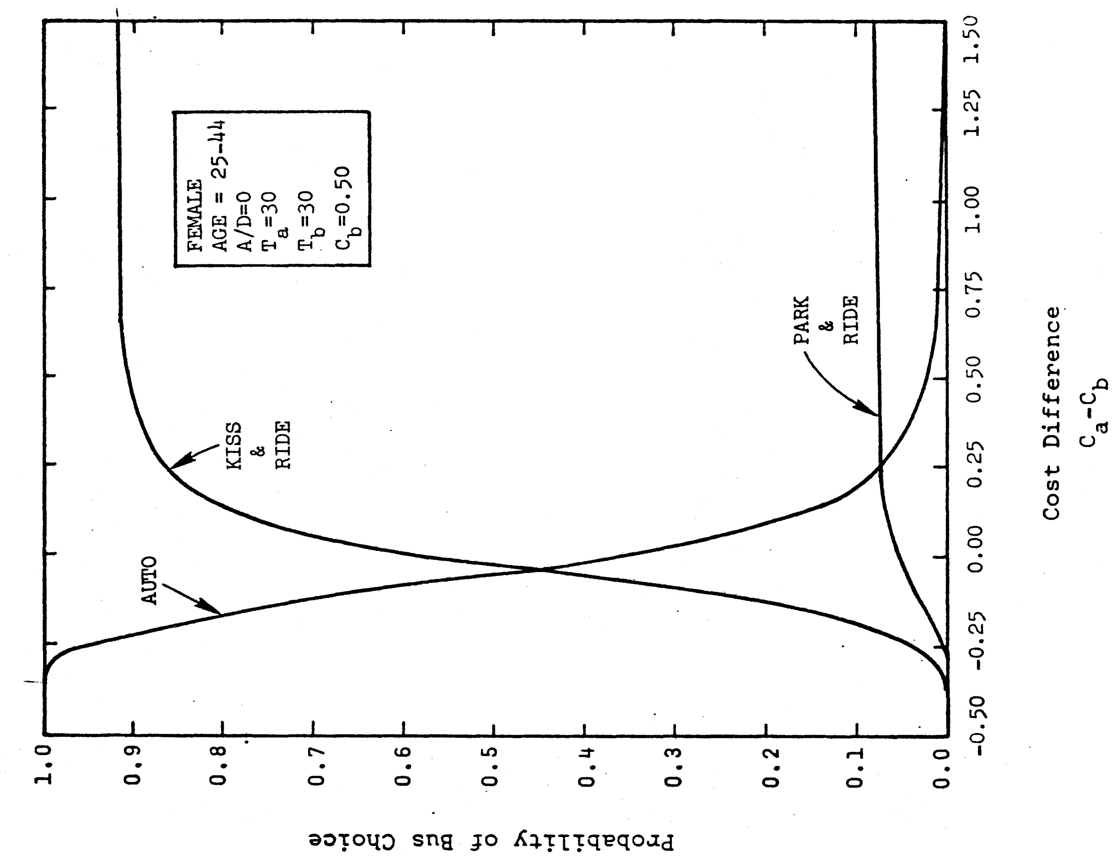
Figure D-12



Cost Difference

C_a-C_b

Figure D-11



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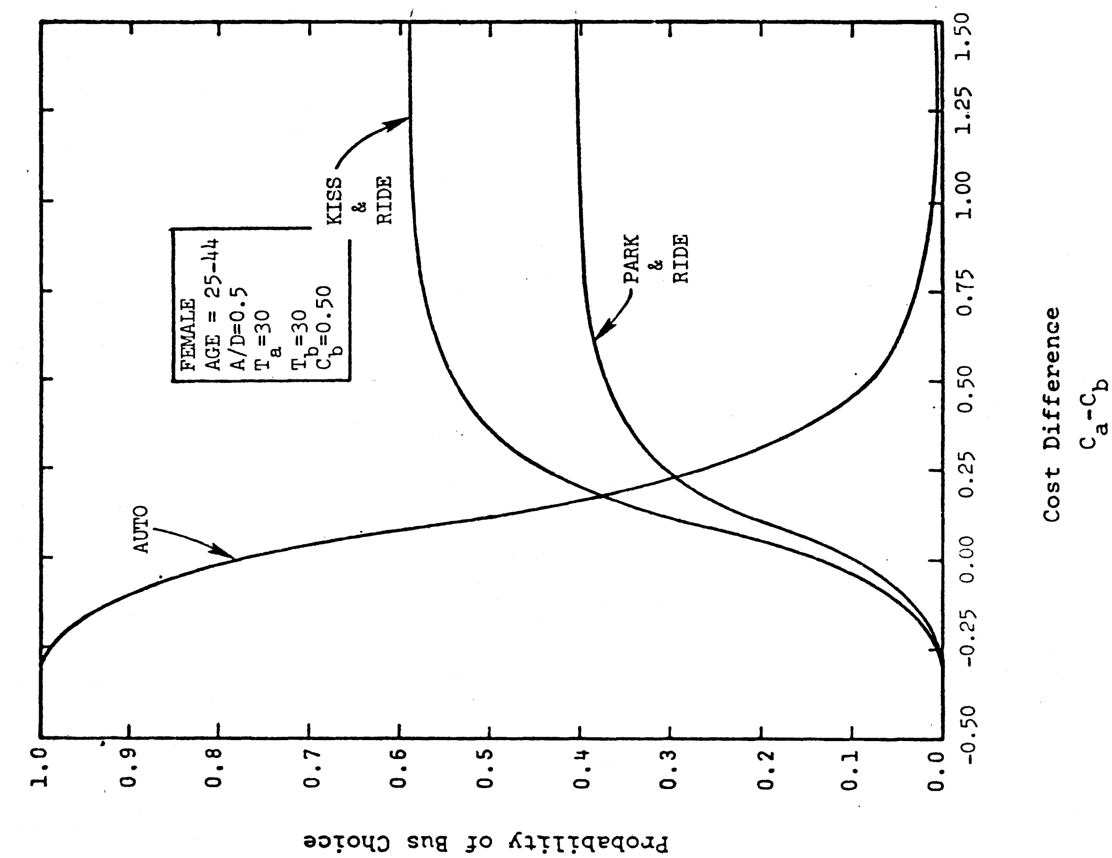
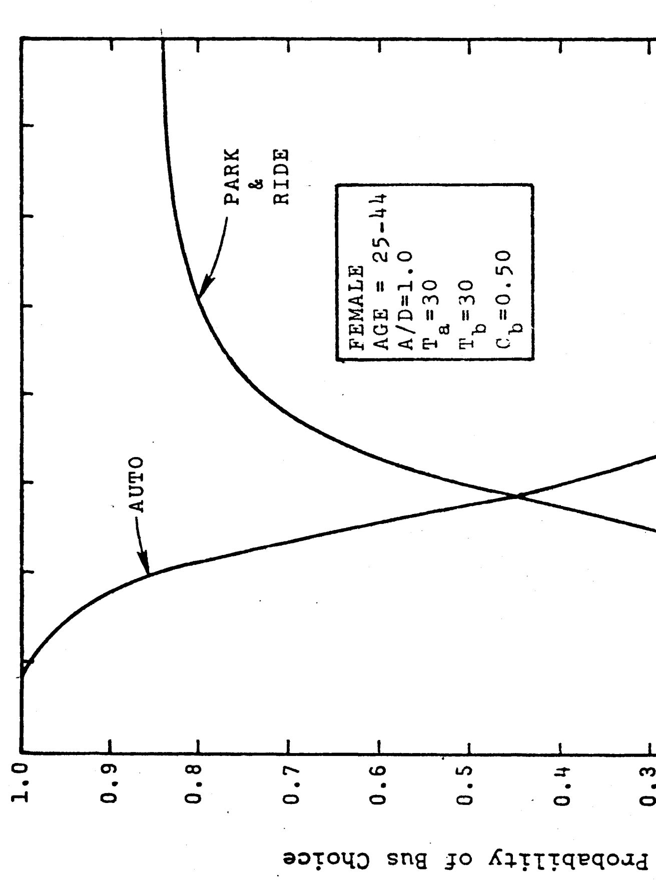


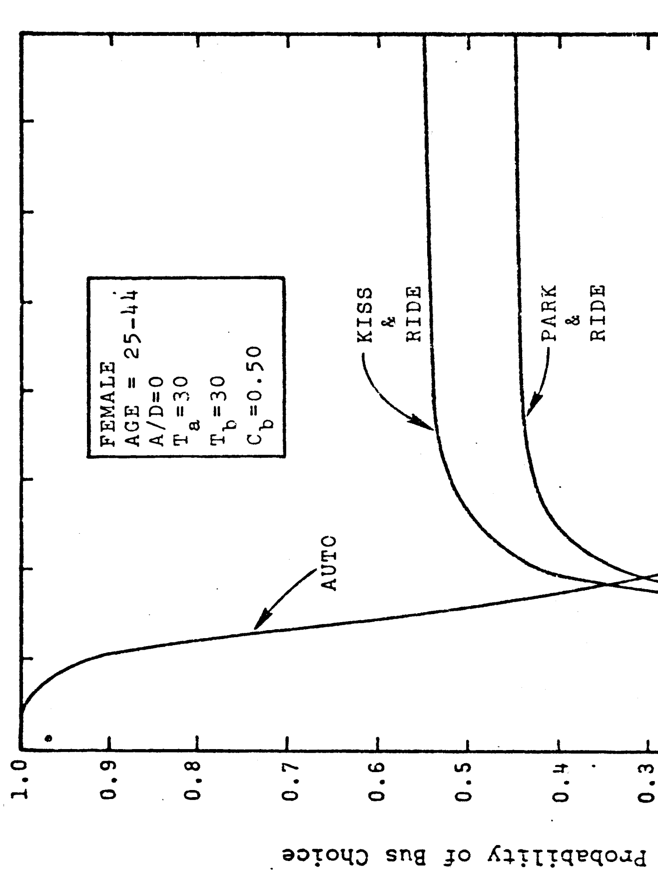
Figure D-14



Cost Difference

C_a-C_b

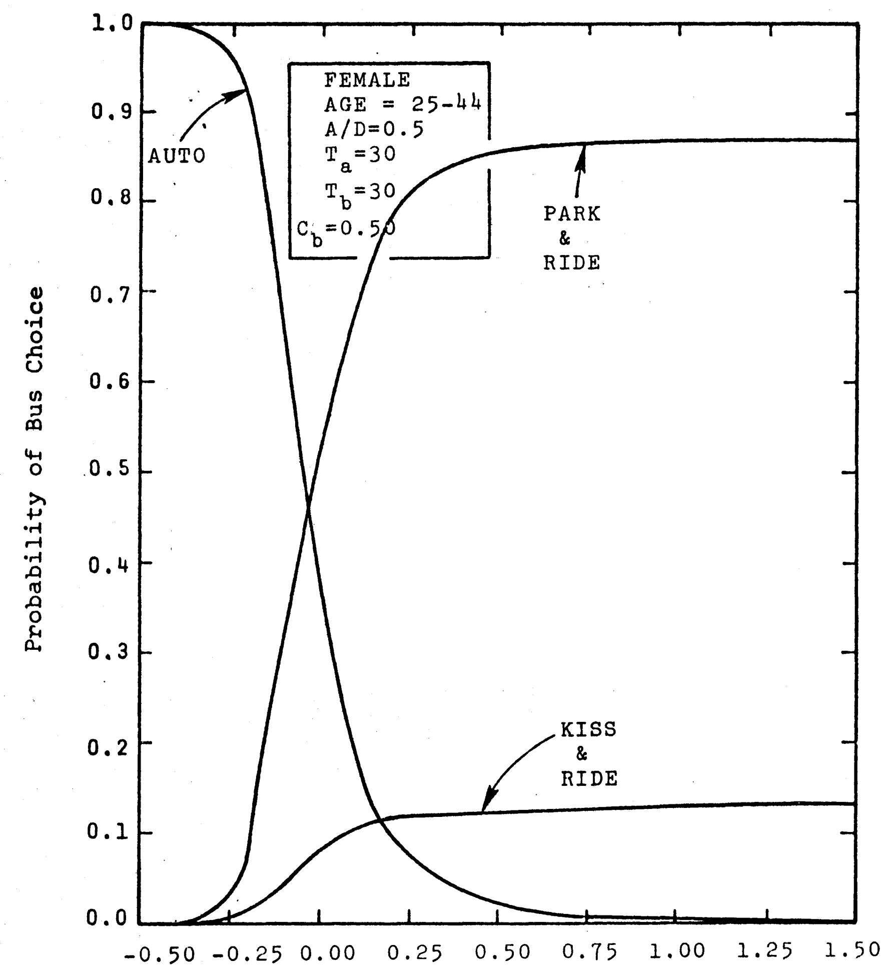
Figure D-5



Cost Difference

C_a-C_b

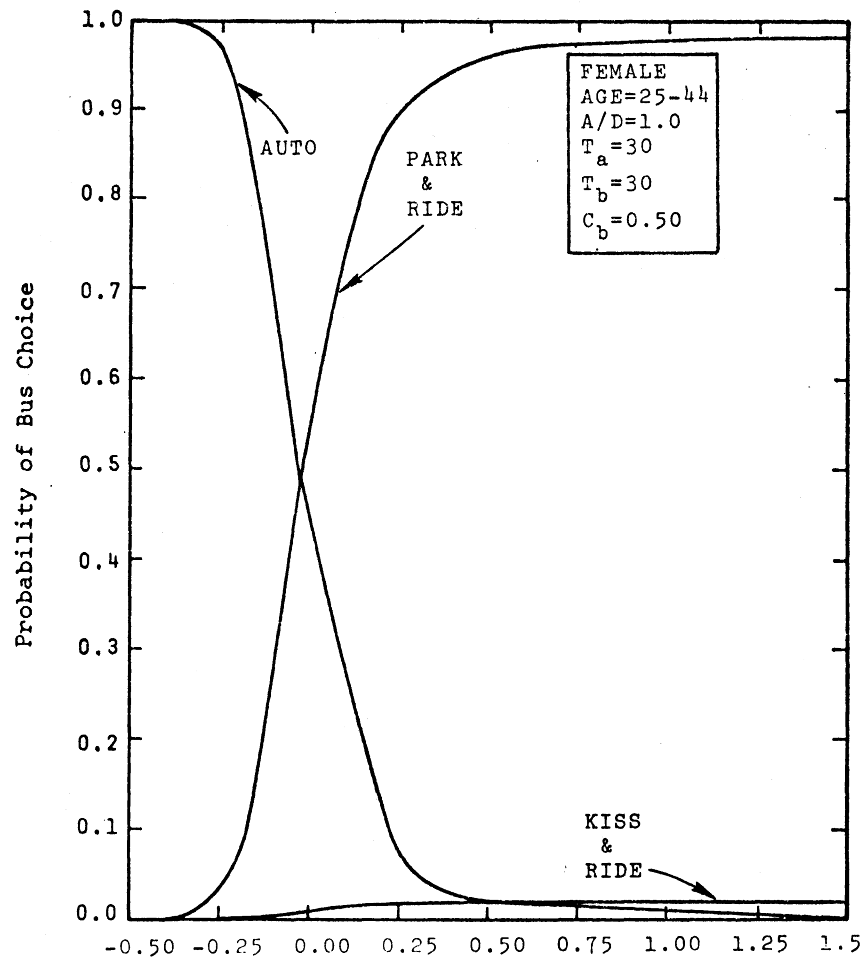
Figure D-16



Cost Difference

$C_a - C_b$

Figure D-17



Cost Difference

$C_a - C_b$

Figure D-18

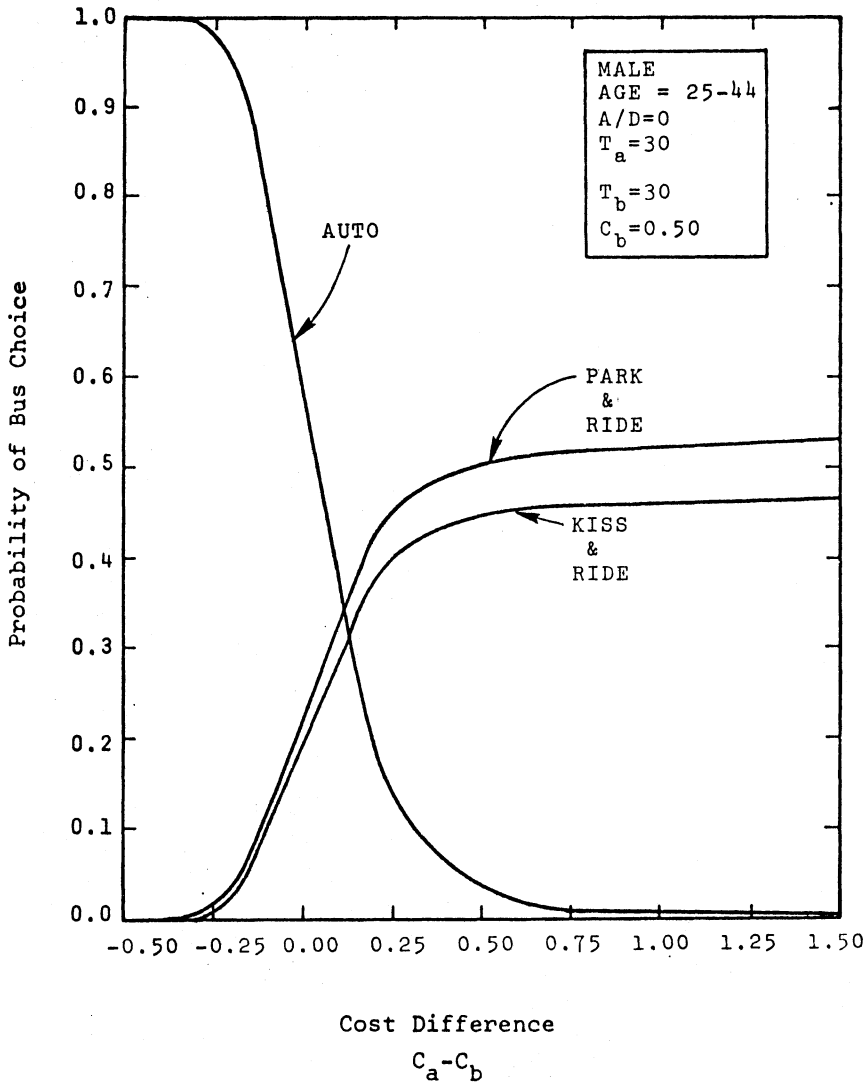


Figure D-19

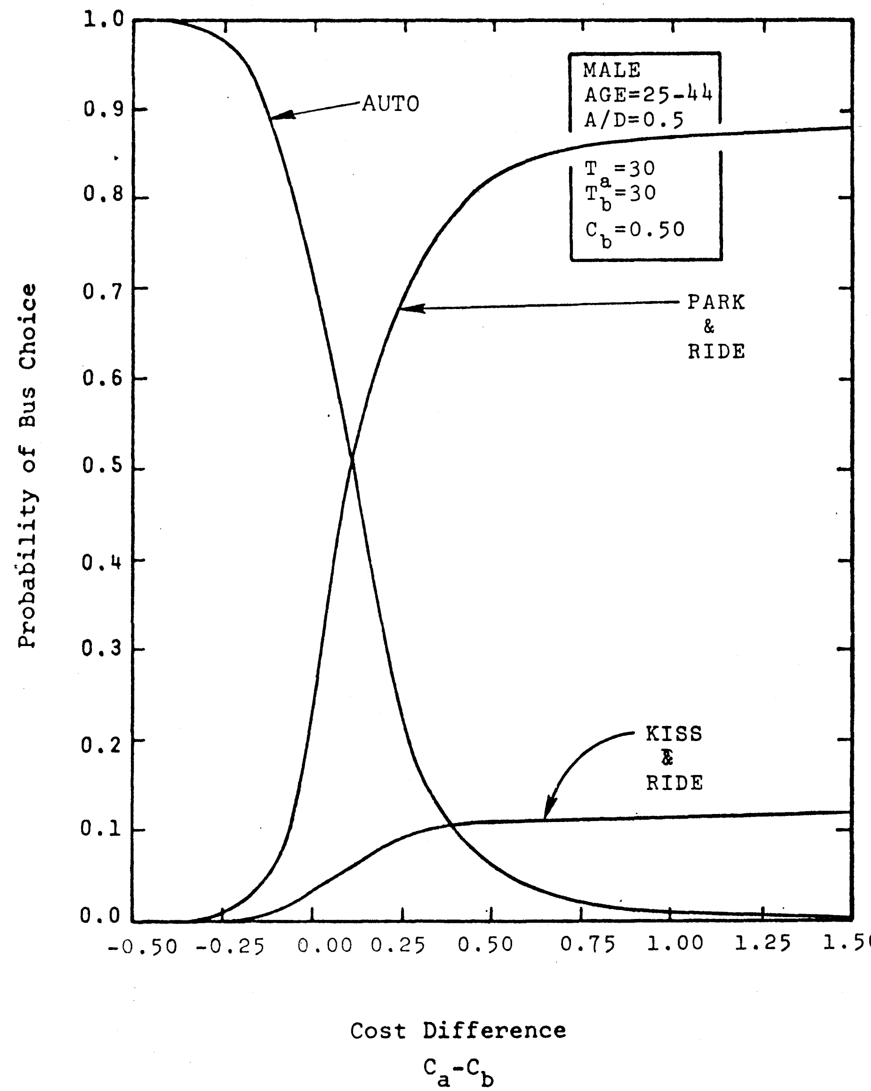
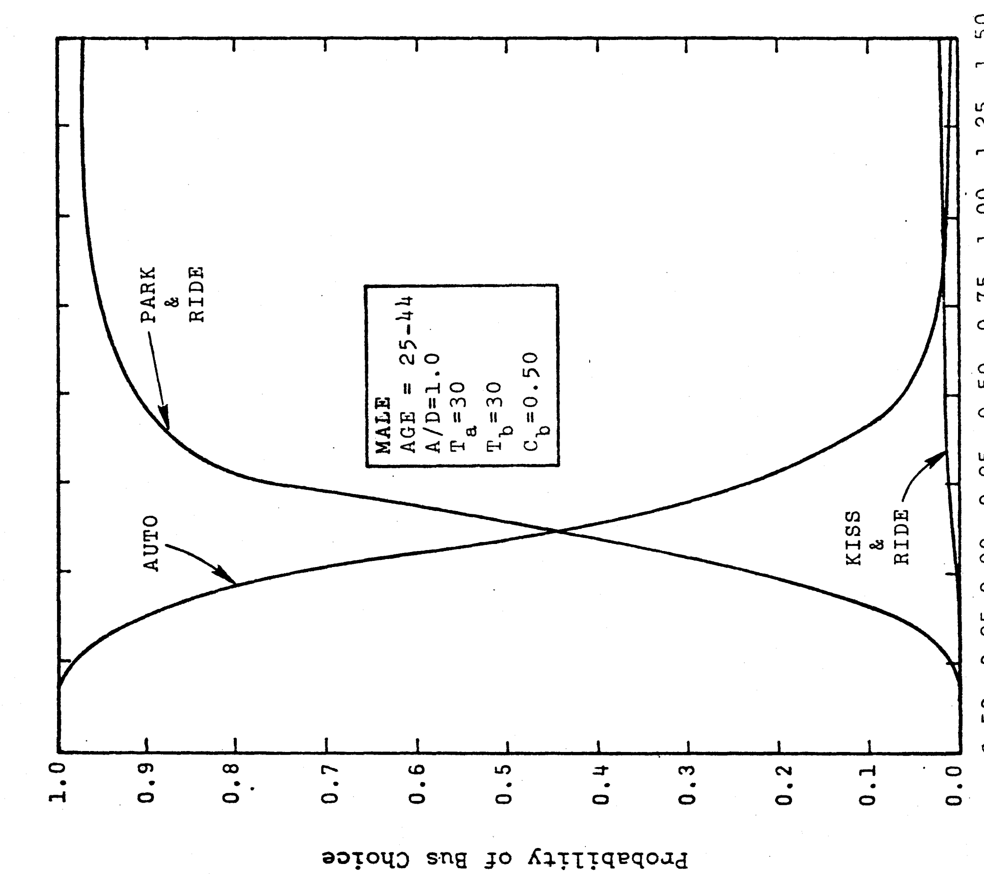


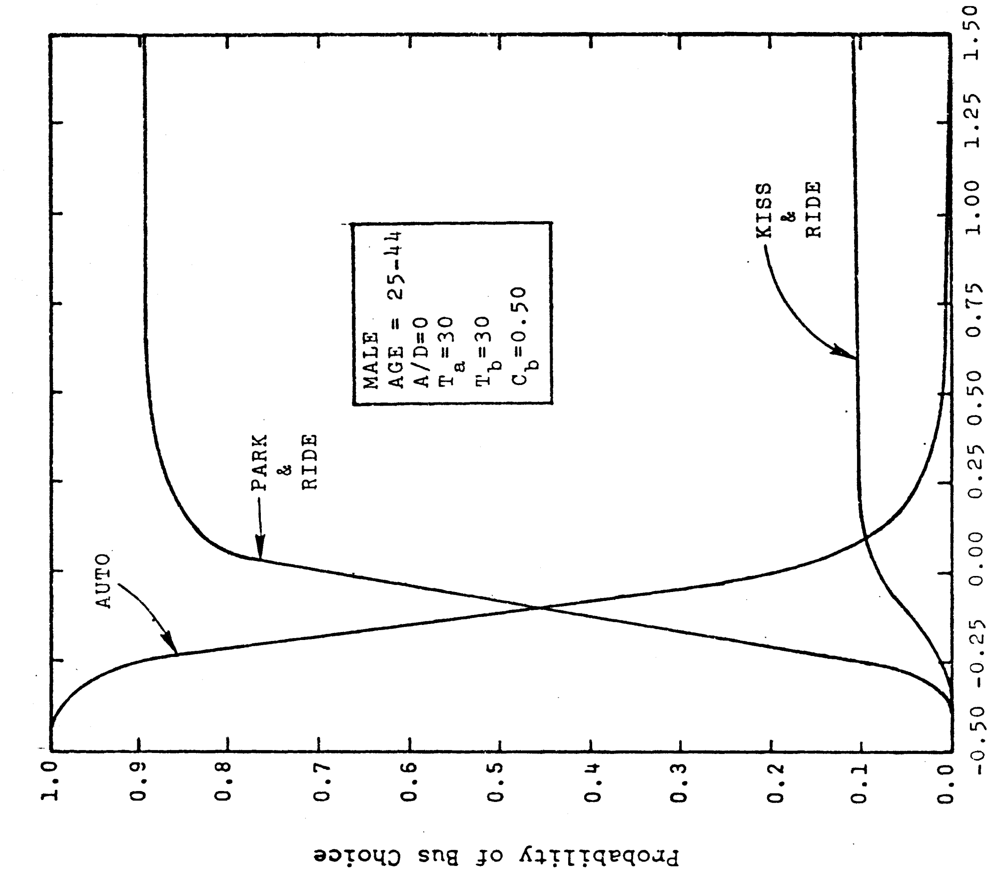
Figure D-20



Cost Difference

C_a-C_b

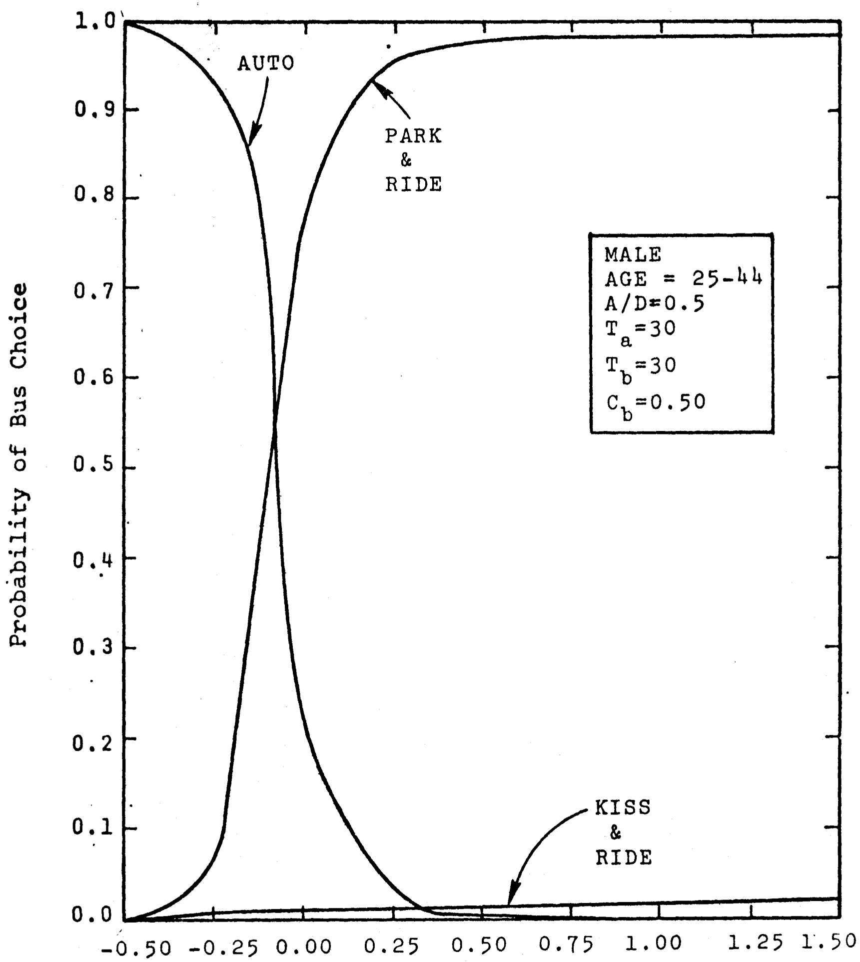
Figure D-21



Cost Difference

C_a-C_b

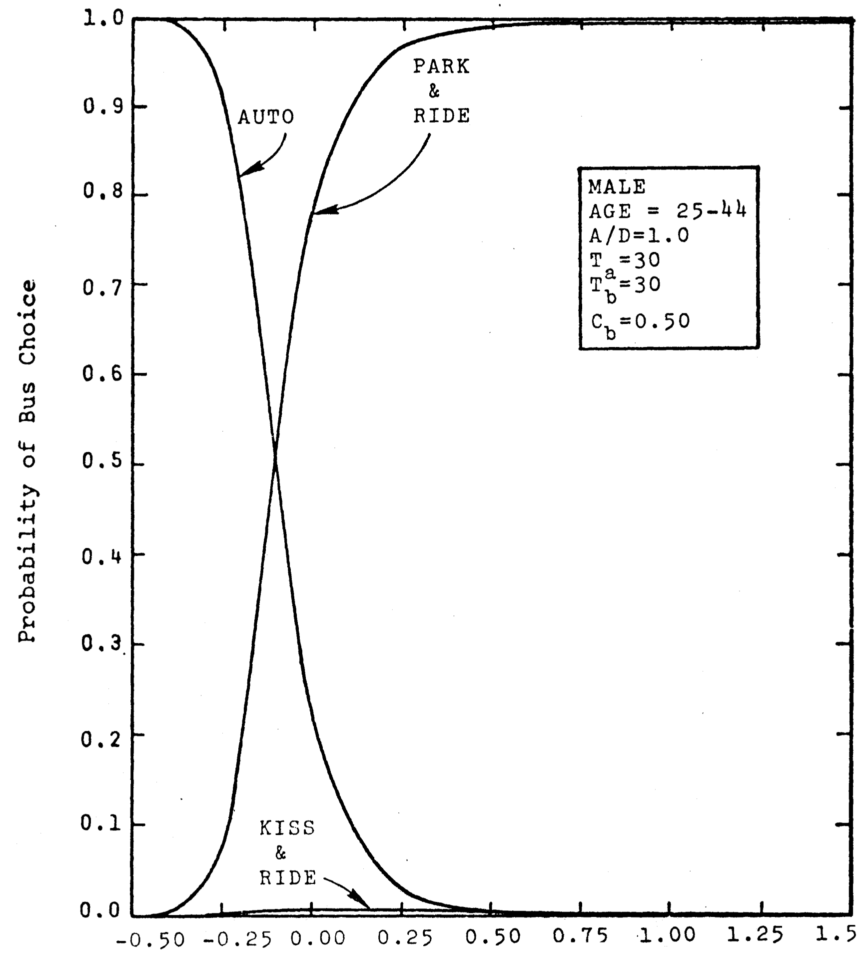
Figure D-22



Cost Difference

C_a-C_b

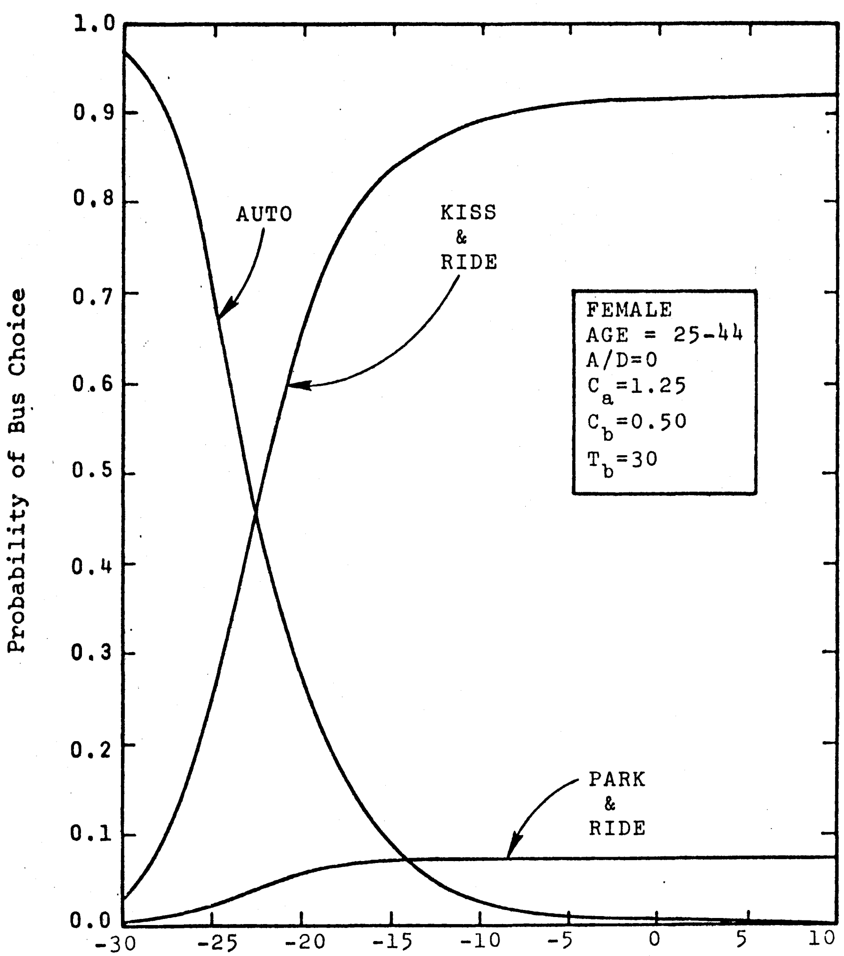
Figure D-23



Cost Difference

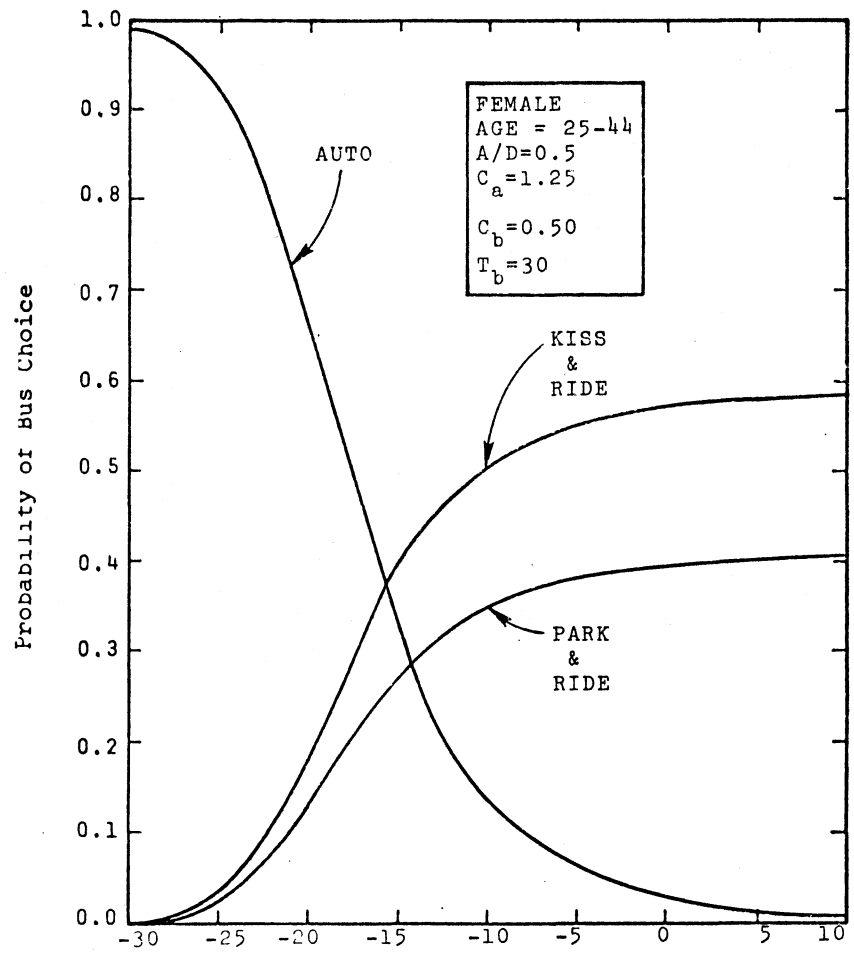
C_a-C_b

Figure D-24



Travel Difference
T_a-T_b

Figure D-25



Travel Difference
T_a-T_b

Figure D-26

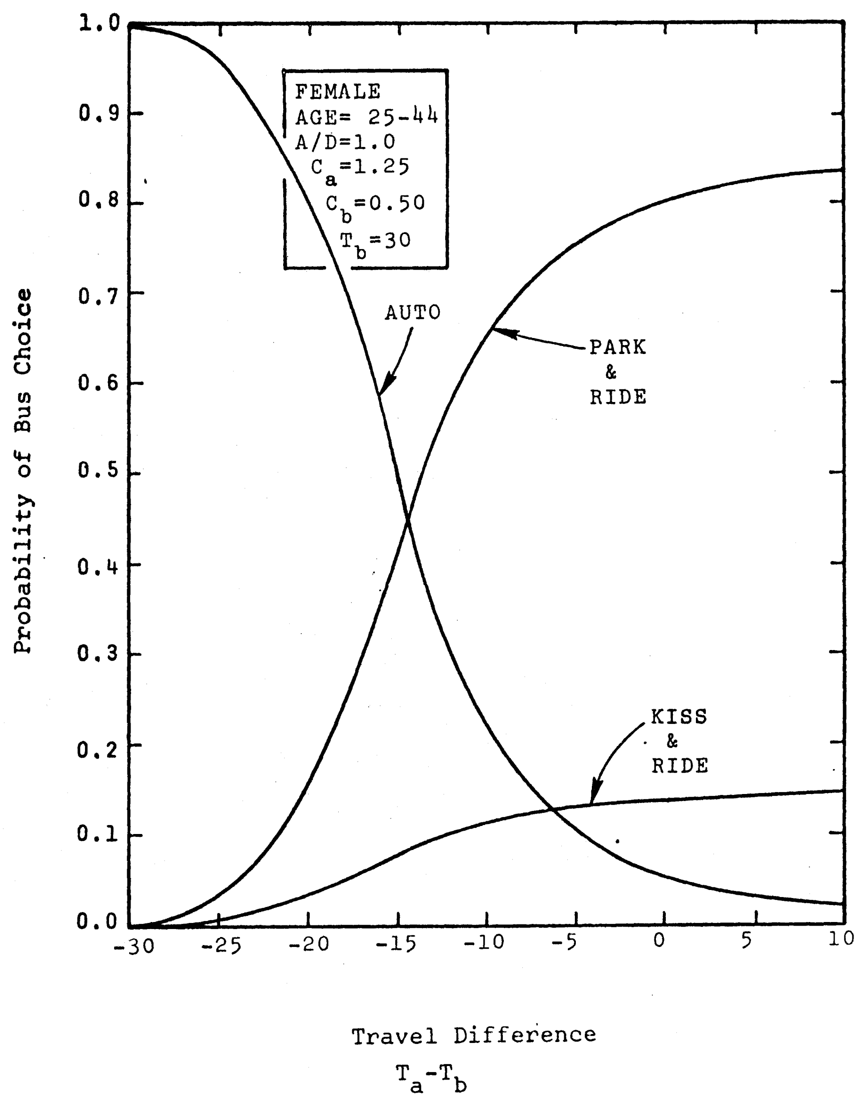


Figure D-27

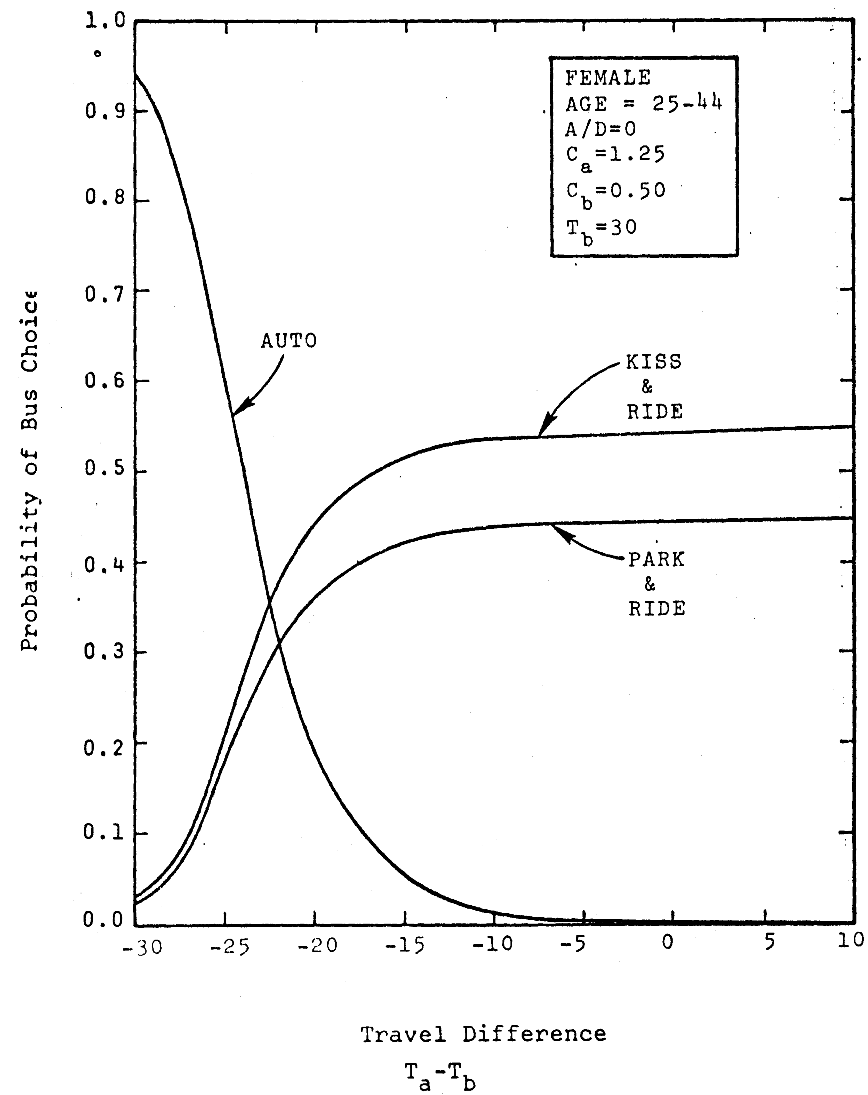


Figure D-28

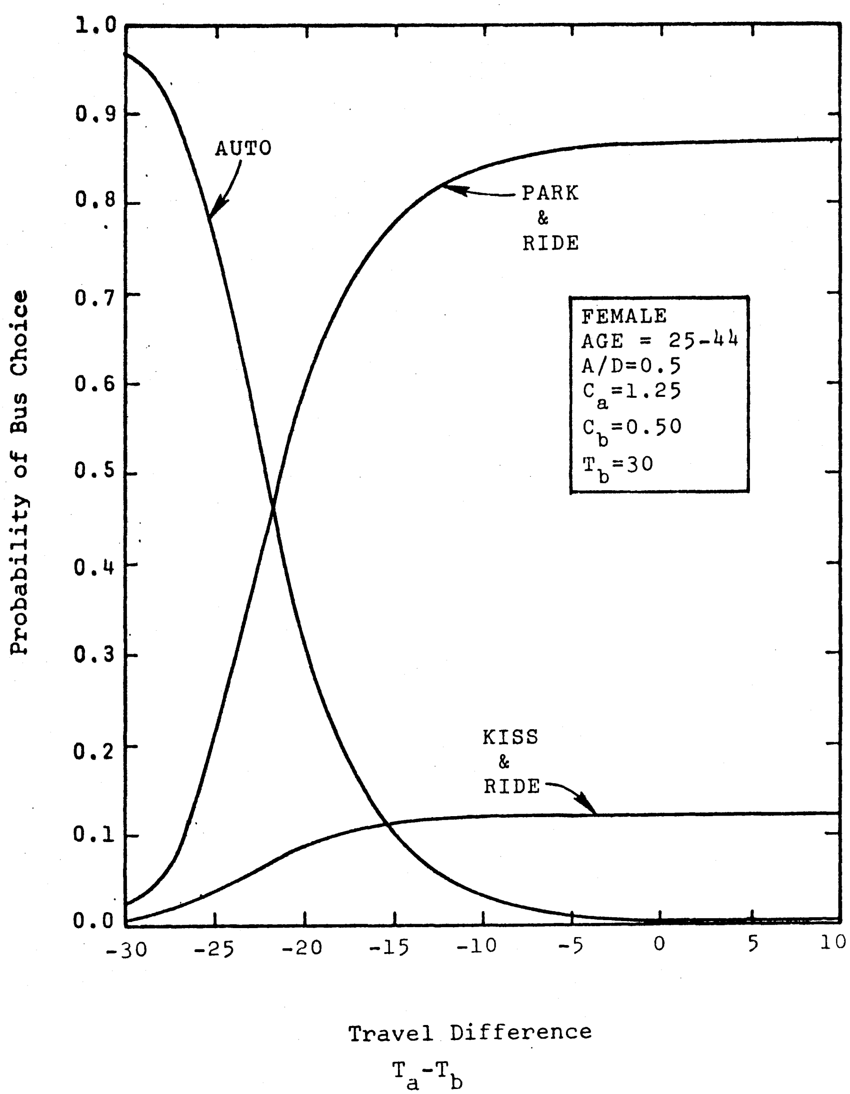


Figure D-29

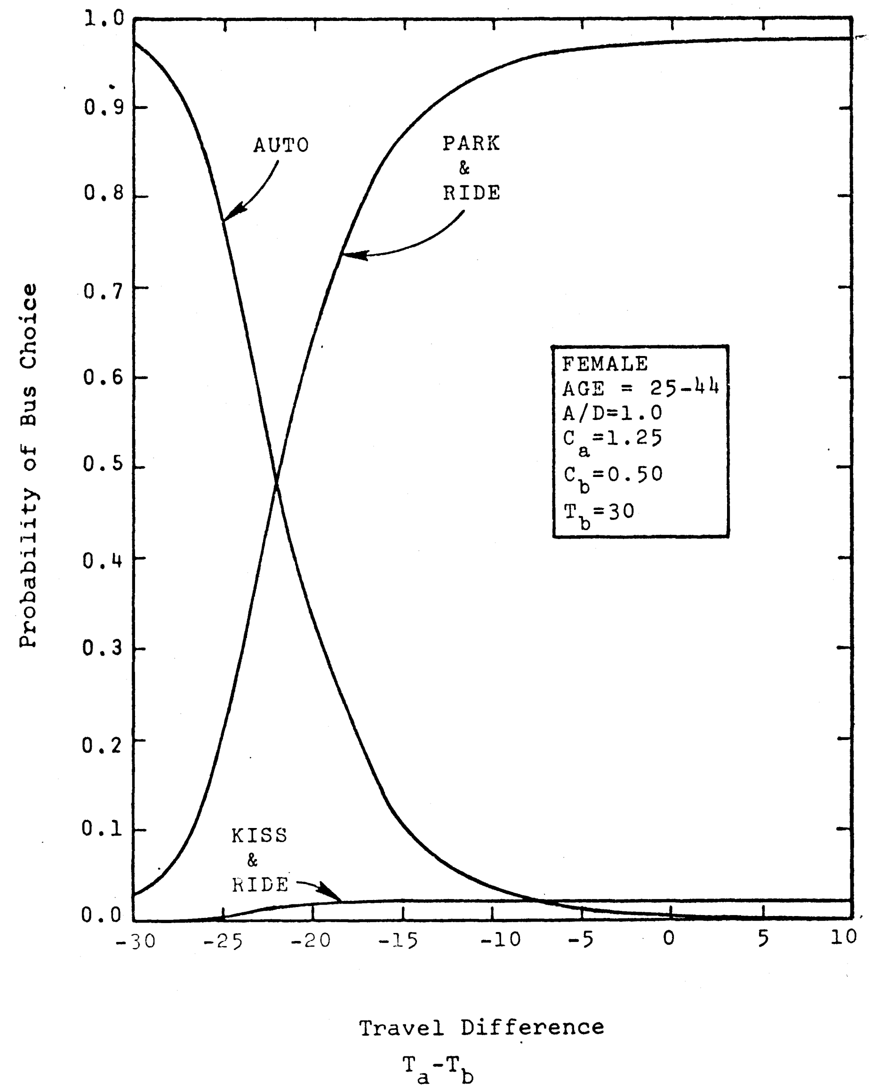


Figure D-30

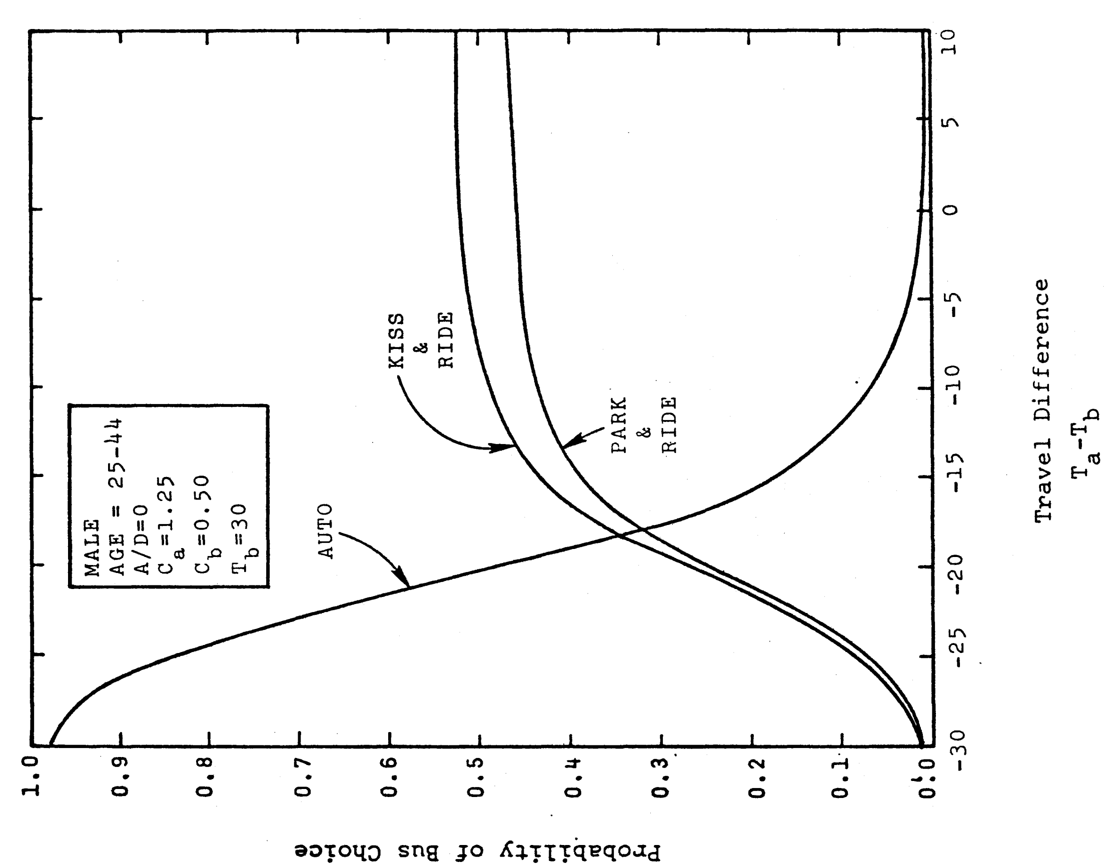


Figure D-31

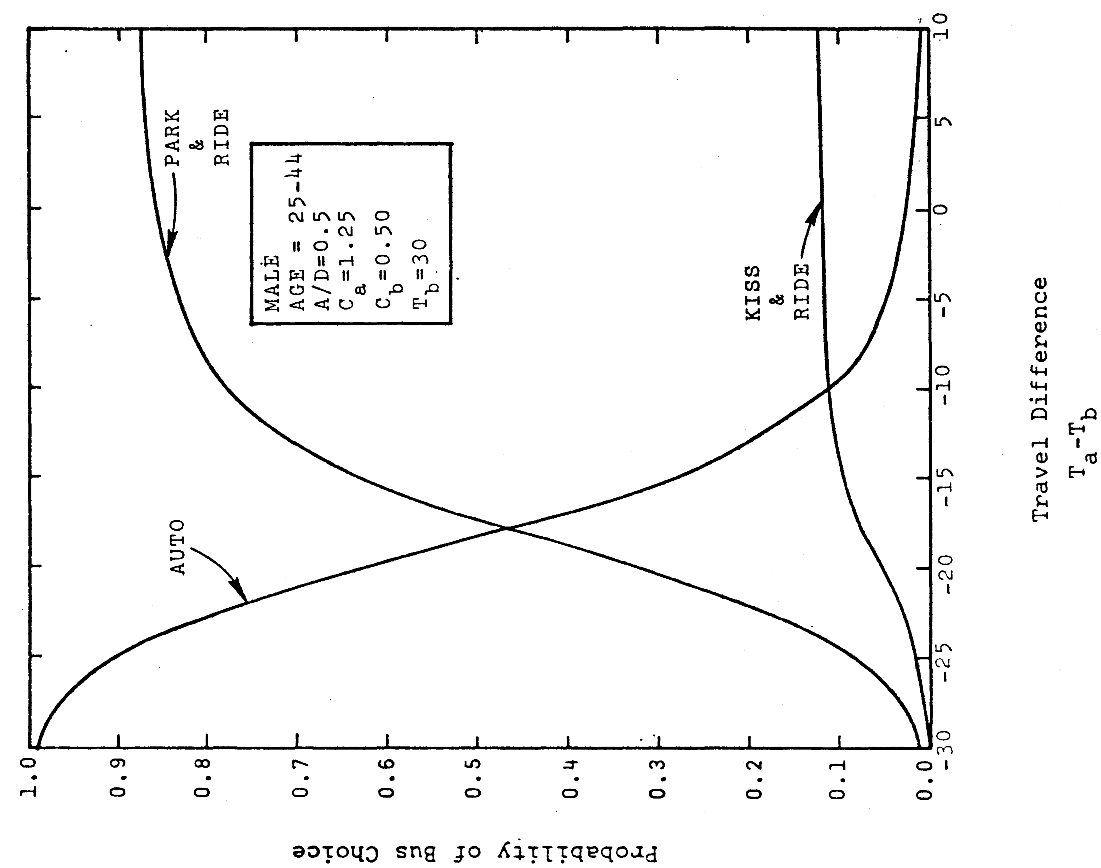


Figure D-32

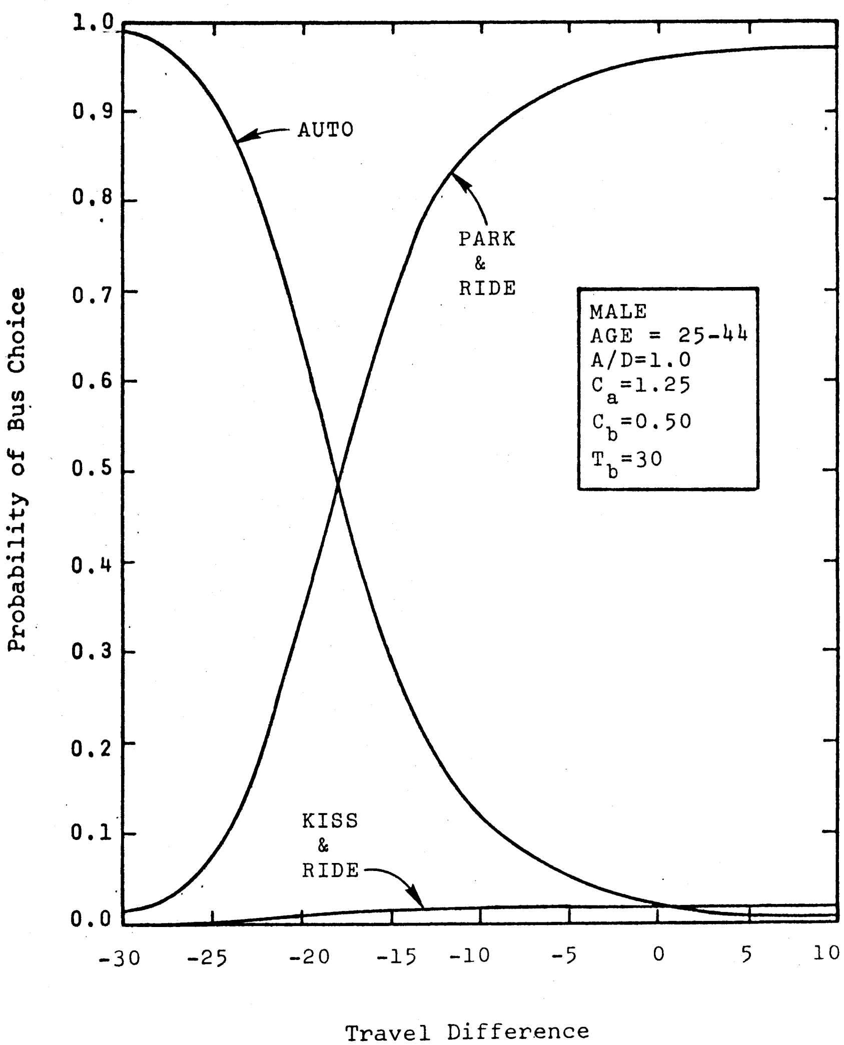


Figure D-33

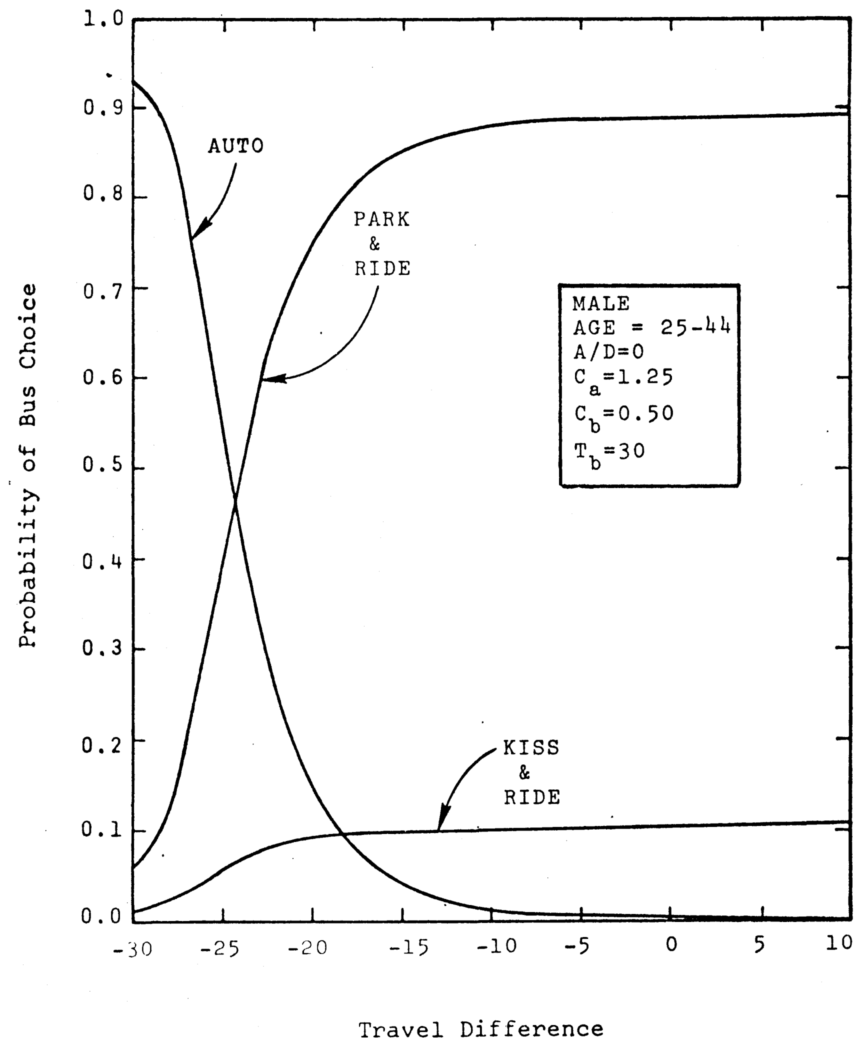


Figure D-34

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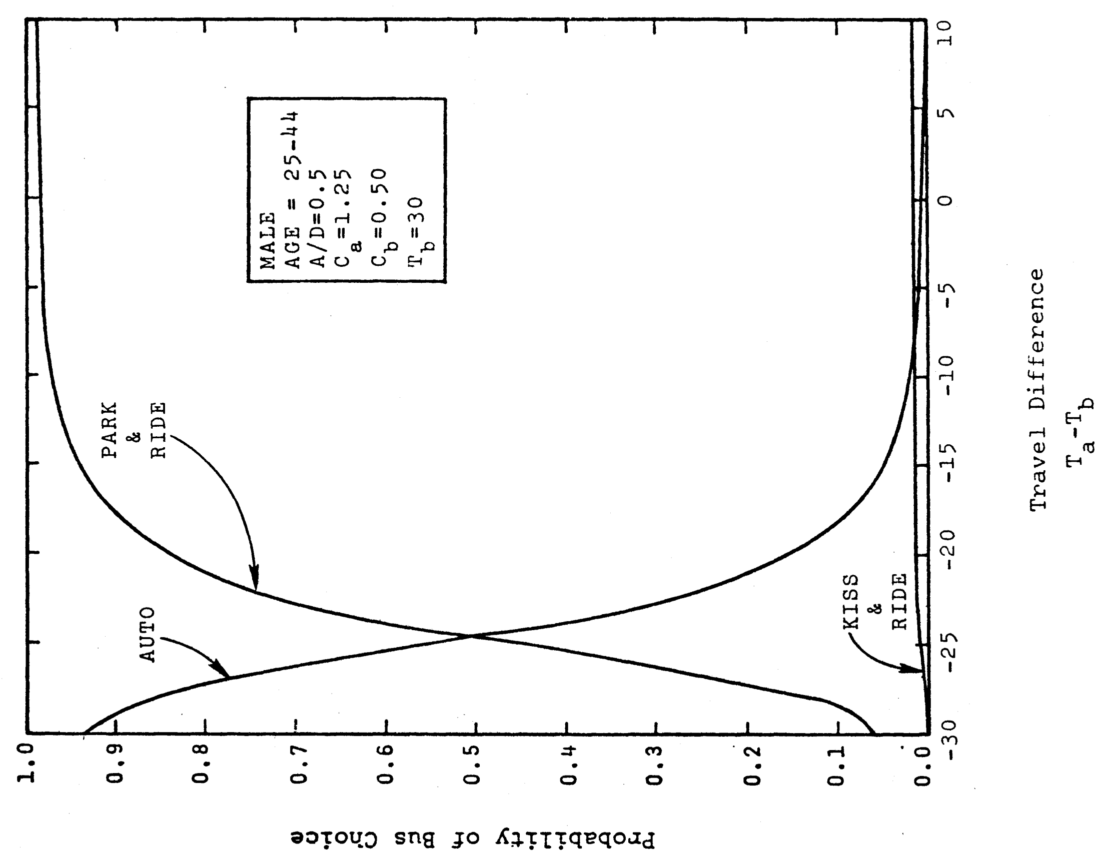

Figure D-35

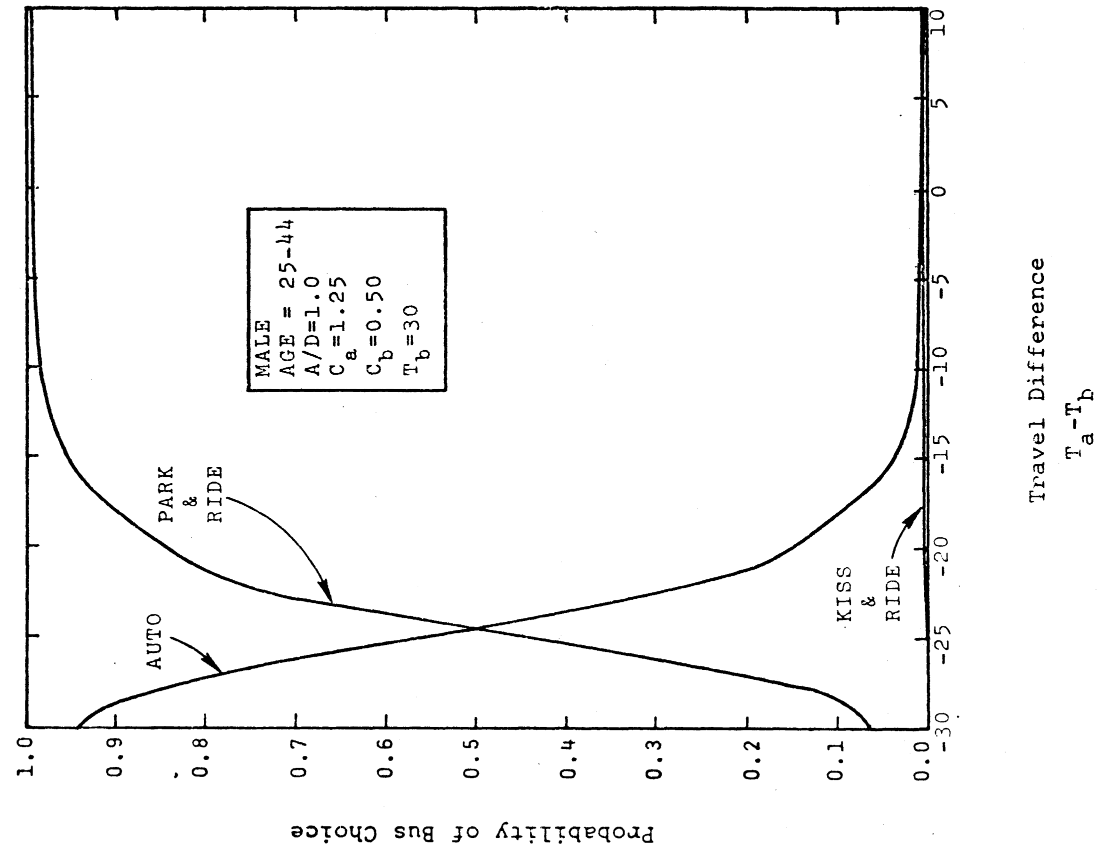

Figure D-36

APPENDIX E

FORTRAN SUBROUTINE FOR UMODEL

The discussion that follows is directed toward those planners who are familiar with UTPS procedures. It refers to an example deck configuration (Figure E-1) of a UTPS computer implementation of the logit model referred to in the text of this report as equation (6).

The UTPS computer package provides a set of cataloged Job Control Language (JCL) procedures that facilitate the insertion of the user provided FORTRAN code into the UMODEL program. This JCL procedure is named USERCODE and its use is illustrated. It should be noted that those cards beginning with // are JCL cards used to invoke and, in some cases, modify the cataloged procedures Cards beginning with //* are JCL comment cards which serve to explain these control cards. The cards that contain /. in the first two columns are command cards for the IBM system utility program IEBUPDTE which does the actual insertion of the fortran code.

The cards following the /. cards and terminated by the next set of JCL cards constitute the FORTRAN code necessary to use the logit model for modal split forecasting. The execution of this code within the framework of the UMODEL program is initiated by the JCL cards shown immediately following the code.

For purposes of illustration, three data files are assumed to exist. The first file, named RCO.ZONEDATA, is a table of statistics on certain zonal characteristics. This can be viewed as equivalent to a deck of data cards, one for each zone, that are sorted in ascending zonal order. Columns 1 through 3 of these cards contain the zone number; columns 5 through 8 contain the decimal fraction of the zone's work force that is male; columns 10 through 13 contain the number of vehicles registered in the zone; and columns 14 through 16 contain the number of licensed drivers in the zone. These production data are made known to the UMODEL program by assigning the file to any 1 of 7 possible special names (i.e., A1 through A7, with A1 chosen for this example).

The second file, named RCO.XCIMPEDS, contains four tables in standard UTPS interleaved format. These are tables of interchange impedances in terms of time and cost. Tables one and two are interchange transit travel times and auto travel times, respectively. Tables three and four contain transit travel costs and auto travel costs, respectively. These tables are made available to the UMODEL program by assigning the file the special name "J1".

The third file, named RCO.WORKTRPS, contains a trip table of CBD work trips. This table is assigned to the UMODEL program by giving it the special local name of "J2".

The execution of the UMODEL program produces a fourth file, named RCO.CBDTRIPS, that contains two tables of CBD work trips in the standard UTPS interleaved format. The first table reflects the logit model development of CBD transit trips while the second table is its complement, that of auto person trips. The special local name for this file is "J8". The JCL card immediately following the "J8" assignment card is used to specify that the output file be saved for future use. The FORTRAN code contains comments that clarify the purpose of individual statements.

The algorithm calculates separate $G_2(X)$ functions for male and female tripmakers. The probability of choosing transit is then determined for each sex on a zone by zone basis. These two sex groups are then summed to produce the first output table, that of forecasted CBD transit work trips for the zone. The auto work trips are established by simple subtraction to produce the second table to be outputed.

```
//LOGIT  EXEC  USERCODE,PROGRAM=UMODEL,DISK=MTS000,UNITDIS=SYSDA,
//             UNITPRO=SYSDA,LIB='&LOGITMDL',
//             PARM.FORT='NOSOURCE,LOAD,NODECK,NOLIST,NOMAP',
//             PARAM.LKED='NOXREF,NOLIST,LET,NOMAP,OVLY,DC'
//*
//*        THE ABOVE PARAM CARDS ARE INCLUDED TO PROVIDE THE USER WITH A
//*        MINIMUM OF UNNECESSARY OUTPUT.
//*
//USERCODE.SYSIN DD *
/. CHANGE  NAME=UMODEL
/. NUMBER  INSERT=YES,SEQ1=442000,NEW1=442001,INCR=1
C
C          THE FOLLOWING FORTRAN CODE PROVIDES AN IMPLEMENTATION OF
C          THE G2(X) LOGIT MODEL
C
      REAL*4    ORATIO, TRATIO, CRATIO, G2OFXM, G2OFXF, EXOFGM, EXOFGF,
     -          NMMALS, NMFMLS, PROBTM, PROBTF, TRNTRP
C
C          ORATIO - AUTOS OWNED PER DRIVER
C          TRATIO - TRAVEL TIME DIFFERENCE RATIO
C          CRATIO - TRAVEL COST DIFFERENCE RATIO
C          TRNTRP - NUMBER OF TRANSIT TRIPS
C          G2OFXM - THE FUNCTION VALUE FOR G2(X) FOR MALES
C          G2OFXF - THE FUNCTION VALUE FOR G2(X) FOR FEMALES
C          EXOFGM - EPSILON RAISED TO THE G2(X) POWER FOR MALES
C          EXOFGF - EPSILON RAISED TO THE G2(X) POWER FOR FEMALES
C          NMMALS - NUMBER OF MALE CBD WORK TRIPS
C          NMFMLS - NUMBER OF FEMALE CBD WORK TRIPS
C          PROBTM - PROPORTION OF A ZONES MALE WORK TRIPS USING TRANSIT
C          PROBTF - PROPORTION OF A ZONES FEMALE WORK TRIPS USING TRANSIT
C
      ORATIO = X(3)/X(4)
      TRATIO = 2.0 * (X(6) - X(5))/(X(6) + X(5))
      CRATIO = 2.0 * (X(8) - X(7))/(X(8) + X(7))
C
      G2OFXF = 4.3230 + 3.9319 * ORATIO + 10.8990 * TRATIO +
     -                                    4.7533 * CRATIO
      G2OFXM = G2OFXF - 1.3092
C
      EXOFGM = EXPON(G2OFXM)
      EXOFGF = EXPON(G2OFXF)
C
      PROBTM = EXOFGM/(1.0 + EXOFGM)
      PROBTF = EXOFGF/(1.0 + EXOFGF)
C
C
C          STRATIFY THE NUMBER OF CBD WORK TRIPS BY SEX
C
      NMMALS = X(2) * X(9)
      NMFMLS = X(9) - NMMALS
```

Figure E-1. Example UTPS Job Control Language and User Subroutine.

Figure E-1 (continued).

```
C
C         ASSIGN TRANSIT PERSON TRIPS TO TABLE NO. 1 - TABSO(1)
C         ASSIGN AUTO    PERSON TRIPS TO TABLE NO. 2 - TABSO(2)
C
      TRNTRP = PROBTM * NMMALS + PROBTF * NMFMLS
      TABSO(1) = TRNTRP
      TABSO(2) = X(9) - TRNTRP
C
C         ASSIGN TRANSIT PERSON TRIPS TO TABLE NO.1 SUMMARY - TETAB(1,1)
C         ASSIGN AUTO    PERSON TRIPS TO TABLE NO.2 SUMMARY - TETAB(2,1)
C         ASSIGN TOTAL WORK TRIPS TO PERSON TRIP SUMMARY - TEPERS(1)
C
      TETAB(1,1) = TABSO(1)
      TETAB(2,1) = TABSO(2)
      TEPERS(1) = X(9)
C


//LOGIT   EXEC  UMODEL.LIB='&LOGITMDL',
//               A1='DSN=RC0.ZONEDATA,VOL=SER=VHDP00',UNITA1=SYSDA,
//               J1='DSN=RC0.XCIMPEDS,VOL=SER=VHDP00',UNITJ1=SYSDA,
//               J2='DSN=RC0.WORKTRPS,VOL=SER=VHDP00',UNITJ2=SYSDA,
//               J8='DSN=RC0.CBDTRIPS,VOL=SER=VHDP00',UNITJ9=SYSDA
//UMODEL.FT18F001  DD  DISP=(NEW,CATLG),SPACE=(TRK,(3,1))
//*
//*       THE ABOVE "A" & "J" FILE ASSIGNMENTS PROVIDE INFORMATION TO
//*       THE PROGRAM "UMODEL" IDENTIFYING THE SOURCE OF THE DATA TO BE
//*       PROCESSED.  THE "J8" FILE IS USED TO STORE THE RESULTING
//*       TRANSIT AND AUTO CBD TRIP MATRICES.
//*
//*       THE FOLLOWING DATA CARDS ASSOCIATE THE "X" VARIABLES IN THE
//*       FORTRAN CODE WITH THE LOCATION OF THE DATA BY FILE AND
//*       POSITION WITHIN THE FILE.
//*
//UMODEL.SYSIN  DD *
 &PARAM  ZONES=25, TABOUT=2, TESUM(1)=2, NAME01="TRANSIT TRIPS",
         NAME02="AUTO TRIPS  &END
 &SELECT   REPORT=4   &END
 &DATA
  1 P      1    3    1                 ZONE NUMBER
  2 P      5    8    1                 PROPORTION MALE
  3 P     10   13    1                 AUTOS
  4 P     14   16    1                 DRIVERS
  5 X   1001                           TRANSIT TIME
  6 X   1002                           AUTO TIME
  7 X   1003                           TRANSIT COST
  8 X   1004                           AUTO COST
  9 T   2001                           CBD WORK TRIPS
/*
//
```