QUADATT II: A TRANSPORTATION PLANNING TOOL

by

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CHAPTER I

Introduction

In the past, computerized transportation planning models have produced some feelings of disillusionment among planners and decision-makers (Lee, 1972). This disillusionment stems in part from the high cost of data collection and computer time and the difficulty of interpretation and translation of model output. QUADATT II (Quick And Dirty Analysis Technique for Transportation - Second Version) is a computerized transportation planning model which attacks these problems by simplifying the data collection process and outputs of the model.

Looking in more detail at existing modeling endeavors, we see that data collection is a necessary phase of any transportation model building effort. Not only is an extensive and costly input data base required for most models, but an indeterminant amount of data is also needed during the calibration phase to fit model parameters to the characteristics of the study region. Once the data have been collected and the model calibrated, the cost of computer execution of the model must be borne. Most models require hours of computer time to generate the impacts of a single transportation configuration. The combined costs of data collection and computer time thus often prevent the display of a broad spectrum of alternative transportation plans and associated impacts.

Computer output which is difficult to analyze is the second problem which plagues transportation models. Unfortunately, computer output is not a highly readable medium and must be formatted and documented to be comprehensible. Beyond this, the decisionmaker must be educated as to the proper use of the model output as an aid in policy formulation. A transportation model with clear, concise output and documentation will assist in convincing both planners and decisionmakers that the computer models are valuable tools.

The QUADATT II package is designed to attack both the cost and output problems discussed above. Compared to most comprehensive transportation planning packages, QUADATT II generally requires only a small amount of input data (Creighton, Hamburg Planning Consultants, 1971). These may be obtained from readily available sources such as the Census Bureau, planning agencies, and highway departments. No calibration costs are incurred by QUADATT II, since it is assumed that most of the unique characteristics of metropolitan areas already have been discovered in previous studies, especially those dealing with transportation planning.* The computer execution time required by QUADATT II is gauged in seconds rather than hours, which also decreases costs. The output of QUADATT II is presented in a highly documented, tabular form in an attempt to improve the understanding of the user.

This is not to say that nothing has been sacrificed by QUADATT II in solving the problems of high cost and simplified output, but rather

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*Transportation studies already have been completed in almost all metropolitan areas with a population greater than 50,000 and in many smaller areas.

that a new tack should be undertaken in the field of planning models. This tack would focus upon generating the maximum number of transportation planning alternatives and relative measures of their impacts for a low cost. It is hoped that this objective is satisfied by the QUADATT II approach.

The role of forecasting in transportation planning has been ignored in the discussion thus far. It is obvious that a simplified package such as QUADATT II can only provide relative indicators for forecasting purposes. It is the premise of this author that forecasting models will be of little value until:

1) the current disillusionment of some planners and decision-makers with computer models is dispelled,

2) the causal factors in the urban system are better understood.

In the light of these premises, QUADATT II can be viewed as an attempt to restore credibility to computer-aided transportation planning models, to assist in metropolitan policy formulation, to increase understanding of the urban system, and to prepare an atmosphere for development of more sophisticated planning models.

CHAPTER II

A General Description of QUADATT II

QUADATT II is a transportation planning tool which encourages the evaluation of concomitant impacts of a set of alternative transportation plans. These concomitant impacts are presented to the planner in terms of the number of families in each of four income groups, the number of employees in each of five S. I. C. (Standard Industrial Classification) categories in each zone, and a measure of segregation by family income. In addition to these impacts of alternative transportation plans, QUADATT II also presents the planner with standard transportation model outputs such as zone-to-zone trip matrices stratified by auto and transit and a table of trip generation and attraction data.

The general QUADATT II procedure is diagrammed in Figure 1. As shown there, the procedure is an iterative one, terminating when all proposed transportation plans have been submitted to the program. The computer output of each iteration is then compared and the optimal plan selected on the basis of the planner's (i.e., his constituents') goals and objectives.

The value of QUADATT II as a transportation planning tool can be gauged with the help of the graphs in Figure 2. QUADATT II represents a trade-off between the cost of achieving a fine level of detail and of evaluating a large number of transportation alternatives. The procedure attempts to minimize the amount of detailed input data required

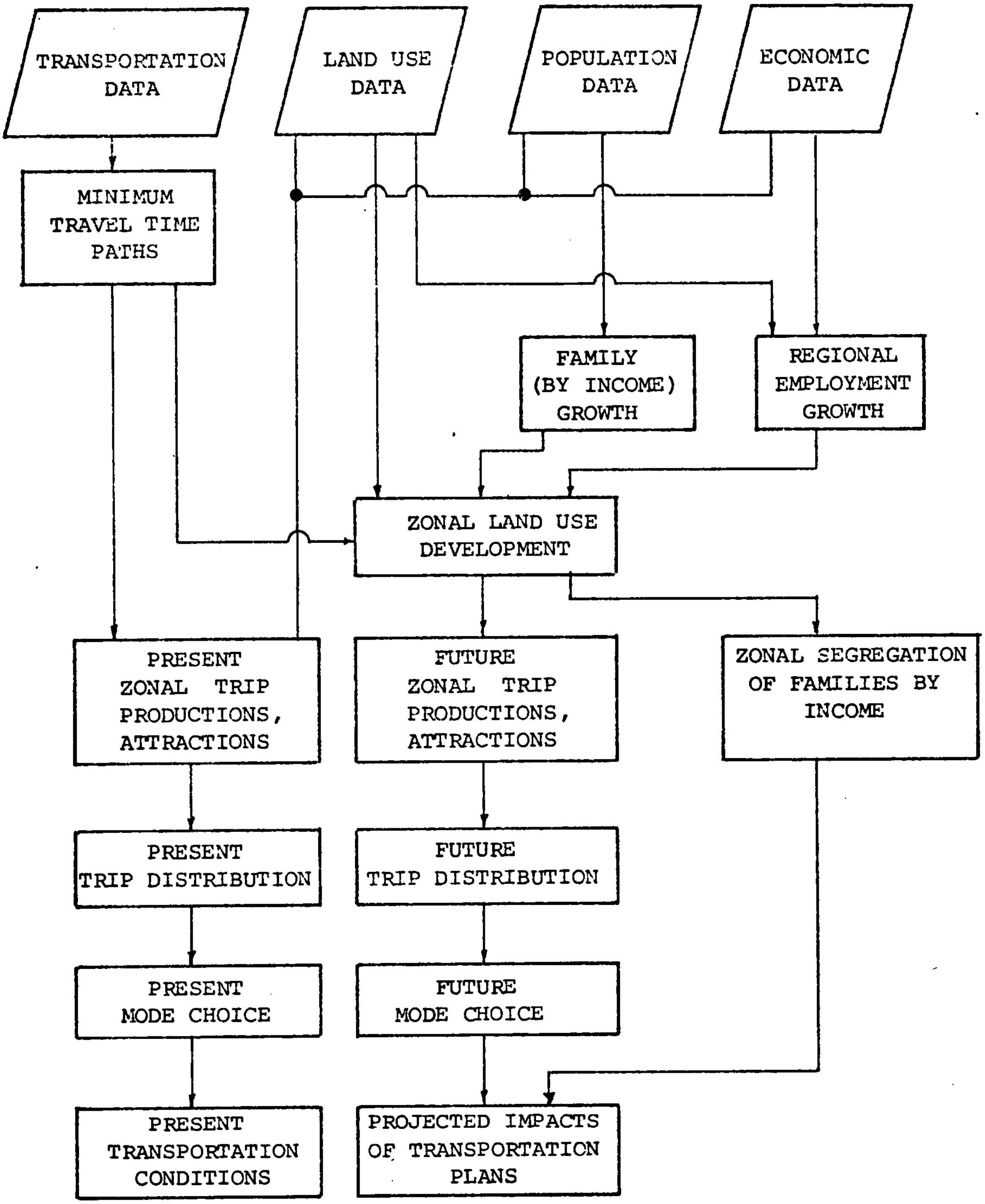

Figure 1
Interaction of Models Used in QUADATT II

QUADATT II MODELS / INPUT DATA	Cohort survival	Family by income	Input-output	EMPIRIC Land Use	Segregation by income	Trip production & attraction	Trip distribution	Modal split
At zonal level				●	●	●	●	●
At regional level	●	●	●					
Lagged (1960) No. of families by income for the region		●						
Lagged (1960) regional population		●						
Present (1970) population by age & sex, death rate, birth rate and migration rate for the region		●						
Present inter-industry financial relationships (the 5 types of industry in EMPIRIC (1970)			●					
Total demands + gross output for each industry (1970)			●					
Future (1980) total demand for each industry			●					
Present (1970) no. families by income by zone		●		●		●		●
Present (1970) employment by industry by zone			●	●		●		●
Present (1970) amount of land by type of use by zone				●				
Minimum travel times by zone pairs								
a. Present (1970) auto				●			●	●
b. Future (1980) auto				●			●	●
c. Present (1970) transit				●				●
d. Future (1980) transit				●				●
Present (1970) terminal times								●
Future (1980) terminal times								●
Present (1970) auto parking cost								●
Future (1980) auto parking cost								●
Present (1970) transit transfer time								●
Future (1980) transit transfer time								●

Figure 2
Data Required by Each QUADATT II Model

to generate transportation planning impacts in order to increase the time and money spent on evaluating a variety of alternative plans. This thesis will attempt to demonstrate that QUADATT II is an inexpensive and useful tool for generating impacts of transportation plans. However, it should be noted that QUADATT II does sacrifice some accuracy in achieving the simplicity and low cost objectives emphasized in the introduction. Therefore, QUADATT II's most valuable role in planning is in sketch planning, not as a precise forecasting device.

The next chapter describes the role of QUADATT II in each stage of the planning process.

CHAPTER III

QUADATT II As a Planning Tool

The planning process can be summarized by the following five stages:

1) Goal Identification
2) Policy and Plan Design
3) Impact Estimation
4) Evaluation and Choice
5) Implementation

QUADATT II is involved primarily with the Impact Estimation stage. However, the procedure is indirectly involved in each of the other planning phases as well.

Goal Identification

Goal identification in the planning process is encouraged by the placing of responsibility for evaluation of plans in the lap of the QUADATT II user. If the planner and/or decisionmaker who uses QUADATT II does not or can not explicitly identify his goals, then his goals may be deduced *ex post facto* through his evaluation of the impacts generated by the proposed plans. In this way QUADATT II assists in identifying the goals of its users. QUADATT II also forces planners to express their general goals in terms of the concrete variables predicted by the program. For example, a goal of "improving the quality of life for the poor" might have to be formulated in terms of improving transit facilities to decrease the number of families in the under $5,000 category in a particular zone. In evaluating the concomitant effects of different transportation plans, the QUADATT II user might be encouraged to alter his original goals. In any case the QUADATT II package has a definite role in the goal identification phase of the planning process.

Policy and Plan Design

Plans are designed for the QUADATT II procedure in terms of alternative transportation networks. The travel times for each link of the network* are policy inputs to QUADATT II and reflect changes in transportation networks designed by the planner. Transportation plan design may involve the future highway system, the future transit system, or both. A policy alternative which should be considered in all studies is that of the status quo or no change in the existing system. The low cost and simplified data requirements of QUADATT II encourage the generation of many transportation plans during the policy and plan design phase of the planning process.

Impact Estimation

QUADATT II contributes most significantly to the estimation of impacts in the planning process. QUADATT II is a computerized combi-

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*The "network" can be either the actual street and transit network or a conceptual network such as a spiderweb network that represents zone to zone travel times through broad transportation corridors.

nation of planning models and techniques. It generates impacts incurred by the choice of certain future levels for policy variables. All of the variables required by the QUADATT II models are presented in Figure 2. Any of the exogenously determined, future year inputs to QUADATT II might be varied if the planner felt that such variables could be controlled through policy formulation. The future transit minimum travel time matrix was chosen as the policy variable in this study, since it was assumed that the planner has modest control over this sector of the transportation realm.

Evaluation and Choice

This stage of the planning process parallels the evaluation of QUADATT II output and the choice of a new transportation network for each iteration. Execution of QUADATT II ceases when the planner becomes satisfied with the impacts generated by a particular transportation configuration. The QUADATT II output variables are displayed in tabular form after each iteration. These tables facilitate the comparison of the impacts of alternative plans. Repeated use of the QUADATT II programs for a metropolitan area familiarizes the planner with the general nature of impacts which various plans induce. Therefore, familiarity with QUADATT II decreases the number of iterations necessary to arrive at an "optimal" solution with respect to the planner's and/or decisionmaker's goals.

Implementation

QUADATT II is involved in the implementation phase of the planning process as an inexpensive technique for generating impacts of implemented plans over time. As the demographic and economic characteristics of a region change, the impacts of a transportation plan will also be altered. QUADATT II output can be used to gauge the "success" of a plan which has been implemented in terms of transportation and land use criteria selected in the Goal Identification stage. In this way, QUADATT II becomes the feedback mechanism between the Implementation stage and the Policy and Plan Design stage of the planning process.

The Implementation stage is important in the refinement of the QUADATT II procedure as well. By evaluating the real world effects of plans which were selected by the QUADATT II technique or a similar methodology, the QUADATT II package can be continually improved. In addition, measures for the reliability of QUADATT II projections can be developed as "optimal" plans generated by the procedure are implemented and evaluated.

The preceding chapters have attempted to justify the need for a procedure such as QUADATT II in the planning process. The techniques and models which make up the QUADATT II program are presented in detail in the next chapter.

CHAPTER IV

QUADATT II Program Content

This chapter contains a description of QUADATT II models and procedures for predicting:

1) Minimum Travel Time Paths
2) Regional Population Growth
3) Number of Families by Income
4) Regional Employment Growth
5) Zonal Land Use Development
6) Segregation of Families by Income
7) Trip Production and Attraction
8) Trip Distribution
9) Modal Split

The manner in which these various models interact has been illustrated in Figure 1.

The Minimum Path Procedure

The procedure for determining minimum travel time paths between zonal pairs transforms transportation network data into a format acceptable to the QUADATT II Package (See Figure 3). If the user has access to a Federal Highway Administration (FHWA) network for the study area (FHWA, 1971), he may invoke the BPR editor routine to convert link cards from BPR format to the correct input format for TRANSET (Ruiter, 1968). Once transportation network data have been created in or con-

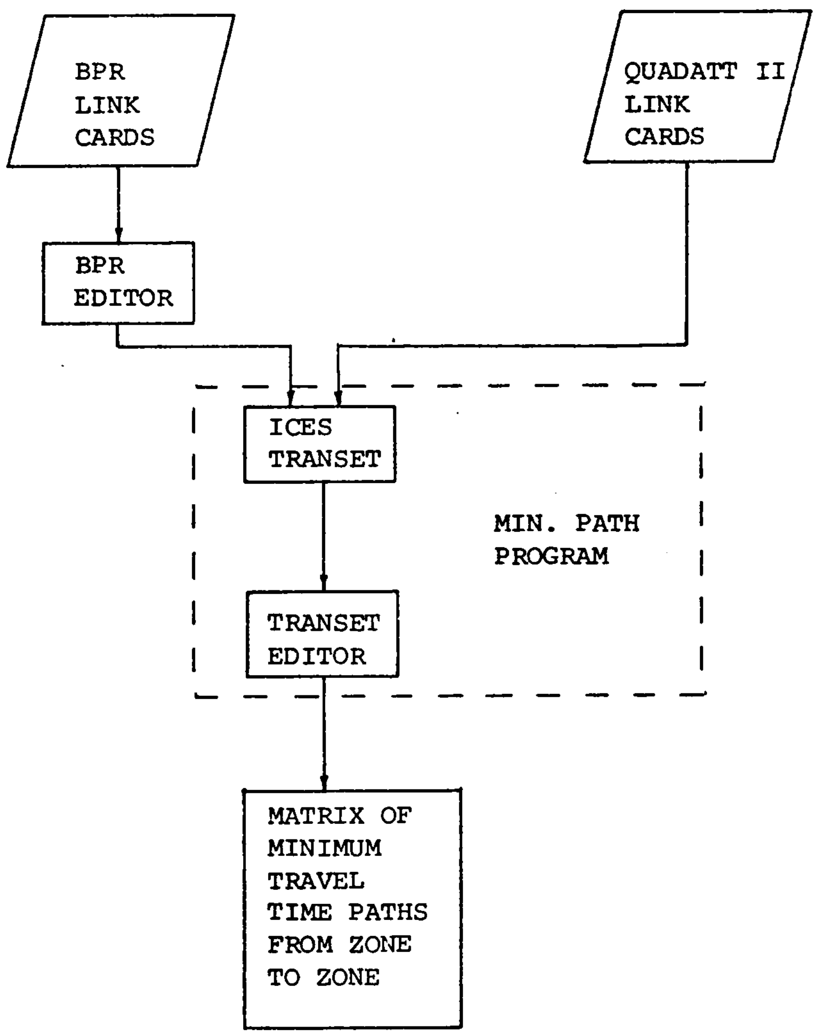

Figure 3.

Procedure for Determining the Matrix of Minimum Time Path from Zone to Zone (Part of the Transportation Input Data) verted to the correct TRANSET input format, they are submitted to the minimum path routine of the ICES (Integrated Civil Engineering System) TRANSET package. TRANSET calculates the minimum travel time trees between all zones. TRANSET output is stored directly on disk from which it is read by the QUADATT II editor program.* This program converts the TRANSET output to a zone to zone travel time matrix used by several QUADATT II models.

In summary, the minimum path procedure has been created in order to reduce the work required in submitting transportation networks to QUADATT II. The user is only required to construct a travel time network, to specify the total number of nodes in the travel time network on the TRANSET "read network" card, and to produce a data card which indicates the number of zones in the study area.

Population Projection

The cohort-survival technique is used in this study to predict the total population of the study area in ten years. This technique assumes that the future total population is a function of the resident population in the base year; the net in-migration and the survivors of births due to residents and in-migrants during the forecast interval (Hermann, 1964). (See Tables 1 - 4).

Families by Income Group

This model predicts the number of families in each zone in the

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* A Fortran IV Program written by the author.

TABLE 1

COHORT-SURVIVAL (BIRTH, DEATH, MIGRATION) POPULATION FORECASTS INPUTS FOR FEMALES
1970-1975

Total 1970 Population - 164,159

AGE GROUPS (YEARS)	.0 to 4.9	5.0 to 9.9	10.0 to 14.9	15.0 to 19.9	20.0 to 24.9	25.0 to 29.9	30.0 to 34.9	35.0 to 39.9
POPULATION	6215.00	7139.00	7575.00	7585.00	7494.00	5213.00	5212.00	5252.00
FEMALE NET MIGRATION*	532.00	491.00	471.00	471.00	522.00	502.00	461.00	205.00
FEMALE DEATH RATE*	4.51	.37	.29	.57	.63	.79	1.18	1.92
FEMALE BIRTH RATE*	.00	.00	.00	62.66	154.63	135.00	73.41	36.25

* Per thousand

AGE GROUPS (YEARS)	40.0 to 44.9	45.0 to 49.9	50.0 to 54.9	55.0 to 59.9	60.0 to 64.9	65.0 to 69.9	70.0 to 74.9	75.0 to 79.9
POPULATION	5251.00	5189.00	5189.00	4393.00	4160.00	3314.00	3313.00	4037.00
FEMALE NET MIGRATION*	205.00	205.00	205.00	205.00	205.00	102.00	92.00	92.00
FEMALE DEATH RATE*	2.89	4.33	6.22	9.01	13.08	21.58	34.64	53.66
FEMALE BIRTH RATE*	9.71	.00	.00	.00	.00	.00	.00	.00

* Per thousand

TABLE 2

COHORT-SURVIVAL (BIRTH, DEATH, MIGRATION) POPULATION FORECASTS INPUTS FOR MALES
1970-1975

Total 1970 Population - 164,159

AGE GROUPS (YEARS)	.0 to 4.9	5.0 to 9.9	10.0 to 14.9	15.0 to 19.9	20.0 to 24.9	25.0 to 29.9	30.0 to 34.9	35.0 to 39.9
POPULATION	6543.00	7281.00	7851.00	7008.00	5466.00	5016.00	5015.00	4811.00
MALE NET MIGRATION*	553.00	430.00	481.00	614.00	532.00	512.00	491.00	215.00
MALE DEATH RATE*	5.86	.53	.51	1.47	1.62	1.78	2.20	3.14

* Per thousand

AGE GROUPS (YEARS)	40.0 to 44.9	45.0 to 49.9	50.0 to 54.9	55.0 to 59.9	60.0 to 69.9	65.0 to 69.9	70.0 to 74.9	75.0 to 79.9
POPULATION	4811.00	4926.00	4926.00	3849.00	3096.00	2362.00	2362.00	2305.00
MALE NET MIGRATION*	215.00	215.00	215.00	215.00	215.00	154.00	154.00	154.00
MALE DEATH RATE*	4.82	7.42	11.99	18.71	27.85	27.85	41.19	64.15

* Per thousand

Total 1975 Forecasted Population - 177,483

TABLE 3

COHORT-SURVIVAL (BIRTH, DEATH, MIGRATION) POPULATION FORECASTS OUTPUTS FOR FEMALES
1975-1980

AGE GROUPS (YEARS)	.0 to 4.9	5.0 to 9.9	10.0 to 14.9	15.0 to 19.9	20.0 to 24.9	25.0 to 29.9	30.0 to 24.9	35.0 to 39.9
FEMALE POPULATION	7235.80	6600.85	7616.34	8034.67	8033.71	7991.57	5693.42	5640.89
FEMALE NET MIGRATION*	532.00	491.00	471.00	471.00	522.00	502.00	461.00	205.00
FEMALE DEATH RATE*	4.51	.37	.29	.57	.63	.79	1.18	1.92
FEMALE BIRTH RATE*	.00	.00	.00	62.66	154.63	135.00	73.41	36.25

* Per thousand

AGE GROUPS (YEARS)	40.0 to 44.9	45.0 to 49.9	50.0 to 54.9	55.0 to 59.9	60.0 to 64.9	65.0 to 69.9	70.0 to 74.9	75.0 to 79.9
FEMALE POPULATION	5405.60	5378.64	5282.08	5229.43	4395.48	4086.23	3052.92	2823.22
FEMALE NET MIGRATION*	205.00	205.00	205.00	205.00	205.00	102.00	92.00	92.00
FEMALE DEATH RATE*	2.89	4.23	6.22	9.01	13.08	21.58	34.64	53.66
FEMALE BIRTH RATE*	9.71	.00	.00	.00	.00	.00	.00	.00

* Per thousand

TABLE 4

COHORT-SURVIVAL (BIRTH, DEATH, MIGRATION) POPULATION FORECASTS OUTPUTS FOR MALES
1975-1980

AGE GROUPS (YEARS)	.0 to 4.9	5.0 to 9.9	10.0 to 14.9	15.0 to 19.9	20.0 to 24.9	25.0 to 29.9	30.0 to 34.9	35.0 to 39.9
MALE POPULATION	7235.80	6896.19	7691.14	8311.37	7568.23	5951.57	5481.08	5448.13
MALE NET MIGRATION*	553.00	430.00	481.00	614.00	532.00	512.00	491.00	215.00
MALE DEATH RATE*	5.86	.53	.51	1.47	1.62	1.78	2.20	3.14

* Per thousand

AGE GROUPS (YEARS)	40.0 to 44.9	45.0 to 44.9	50.0 to 54.9	55.0 to 59.9	60.0 to 64.9	65.0 to 69.9	70.0 to 74.9	75.0 to 79.9
MALE POPULATION	4948.78	4907.46	4954.26	4839.24	3693.87	2864.91	2176.37	2013.69
MALE NET MIGRATION*	215.00	215.00	215.00	215.00	215.00	154.00	154.00	154.00
MALE DEATH RATE*	4.82	7.42	11.99	18.71	27.85	27.85	41.19	64.15

* Per thousand

Total 1980 Forecasted Population - 194,643 study area in each of the four income groups ($0 - 4,999; $5 - 9,999; $10 - 14,999; $15,000 - up)* employed in the EMPIRIC Land Use Model. (See later discussion). The projections are based on the total population growth over a ten year period and the change in the number of families in each income group over the same period. The forecast year (1980) projected regional population total is provided by the cohort-survival technique. Lagged (1960) and present (1970) population totals and number of families by income group are obtained from Census data.

Regional family growth rates for the period (1960-1970) are calculated and used as the basis for the forecasts. However, a straight-line projection of the growth rates did not seem realistic. Therefore, the following type of calculation was made:

$$X(I) = \frac{\left|\text{Percent Family }(I)_{1970} - \text{Percent Family }(I)_{1960}\right|}{2} \qquad (4\text{-}1)$$

where: I = one of the four family income groups indicated above,

Percent Family (I) = the number of families in income group I divided by the total number of families in the region.

The X(I) values are added to the straight line projections of the number of families in each income group in 1980. All estimates are then normalized to the 1980 regional family control total. The latter is derived by extrapolating the 1960 and 1970 ratios of families-to-population and applying the resultant 1980 families-to-population ratio to the projected 1980 population.

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* Constant 1970 dollars.

This technique for estimating families by income group seems more realistic than a straight line projection because:

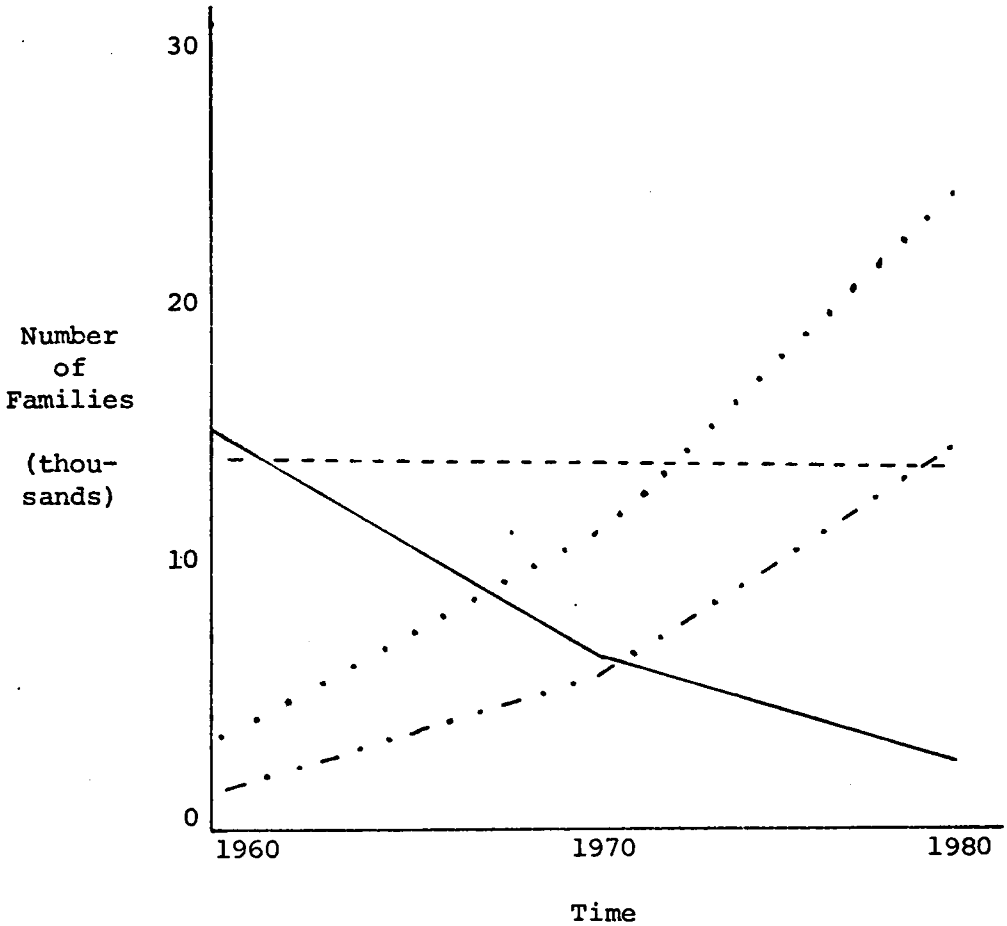
1. Average real family income will probably increase in the future, distributing a greater proportion of families to the higher income groups, but
2. the number of families in the region in the lowest income group will probably not decrease to zero in the near future.

Therefore, the technique described above was devised in order to increase the positive slope of the projection line for higher income groups and decrease the negative slope of the projection line for the lowest income group (See Figure 4).

Employment Projections

The interindustry or input-output approach is a highly sophisticated method of analyzing economic activity (Meck, 1964). For transportation planning purposes it is very expensive; in a rigorous analysis it requires experienced economicsts, extensive input data, and a sizable amount of computer time (Isard, 1960). However, the output of such a method is highly useful in studying the interrelationships between regional industries.

The input-output model has been added to the QUADATT II package to assist in predicting the level of employment for each type of industry which contributes to the total regional economy. The five



INCOME GROUPS
(DOLLARS)

(1) Less than $5,000

(2) $5,000 - 9,999

(3) $10,000 - 14,999

(4) Greater than 14,999

Figure 4.

Projection of Families by Income Group

employment categories required by the EMPIRIC Land Use Model* are used in developing a present input-output table (See Table 5) and a future input-output table (See Table 6) for the study region. The resulting forecasts of increases in total output by industry then are used to predict employment levels for each industry, which subsequently are utilized as input to the EMPIRIC Land Use Model.

More specifically, the projection of the number of employees in each of the five EMPIRIC categories is accomplished using the input-output methodology in conjunction with analogy expansion (Shuldiner, 1965). The input-output technique is used to calculate the growth of total output by industry over the ten year forecast interval. The ratios of employees in each industry to the corresponding gross output for that industry in the base year are assumed to remain constant over the forecast interval and are applied in predicting the forecast year employment for each industry (See Table 7).

The EMPIRIC Land Use Model

EMPIRIC is the heart of QUADATT in that the trip generation and modal split models require its outputs for predicting future travel. This model was developed by the Traffic Research Corporation for use

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* The five employment categories, based on aggregate S.I.C. (Standard Industrial Classification) categories, are:

Manufacturing and construction
Wholesale, transportation, utilities, communications and government
Retail
Service
Finance, insurance and real estate.

TABLE 5

PRESENT (1970) ROANOKE INTERINDUSTRY MONETARY FLOW (MILLIONS OF DOLLARS)

INDUSTRY PURCHASING / INDUSTRY PRODUCING	MANUFACTURING & CONSTRUCTION	WHOLESALE, TRANSPORT, COMMUNICATIONS, UTILITIES, GOV.	RETAIL	SERVICE	FINANCE, INSURANCE, REAL ESTATE	TOTAL DEMAND (HOUSEHOLD)	GROSS OUTPUT
MANUFACTURING & CONSTRUCTION	890.0	360.0	30.0	390.0	10.0	230.0	1910.0
WHOLESALE, TRANSPORTATION, COMMUNICATIONS, UTILITIES & GOV.	660.0	460.0	220.0	260.0	260.0	390.0	2250.0
RETAIL	70.0	90.0	0.0	80.0	20.0	120.0	380.0
SERVICE	60.0	60.0	70.0	50.0	10.0	30.0	280.0
FINANCE, INSURANCE & REAL ESTATE	40.0	130.0	50.0	90.0	70.0	120.0	500.0

Source: See Kavesh, 1953

TABLE 6

FUTURE (1980) ROANOKE INTERINDUSTRY MONETARY FLOW (MILLIONS OF DOLLARS)

INDUSTRY PRODUCING / INDUSTRY PURCHASING	MANUFACTURING & CONSTRUCTION	WHOLESALE, TRANSPORT, COMMUNICATIONS, UTILITIES, GOV.	RETAIL	SERVICE	FINANCE, INSURANCE, REAL ESTATE	TOTAL DEMAND (HOUSEHOLD)	GROSS OUTPUT
MANUFACTURING & CONSTRUCTION	1503.0	592.1	55.1	757.3	18.1	300.0	3225.6
WHOLESALE, TRANSPORTATION, COMMUNICATIONS, UTILITIES & GOV.	1114.6	756.5	404.0	504.9	470.4	450.0	3700.3
RETAIL	118.2	148.0	0.0	155.3	36.2	240.0	697.8
SERVICE	101.3	98.7	128.5	97.1	18.1	100.0	543.7
FINANCE, INSURANCE & REAL ESTATE	67.6	213.8	91.8	174.8	126.6	230.0	904.6

TABLE 7

RELATIONSHIPS USED TO GENERATE FUTURE EMPLOYMENT BY INDUSTRY

I Gross Industry Dollar (millions) Output (I) Ratios

1. $$\frac{\text{Manufacturing + Construction 1980}}{\text{Manufacturing + Construction 1970}} = \frac{3225}{1910} = 1.69$$

2. $$\frac{\text{Wholesale + Transportation 1980}}{\text{Wholesale + Transportation 1970}} = \frac{3700}{2250} = 1.64$$

3. $$\frac{\text{Retail 1980}}{\text{Retail 1970}} = \frac{697}{380} = 1.84$$

4. $$\frac{\text{Service 1980}}{\text{Service 1970}} = \frac{543}{280} = 1.94$$

5. $$\frac{\text{Finance 1980}}{\text{Finance 1970}} = \frac{904}{502} = 1.8$$

$$\text{Employment (I)}_{1980} = \text{Employment (I)}_{1970} \times \text{Gross Industry (I) Ratio}$$

in the Boston metropolitan area and has since been calibrated for a number of other metropolitan areas in the United States (Traffic Research Corporation, 1966).

The basic concept behind the EMPIRIC model is that locational decisions made by individuals and businesses are affected by one another and by changes in public facilities. The model thus uses empirically derived relationships between regional growth patterns and public facility developments to predict future allocations of urban activities.

EMPIRIC requires four basic types of inputs to predict future levels of employment and families by income in each zone: (1) present levels of employment and families by income in each zone, (2) land developability characteristics of each zone, (3) the projected total growth of each land use variable in the region, and (4) the present and future transportation networks and utilities in and between each zone (Traffic Research Corporation, 1966). These relationships are formalized in a set of nine simultaneous equations described in terms of changes in shares of land use levels within each zone. The final equations may be expressed in the following form:

$$\Delta R_{ih} = f\,[R_{ih}(t), \Delta R_{jh}, Z_{kh}(t), \Delta Z_{kh}, M_{eh}(t)], \qquad (4\text{-}2)$$

where: ΔR_{ih} = change in share of families or employees of type i in zone h over the forecast interval,

$R_{ih}(t)$ = present share of families or employees of type i in zone h,

ΔR_{jh} = change in share of families or employees of type j ($j \neq i$) in zone h over the forecast interval,

$Z_{kh}(t)$ = present share of access variable k in zone h,

ΔZ_{kh} = change in share of access variable k in zone h over the forecast interval, and

$M_{eh}(t)$ = present share of land developability variable e in zone h.

Land developability variables measure the potential of base year undeveloped land for residential, manufacturing, or retail development.

Access variables are multiplicative relationships between various employment, land use, sewer, water, and transportation inputs.

To obtain the output desired by QUADATT II, a simple mathematical relationship is used to convert the EMPIRIC output, ΔR_{ih}, to V_{ih} $(t+\Delta t)$ which is the future level of employment or number of families of type i in zone h at time $(t+\Delta t)$. The nine dependent variables, V_{ih} $(t+\Delta t)$, i = 1 to 9, are: the number of families in zone h with an income of:

- less than $5,000
- $5,000 to $9,999
- $10,000 to $14,999
- greater than $14,999

and the number of employees in zone h in:

- manufacturing and construction
- wholesale, transportation, utilities, communications and government

. retail employment

. service employment

. finance, insurance, and real estate.

Segregation of Families by Income

This model operates on the premise that an optimal residential mix of families by income is one in which the various income groups are represented in each zone in the same proportion as in the entire region (Dickey, 1971). This model is included in the QUADATT II battery in an attempt to introduce some social impacts into the planning process. Until urban theory becomes more refined, such fairly crude social impact predictions are the only measures available to the transportation planner.

The segregation by family income model attempts to identify zonal imbalances in the number of families in each income group for the forecast year. The mathematical relationship which determines the optimal allocation of families in income range i in zone j is as follows:

$$OPTNUM(i,j) = TFZ(j)*TOTR(i)/TOTFAM, \qquad (4\text{-}3)$$

where: OPTNUM(i,j) = the optimal number of families in income range i in zone j in the forecast year (1980),

TFZ(j) = the predicted total number of families in zone j in the forecast year (1980),

TOTR(i) = the total number of families of income range i in region, and

TOTFAM = the predicted total number of families in region.

Deviations from the optimal income mix are determined by QUADATT II for each zone and income group. The contribution which each transportation system makes toward improving zonal integration of income groups can then be evaluated from QUADATT II output.

Trip Productions and Attractions

The trip generation phase of QUADATT II involves the estimation of trips produced at residential and attracted to non-residential sources within each zone. The trip attractions to each zone by purpose are calculated using a relationship developed by Alan M. Voorhees and Associates, Inc. (Hall, 1971). A general description of the trip production and attraction models is presented below.

Residential trips are produced for each zone by families in each of those income groups predicted by the EMPIRIC Land Use Model. The following trip generation rates are assumed: families with an annual income of less than $5,000 produce 6.8 trips per day, families with an annual income of $5,000 to $9,999 generate 7.5 trips per day, those in the $10,000 to $14,999 bracket generate 8.1 trips per day and families with incomes over $14,999 generate 8.5 trips per day (Voorhees, 1964). Once total trips have been calculated for each zone, total trips by purpose are derived as input to the trip distribution model. Trips are assumed to be divided by purpose, with 32 percent for home to work, 48 percent for home to non-work, and 20 percent for non-home and truck.

Trip attractions also are calculated by trip purpose to provide the necessary input for the trip distribution model. Trip attractions for each zone are assumed to be a function of total zonal population and zonal employment (Shuldiner, 1965). The latter is divided into the five categories of the EMPIRIC Land Use Model. The trip attraction totals are used by the trip distribution model in calculating an attractiveness index for each zone.

Trip Distribution Model

The trip distribution function of QUADATT II is accomplished with the gravity model. This model is employed under the assumptions that the trips produced at an origin and attracted to a destination are directly proportional to the total trip productions at the origin, the total trip attractions at the destination, and the spatial separation between the origin and destination (FHWA, 1970).

A local calibration generally is made to reflect the fact that travel time varies with the importance of trip purpose. However, since calibration of the gravity model is one of the most expensive and time consuming phases of a transportation study, such a task was not undertaken for QUADATT II. Instead, travel time factors for the QUADATT II gravity model are derived using the following mathematical expression (University of Tennessee, 1965):

$$FF = A_o + A_1 T_{ij} + A_2 \ (1/(T_{ij}-3)), \qquad (4\text{-}4)$$

where: FF = friction factor or travel time factor,

T_{ij} = travel time between zone i and j, and

A_o, A_1, A_2 = constants.

The same study indicates that friction factors do not vary significantly between regions. Therefore, the friction factor constants developed for Waterbury, Connecticut, are used in the QUADATT II gravity model, (see Table 8).

The gravity model was used to distribute trips by three purposes: home-based work; home-based non-work; non-home-based and truck. The last two purposes were combined to produce "other" trips after their distribution by the gravity model.

Trip-Interchange Modal Split Model

The Twin Cities trip-interchange modal split model is used for the mode choice phase of QUADATT II (Fertal, 1966). It has been developed in such a manner that it is sensitive to changes in transit and highway systems. It also has been designed to operate in conjunction with the previously described trip distribution and trip generation models so as to predict the future use of different transportation modes. As such, it accepts as input the zone-to-zone distribution of person trips.

The general form of the model is:

$$TT_{ij} = f\ (S_{ij},\ PC_i,\ AC_j), \qquad (4\text{-}5)$$

where: TT_{ij} = transit passenger trips from i to j as a percentage of person trips,

S_{ij} = relative level of transit and highway service between i and j,

TABLE 8

FRICTION FACTOR RELATIONSHIPS BY TRIP PURPOSE

FF_{ij} home-based work trips	$= -29.9 + .47\,T_{ij} + 516/(T_{ij}-3)$
FF_{ij} home-based non-work trips	$= -70 + 1.72T_{ij} + 616/(T_{ij}-3)$
FF_{ij} non-home-based trips	$= -13 + .3\,T_{ij} + 492/(T_{ij}-3)$

where: FF_{ij} = friction factor between zones i and j, and

T_{ij} = travel time between zones i and j.

PC_i = socioeconomic and land use characteristics of the production zone i, and

AC_j = socioeconomic and land use characteristics of the attraction zone j.

Standard multiple regression techniques were used to determine the following relationships:

$$PWTTR\ (j,k) = 61.1 - 12.1 \ln TTR(j,k) - 4.4 \ln INC\ (j) + 8 \ln RESDEN\ (j) + 1.3 \ln EMPDEN\ (k) + 363.5\ NHPK\ (k), \text{ and} \quad (4\text{-}6)$$

$$POTTR\ (j,k) = 39 - 3.6 \ln TTR\ (j,k) - 3.2 \ln INC\ (j) + 2.4 \ln RESDEN\ (j) + 285.2\ THPK\ (k) \quad (4\text{-}7)$$

where: PWTTR (j,k) = percent work-trips by transit from zones j to k, and

POTTR (j,k) = percent "other" trips by transit from zones j to k.

Level of service variables:

TTR (j,k) = total travel time by transit from zones j to k divided by the total travel time by auto from zones j to k.

Production-end variables:

INC (j) = median income of zone j, and

RESDEN (j) = housing units per net residential acre in zone j.

Attraction-end variables:

NHPK (k) = nine hour parking cost in zone k,

THPK (k) = three hour parking cost in zone k, and

EMPDEN (k) = employment per gross acre in zone k.

Summary Comments

The type of models presented in this chapter are not inflexible components of QUADATT II. One of the assets of a sequential procedure such as QUADATT II is that submodels may be replaced easily as new theories and concepts are introduced into the transportation planning process. A disadvantage of such a set of submodels is that errors might be exaggerated by the inadequacies of each successive model. However, given the time and financial limitations which have constrained the development of QUADATT II, the models discussed in this chapter seem quite adequate.

The various submodels involved in the QUADATT II procedure demonstrate the interdisciplinary nature of any transportation planning endeavor. Cohort-survival and input-output are both techniques which were developed outside of the transportation planning profession. Exposure to techniques adopted from other disciplines is a valuable by-product of the QUADATT II procedure.

CHAPTER V

An Application of QUADATT II

The Roanoke, Virginia, Area (See Figure 5) was chosen to test the QUADATT II procedure. Roanoke was chosen because of its relatively small size, the proximity of data sources, and the availability of corresponding information.

To demonstrate the use of QUADATT II in the planning process, we have adopted the role of a regional transportation planner concerned with mass transit. Such a planner might be especially concerned with trends in the following output variables between 1970 and 1980:

1) Transit ridership and percent transit ridership,
2) Office workers (finance, insurance, and real estate employees) in the Central Business District,
3) Total number of transit trips into the CBD,
4) Total number of auto trips into the CBD,
5) Mean family income in CBD,
6) An indication of disparities from the optimum income mix for the region, and
7) Activity growth patterns for each transportation alternative.

The transportation planner might be interested in increasing mass transit ridership as a means of decreasing regional pollution levels and decreasing demand for highways, as well as providing more mobility for the poor. An increase in the number of office workers in the CBD might imply new construction and new sources of revenue for the

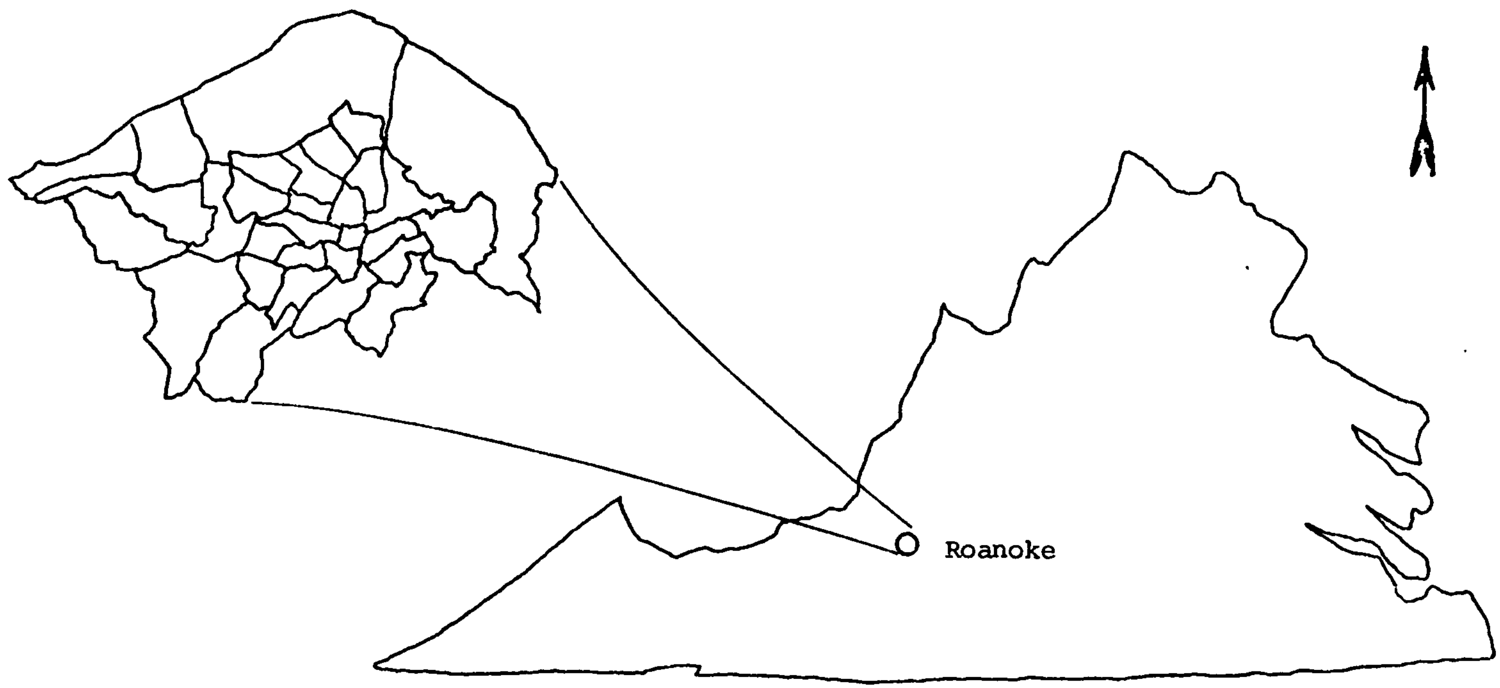


Figure 5

LOCATION MAP
ROANOKE VALLEY TRANSPORTATION STUDY AREA

city. The number of daily transit trips and auto trips into the Roanoke CBD would be an indicator of central city vitality. Higher income would be of benefit to the central city, especially if the average income in any other zone were not adversely affected. Lack of differences in family income between zones would indicate great homogeneity of rich and poor in the metropolitan area population. These considerations would be of particular concern to the planner in evaluating the impacts of four future transit plans which were tested using QUADATT II. These four future plans were:

1) Plan 1, the null alternative: no change in existing transit travel times (Figure 6),
2) Plan 2, which is a simple pattern of radial arms centered on the CBD (Figure 7),
3) Plan 3, which is a warped grid (see Figure 8), and
4) Plan 4, which is the "Plan 2" network with three circumferential loops plus two half-loops (see Figure 9).

In order to implement QUADATT II, thirty census tracts in the Roanoke Metropolitan Area (Figure 10) were designated as transportation zones. Roanoke City, the City of Salem, and urbanized areas of Roanoke County were included in the study area. Census tracts were selected to be used as transportation zones because of their desirability in the following respects:

1) Zones were small enough to indicate the spatial distribution of traffic flow in the region.
2) The number of zones limited data requirements to a reasonable

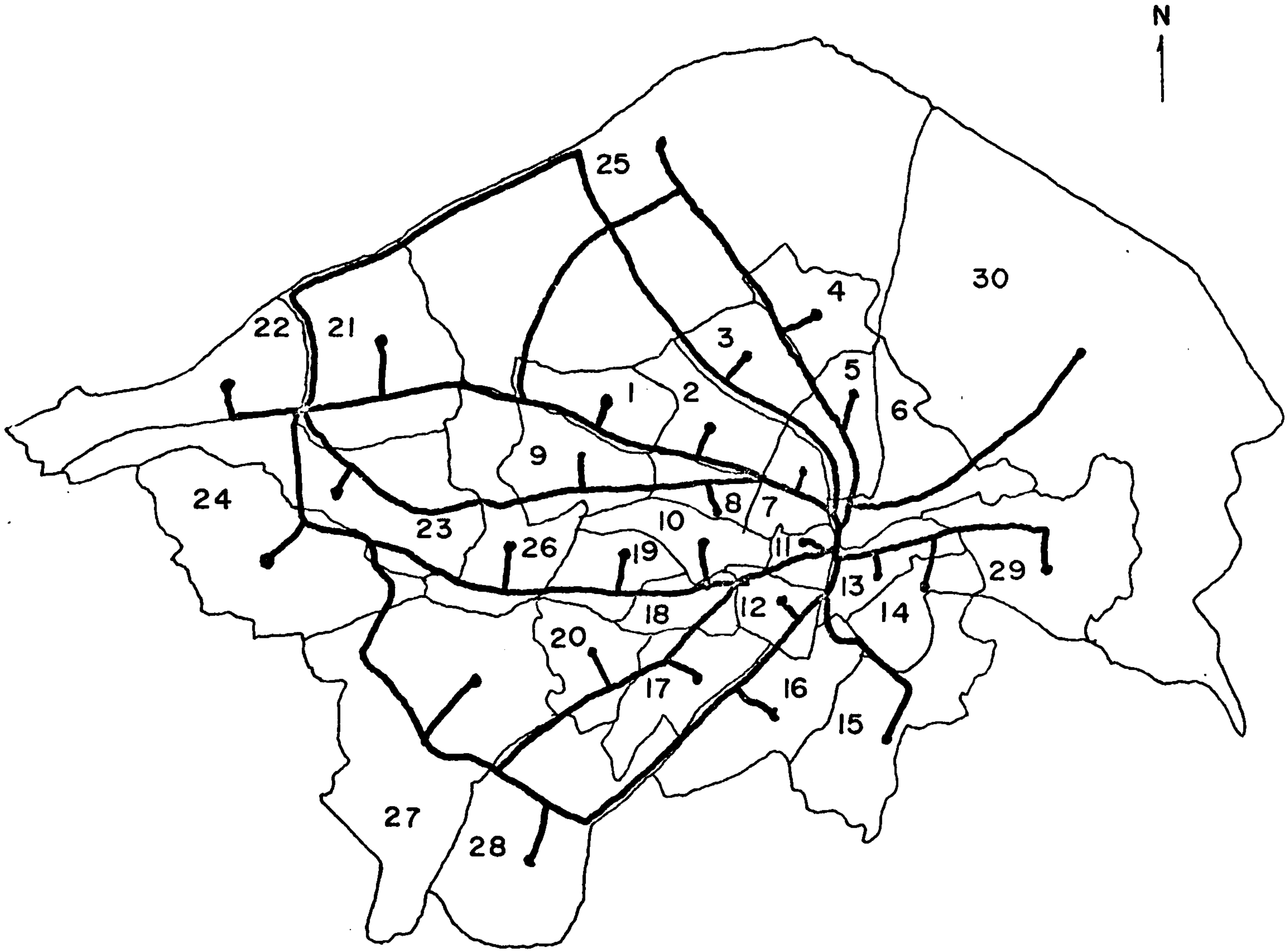


Figure 6
ROANOKE VALLEY TRANSIT ALTERNATIVE
PLAN 1

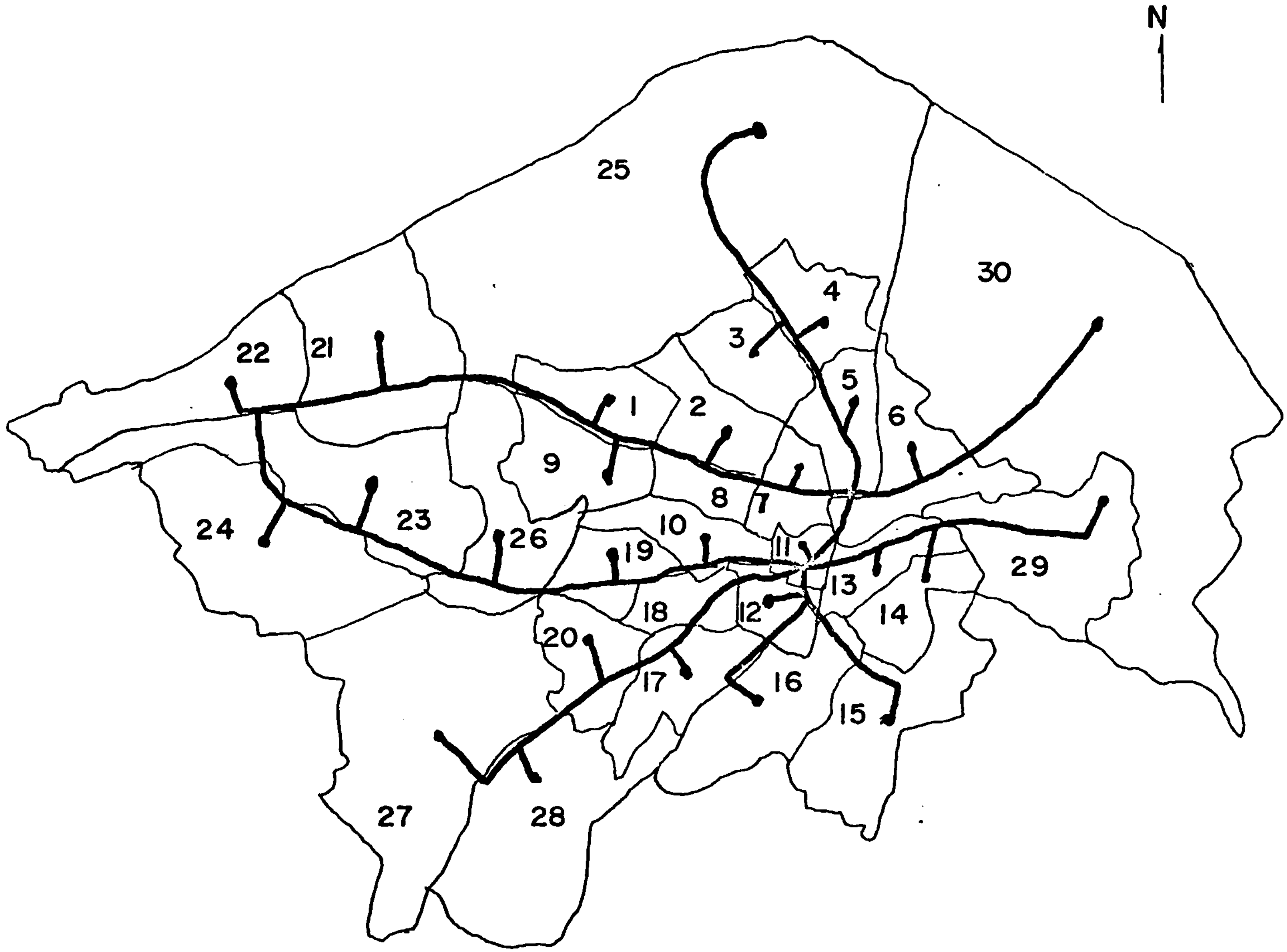


Figure 7
ROANOKE VALLEY TRANSIT ALTERNATIVE
PLAN 2

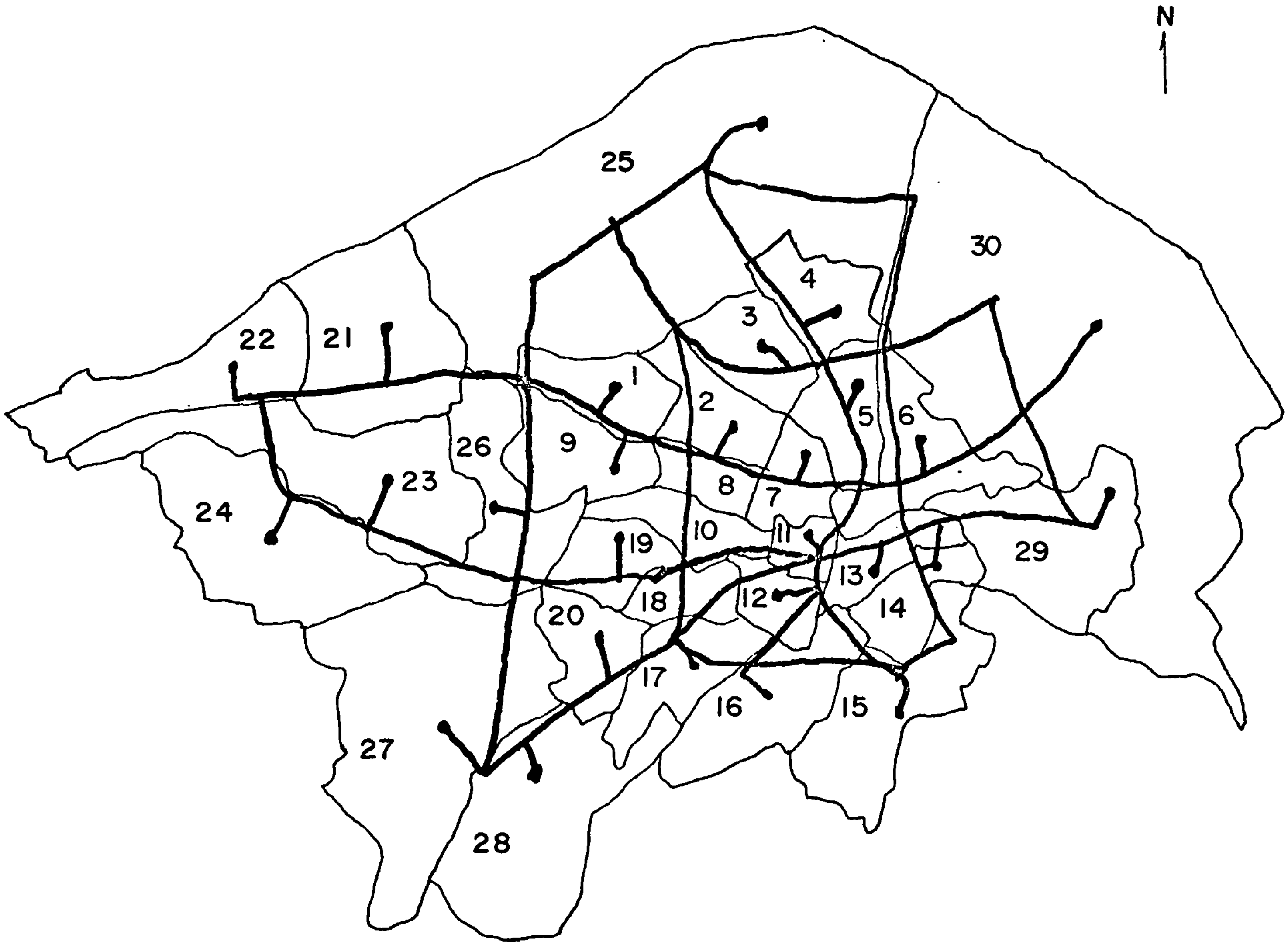


Figure 8
ROANOKE VALLEY TRANSIT ALTERNATIVE
PLAN 3

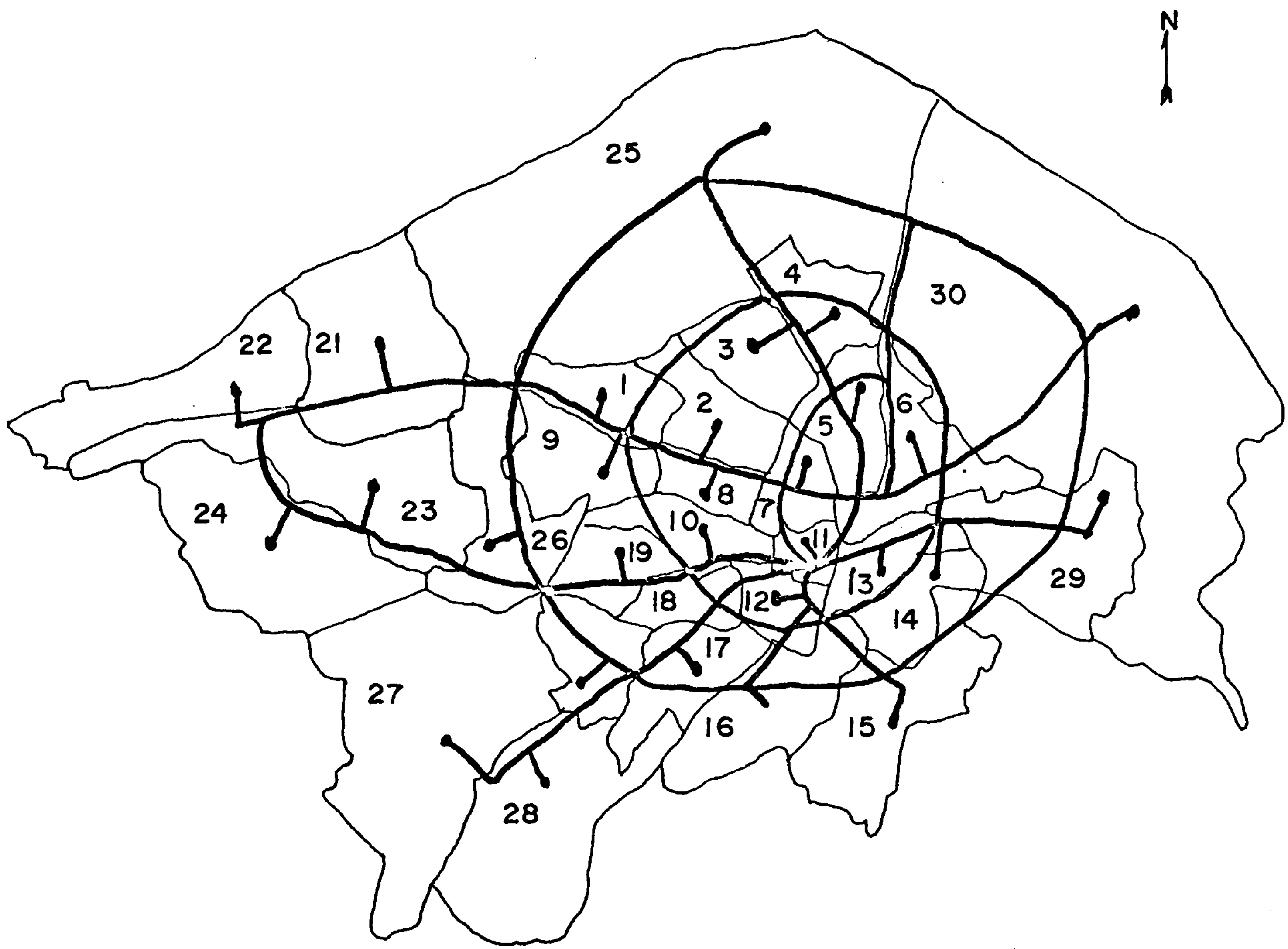
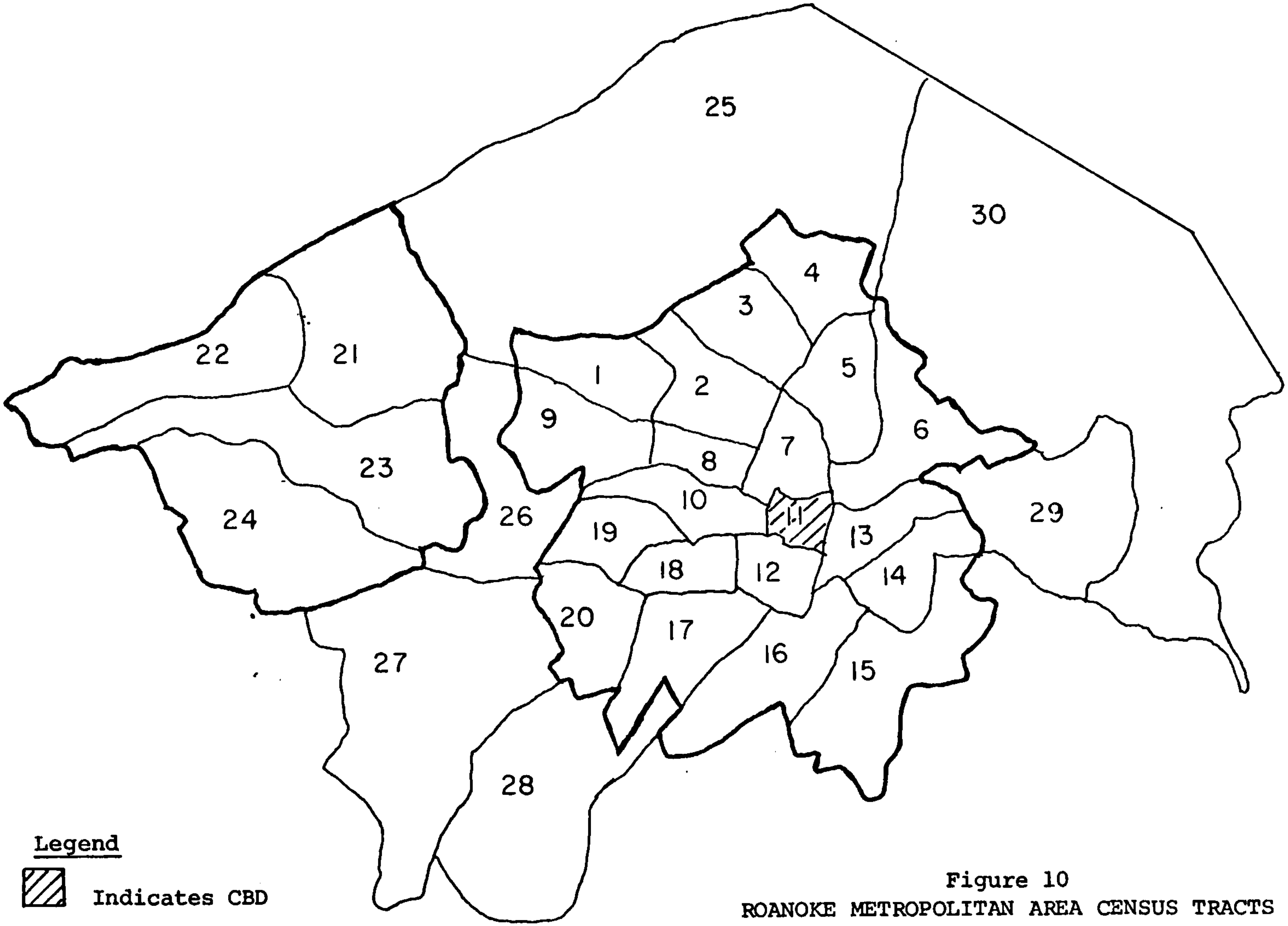


Figure 9
ROANOKE VALLEY TRANSIT ALTERNATIVE
PLAN 4



Legend

Indicates CBD

Figure 10
ROANOKE METROPOLITAN AREA CENSUS TRACTS
1 - 20 Roanoke City
21 - 24 Salem City
25 - 30 Part of Roanoke County

level for this study.

3) Internal variations in demographic and transportation-related characteristics within the selected zones were generally low.

4) Land use data were available for the thirty census tracts.

5) Zones did not cross major political boundaries.

6) Census tracts would remain the same in the future.

The QUADATT II input and output data for one alternative transit system are presented in Tables 9 to 29. These data may be divided into two categories: transportation system data and land use data. The basic elements of the transportation data, present interzonal travel times, were determined by extracting the minimum path between transportation zones from Bureau of Public Roads networks created for the Roanoke Area for 1965 and 1980. Present transit times were developed with the aid of a Wilbur Smith transit study of Roanoke by locating only the links in the BPR network on which the transit lines operate (Wilbur Smith and Associates, 1970). Transfer and terminal times were estimated based on previous studies (University of Tennessee, 1965). The future transit networks, which were the decision variables, were determined by coding networks for each alternative and applying the minimum path procedure to obtain minimum travel time zone to zone matrices.

The data needed for the modal split model are displayed in Tables 9 and 10. Transit walk and wait times were assumed to be higher in the suburbs, while auto terminal time and parking costs were assumed to be higher in the CBD.

TABLE 9

FUTURE ZONE TO ZONE TRANSFER TIMES
(minutes)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	0	0	0	0	10	0	0	0	0	10	0	10	10	10	10
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	10	0	10	10	10	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	10	10	10	10	10	0	10	10	10	10	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	10	10	10	0	10	10	10	10	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	10	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	10	0	10	10	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	10	0	0	10	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	10	0	10	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	10	0	10	10	10	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	0	10	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	0	10	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	10	0	10	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	10	10	10	0	10	0	0	0
14	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	10	10	10	10	0	0	0	0
15	10	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	10	10	10	10	10	0	10	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	10	0	10	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	10	0	10	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	0	10	0	0	0	0	10
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	10	0	10	10
20	10	10	10	10	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	10	0	10	0	10	10	0	0	10	10
21	0	10	0	0	0	0	0	0	0	0	0	10	10	10	10	10	10	0	0	10	0	0	0	0	10	0	0	10	10	10
22	0	0	10	10	10	10	10	0	0	10	10	10	10	10	10	10	10	10	0	0	0	0	0	0	10	0	0	0	10	10
23	0	0	10	10	0	10	10	0	0	10	10	10	10	10	10	10	10	10	0	10	0	0	0	0	10	10	10	10	10	10
24	0	0	10	10	0	10	10	0	0	0	0	0	10	10	10	0	0	0	0	0	0	0	0	0	10	0	0	0	10	10
25	10	10	0	0	0	0	0	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	0	10	10	10	10	10
26	0	0	10	10	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	10	0	10	0	0	10	10	10
27	10	10	10	10	10	10	10	10	10	0	0	0	10	0	10	0	0	0	10	0	0	0	10	0	10	0	0	0	10	10
28	10	10	10	10	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	10	0	10	0	10	10	0	0	10	10
29	10	10	10	10	0	0	0	10	10	0	0	0	0	0	10	0	0	0	10	10	10	10	10	10	10	10	10	10	0	10
30	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	10	10	10	10	10	10	10	10	10	10	10	0

TABLE 10

FUTURE MODAL SPLIT VARIABLES

ZONE NO.	TRANSIT WALK + WAIT TIME (minutes)	AUTO TERMINAL TIME (minutes)	AUTO 3 HR. PARK COST ($)	AUTO 9 HR. PARK COST ($)
1	13.00	2.00	.00	.00
2	13.00	2.00	.00	.00
3	12.00	2.00	.00	.00
4	11.00	2.00	.00	.00
5	9.00	2.00	.00	.00
6	10.00	2.00	.00	.00
7	8.00	2.00	.00	.00
8	7.00	2.00	.00	.00
9	8.00	2.00	.00	.00
10	7.00	2.00	.00	.00
11	2.00	4.00	.10	.10
12	5.00	2.00	.00	.00
13	6.00	2.00	.00	.00
14	7.00	2.00	.00	.00
15	9.00	2.00	.00	.00
16	7.00	2.00	.00	.00
17	10.00	2.00	.00	.00
18	6.00	2.00	.00	.00
19	7.00	2.00	.00	.00
20	7.00	2.00	.00	.00
21	15.00	2.00	.00	.00
22	15.00	2.00	.00	.00
23	15.00	2.00	.00	.00
24	15.00	2.00	.00	.00
25	16.00	2.00	.00	.00
26	15.00	2.00	.00	.00
27	14.00	2.00	.00	.00
28	15.00	2.00	.00	.00
29	14.00	2.00	.00	.00
30	17.00	2.00	.00	.00

Zonal land use data are in the form of number of families by income category and employees by industry type. Other necessary input variables include present and future water and sewer facilities and projections of region-wide population and employment by type. The zonal land use data were estimated from 1970 Census reports. Land acreages by activity were obtained from the City of Roanoke's Planning Department. Water supply and sewage disposal indices were estimated on the basis of the apparent degree of activity in the zone.

Future regional population figures were generated using the Families by Income model and the Cohort Survival model. The data used in these models came from the 1960 and 1970 Census reports. Future employment figures were obtained with the aid of the input-output method as explained in Chapter Three. The input-output table was developed by modifying national figures to fit the characteristics of Roanoke's economy.

As brought out in previous sections, the outputs of QUADATT II are intended to be quite numerous. Thus, it is not feasible to discuss all of them in detail. Instead, some tabular information produced by QUADATT II will be presented and discussed briefly.

Table 11 presents the census tract-transportation zone equivalency table produced by QUADATT II. QUADATT II displays the past number of families by income group, 1960 census count data, and the cohort survival tables, all of which are associated with the projection of the future number of families (Tables 1-4). The input-output tables which are used to predict future employment are produced by QUADATT II

TABLE 11

ZONE IDENTIFICATIONS

Zone	1	Census	Tract	1
Zone	2	Census	Tract	2
Zone	3	Census	Tract	3
Zone	4	Census	Tract	4
Zone	5	Census	Tract	5
Zone	6	Census	Tract	6
Zone	7	Census	Tract	7
Zone	8	Census	Tract	8
Zone	9	Census	Tract	9
Zone	10	Census	Tract	10
Zone	11	Census	Tract	11
Zone	12	Census	Tract	12
Zone	13	Census	Tract	13
Zone	14	Census	Tract	14
Zone	15	Census	Tract	15
Zone	16	Census	Tract	16
Zone	17	Census	Tract	17
Zone	18	Census	Tract	18
Zone	19	Census	Tract	19
Zone	20	Census	Tract	20
Zone	21	Census	Tract	101
Zone	22	Census	Tract	102
Zone	23	Census	Tract	103
Zone	24	Census	Tract	105
Zone	25	Census	Tract	302
Zone	26	Census	Tract	304
Zone	27	Census	Tract	307
Zone	28	Census	Tract	308
Zone	29	Census	Tract	311
Zone	30	Census	Tract	312

as in Tables 6 and 7.

Land use variables one through nine, as defined in Table 12, are displayed for each of the zones, in addition to the totals of these variables for the entire metropolitan area (Tables 13-17). The land use variables with negative values are those for which a loss was incurred over the ten year time period for that particular zone and variable.

The transportation input data required by QUADATT II are also displayed in tabular form. Four thirty-by-thirty input matrices of interzonal and intrazonal travel times are displayed by QUADATT II. They consist of: present auto travel times (Table 18), future auto travel times (Table 19), present transit travel times (Table 20), and future transit travel times (Table 21). Other inputs displayed by QUADATT II are the transit transfer times and the transit and auto terminal information (Tables 9 and 10).

Table 22 portrays a set of demographic indicators of the QUADATT II output. The table includes estimates of residential and employment density; total families; present and future employment; population; students; average income and total density. All of these estimates are derived from models employing as inputs the variables discussed in the previous paragraphs.

Table 23 contains the output from the Family Income Segregation model of the QUADATT II package. Briefly, the display consists of three sections: 1) the optimal distribution of families in zones (the distribution if there were no segregation by income), 2) the number of families of each type by which each zone is in slack of the

TABLE 12

LAND USE VARIABLE IDENTIFICATIONS

Land Use Variable 1 is the number of families with an annual income less than $5000
Land Use Variable 2 is the number of families with an annual income between $5000 and $9999
Land Use Variable 3 is the number of families with an annual income between $10,000 and $14,999
Land Use Variable 4 is the number of families with an annual income equal to or greater than $15,000
Land Use Variable 5 is the number of persons in manufacturing and construction employment
Land Use Variable 6 is the number of persons in wholesale, transportation, communication, utilities and government employment

Land Use Variable 7 is the number of persons in retail employment
Land Use Variable 8 is the number of persons in service employment
Land Use Variable 9 is the number of persons in finance, insurance and real estate employment

OTHER ZONAL VARIABLES

UNAP is the net residential area, in acres
UNAM is the net manufacturing area, in acres
UNAR is the net retail area, in acres
ODA is the other developed area, in acres
DA is the developable area, in acres
W is the present water supply index, indicating type of water supply service
S is the present sewage disposal index, indicating type of sewage disposal service
FW is the future water supply index
FS is the future sewage disposal index

TABLE 13

PRESENT ZONAL LAND USES

ZONE NO.	1	2	3	4	5	6	7	8	9
1	181	575	360	124	114	173	140	120	60
2	287	446	296	98	0	382	120	110	30
3	277	586	429	229	18	319	115	154	45
4	215	636	652	230	149	466	245	175	24
5	321	803	493	165	641	829	260	514	36
6	167	351	157	26	2467	1455	1507	1464	128
7	835	558	167	37	2117	736	1427	791	57
8	303	395	133	49	117	710	360	330	36
9	212	190	104	28	874	967	645	452	121
10	613	653	363	126	1165	584	307	361	127
11	106	53	19	14	4542	3835	2641	987	869
12	609	549	147	51	3567	1967	347	97	46
13	566	740	200	75	1453	798	347	76	45
14	238	540	217	50	267	462	106	36	26
15	161	418	269	75	0	321	80	73	20
16	223	309	350	702	407	790	414	79	28
17	100	186	129	211	349	678	548	88	34
18	215	513	382	201	117	541	201	134	65
19	260	699	488	201	113	98	74	40	12
20	133	476	497	492	0	156	91	76	32
21	224	556	335	127	183	65	623	571	156
22	203	418	505	376	259	109	149	137	37
23	330	646	357	97	3471	1121	554	507	138
24	161	616	400	254	117	222	41	9	43
25	400	1688	1831	915	400	128	141	222	40
26	93	337	396	280	1326	123	138	35	35
27	175	371	784	1347	39	147	133	75	33
28	144	514	705	520	613	112	111	54	63
29	351	716	502	213	354	103	39	136	38
30	140	454	458	128	94	127	101	42	12
Subtotal	8243	15992	12125	7439	25260	18424	12086	7864	2436

Total Families = 43799

Total Persons Employed = 66070

TABLE 14
OTHER ZONAL VARIABLES

ZONE NO.	UNAP	UNAM	UNAR	ODA	DA	W	S	FW	FS
1	358	1	18	39	995	3	3	6	5
2	278	0	9	15	422	3	3	6	5
3	415	0	24	50	248	3	3	6	5
4	478	6	47	99	94	3	3	6	5
5	401	11	42	70	151	3	3	6	5
6	318	63	38	209	462	3	3	6	5
7	243	2	31	49	82	3	3	6	5
8	181	2	27	32	40	3	3	6	5
9	327	15	132	101	285	4	4	6	5
10	146	20	38	374	106	3	3	6	5
11	34	9	48	33	8	3	3	6	5
12	176	10	43	109	53	3	3	6	5
13	239	13	26	46	75	3	3	6	5
14	214	23	8	58	166	3	3	6	5
15	394	0	16	50	604	3	3	6	5
16	613	6	31	60	232	3	3	6	5
17	316	6	41	173	258	3	3	6	5
18	272	2	60	27	37	3	3	6	5
19	342	35	21	47	111	3	3	6	5
20	484	0	26	61	127	3	3	6	5
21	674	27	117	38	853	4	3	6	5
22	762	0	29	128	633	4	3	6	5
23	474	178	103	184	773	4	3	6	5
24	647	6	17	72	1030	4	3	6	5
25	2378	40	119	1025	5031	2	2	6	4
26	503	68	27	284	842	2	2	6	4
27	1135	2	25	118	2195	2	2	6	4
28	712	34	47	143	1384	2	2	6	4
29	604	35	28	95	978	2	2	6	4
30	766	21	19	135	7807	2	2	6	4

TABLE 15

FUTURE REGIONAL LAND USE TOTALS

LAND USE TYPE	1	2	3	4	5	6	7	8	9
	2204	15228	25504	16576	42659	30300	22192	15271	4407

TABLE 16

PREDICTED FUTURE ZONAL LAND USES

ZONE NO.	1	2	3	4	5	6	7	8	9
1	44	489	653	297	176	335	235	224	98
2	79	400	534	219	53	553	157	200	62
3	73	496	748	470	132	512	123	275	81
4	46	477	1089	460	334	714	264	333	56
5	79	657	835	357	870	1143	340	657	91
6	37	369	581	304	3487	1974	1922	1630	260
7	251	611	435	154	2454	801	1653	902	142
8	87	377	292	150	131	934	441	415	86
9	61	279	505	253	1188	1372	1135	619	223
10	176	640	781	355	1538	868	364	528	222
11	30	74	104	70	4638	4585	3123	1311	1491
12	183	583	398	189	4061	2253	429	292	151
13	166	700	401	197	1753	1035	418	197	104
14	64	474	410	155	545	723	160	114	51
15	41	398	603	255	94	509	159	171	45
16	60	280	612	1275	629	1120	305	273	78
17	25	220	411	495	521	918	694	245	84
18	53	401	593	358	179	756	222	245	121
19	64	551	766	370	434	290	71	133	19
20	28	352	750	836	156	318	0	207	59
21	59	579	966	592	770	429	1186	579	234
22	54	421	1135	934	532	304	130	148	64
23	91	675	1053	577	6107	2194	1185	520	204
24	41	581	882	644	378	447	74	19	73
25	80	1572	3784	2199	2169	1304	571	1509	51
26	16	312	782	523	2611	588	291	379	41
27	47	367	1289	2329	462	438	0	651	64
28	30	425	1167	898	1441	486	249	395	89
29	95	647	935	472	1099	488	150	402	50
30	33	483	1067	440	809	514	278	376	10
TOTALS	2194	14891	24563	16825	39752	28902	16329	13952	4404

TABLE 17
CHANGE IN ZONAL LAND USES

ZONE NO.	1	2	3	4	5	6	7	8	9
1	-137	-86	293	173	135	162	95	104	38
2	-208	-46	238	121	53	171	37	90	32
3	-204	-90	319	241	114	193	8	121	36
4	-169	-159	437	230	185	248	19	158	32
5	-242	-146	342	192	229	314	80	143	55
6	-130	18	424	278	1020	519	415	166	132
7	-584	53	268	117	337	65	226	111	85
8	-216	-18	159	101	14	224	81	85	50
9	-151	89	401	225	314	405	490	167	102
10	-437	-13	418	229	373	284	57	167	95
11	-76	21	85	56	96	750	482	324	622
12	-426	34	251	138	494	386	82	195	105
13	-400	-40	201	124	300	237	71	121	59
14	-174	-66	193	105	278	261	54	78	25
15	-120	-20	334	180	94	188	79	98	25
16	-163	-29	262	573	222	330	-109	194	50
17	-75	34	282	284	172	240	146	157	50
18	-162	-112	211	157	62	215	21	111	56
19	-196	-14	278	169	321	192	-3	93	7
20	-105	-12	253	344	156	162	-91	131	27
21	-165	23	631	465	587	364	563	8	78
22	-149	3	630	558	273	195	-19	11	27
23	-239	29	696	480	2636	1073	631	13	66
24	-120	-35	482	390	261	225	33	10	30
25	-320	-116	1953	1284	1769	1176	349	1368	11
26	-77	-25	386	243	1285	465	153	344	6
27	-128	-4	505	982	423	291	-133	576	31
28	-114	-89	462	378	828	374	138	341	26
29	-256	-69	433	259	745	385	111	266	12
30	-107	29	609	312	715	387	177	334	-2

TABLE 18

ZONE TO ZONE TRAVEL TIME MATRIX, IN MINUTES

1970 MINIMUM TRAVEL TIME TABLE

ZONE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	4	4	6	8	9	9	7	6	4	6	4	6	9	9	10	12	13	11	10	12	6	11	7	12	7	6	13	17	14	13
2	4	3	7	8	8	6	7	3	4	3	7	7	8	10	14	11	11	8	8	9	8	12	9	14	8	5	14	15	12	12
3	6	7	3	4	5	7	6	7	11	9	9	10	9	10	14	13	13	12	13	14	11	15	12	17	7	11	18	19	12	12
4	8	8	4	3	4	5	5	6	11	9	8	9	8	7	13	12	12	11	12	13	13	17	14	18	8	11	17	18	11	11
5	9	8	5	4	2	3	3	6	11	9	6	8	5	7	10	10	10	10	12	13	14	18	15	19	9	11	17	16	9	8
6	9	7	7	5	3	3	3	5	10	8	5	7	3	5	8	9	9	9	11	12	13	18	15	19	9	10	16	15	7	6
7	7	6	6	5	3	3	2	4	8	6	4	6	5	6	10	8	8	8	9	11	12	17	13	18	8	9	15	14	8	8
8	6	3	7	6	5	4	2	6	4	5	5	6	8	12	9	9	6	8	8	9	10	14	11	15	10	6	13	14	10	10
9	4	4	11	11	11	10	8	6	2	5	9	9	11	13	15	13	13	10	10	11	8	11	7	12	10	1	12	15	15	14
10	6	3	9	9	9	8	6	4	5	2	5	5	9	11	12	9	9	6	6	7	10	14	11	15	10	5	11	13	13	12
11	9	7	9	8	6	5	4	5	9	5	2	3	4	6	8	6	6	5	8	10	13	18	14	19	10	9	14	11	8	10
12	9	7	10	9	8	7	6	5	9	5	3	2	6	8	7	4	4	3	8	8	13	18	14	18	12	9	12	9	10	12
13	10	8	9	7	5	3	5	6	11	9	4	6	3	3	6	6	8	8	12	13	15	19	16	20	11	12	17	13	5	8
14	12	10	10	9	7	5	6	8	13	11	6	8	3	3	5	10	10	10	14	14	16	21	18	22	12	13	19	15	6	9
15	15	14	14	13	10	8	10	12	15	12	8	7	6	5	3	8	8	10	14	13	20	23	19	32	16	16	17	13	10	13
16	13	11	13	12	10	9	8	9	13	9	6	4	8	10	4	3	6	6	8	8	16	18	14	18	14	13	11	7	12	14
17	13	11	13	12	10	9	8	9	13	9	6	4	8	10	8	3	3	4	8	7	16	17	13	17	14	13	10	7	12	14
18	11	8	12	10	9	8	6	10	6	5	3	8	10	10	6	4	3	6	6	14	16	12	16	14	11	11	10	8	12	13
19	10	8	13	12	12	11	9	8	10	6	8	8	12	14	14	8	8	6	3	3	11	13	9	13	15	10	7	11	16	16
20	12	9	14	13	13	12	11	9	11	7	10	8	13	14	13	8	7	6	3	3	11	12	8	12	16	10	6	9	17	17
21	6	8	11	13	14	13	12	10	8	10	13	13	15	16	20	16	16	14	11	11	3	7	5	8	10	8	11	15	18	18
22	11	12	15	17	18	18	17	14	11	14	18	18	19	21	23	18	17	16	13	12	7	5	5	3	14	10	12	16	23	22
23	7	9	12	14	15	15	13	11	7	11	14	14	16	18	19	14	13	12	9	8	5	5	5	6	11	6	9	12	20	19
24	12	14	17	18	19	19	18	15	12	15	19	18	20	22	23	17	16	13	12	8	3	6	10	15	11	11	13	16	24	23
25	7	8	7	8	9	9	8	10	10	10	10	12	11	12	16	14	14	14	15	16	10	14	11	15	6	11	17	20	14	14
26	6	5	11	11	11	10	9	6	1	5	9	9	12	13	16	13	13	11	10	10	8	10	6	11	11	4	10	14	15	15
27	13	14	18	17	17	15	16	13	12	11	14	12	17	19	17	11	10	10	7	6	11	12	9	13	17	10	5	6	21	21
28	17	15	19	18	16	15	14	14	15	13	11	9	13	15	13	7	7	8	11	9	15	16	12	16	20	14	6	4	17	19
29	14	12	12	11	9	7	8	10	15	13	8	10	5	6	10	12	12	12	16	17	18	23	20	24	14	15	21	17	4	6
30	13	12	12	11	8	6	8	10	14	12	10	12	8	9	13	14	14	13	16	17	18	22	19	23	14	15	21	19	6	10

TABLE 19

ZONE TO ZONE TRAVEL TIME MATRIX, IN MINUTES

1980 PROPOSED VIRGINIA DEPARTMENT OF HIGHWAYS NETWORK

ZONE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	4	4	6	8	8	9	7	6	4	6	8	8	10	12	13	12	11	9	9	8	6	10	7	11	7	4	10	12	13	12
2	4	3	7	6	6	7	4	3	4	3	5	6	8	11	11	10	8	7	7	8	8	13	9	13	8	5	12	13	12	10
3	6	7	3	4	5	7	6	8	10	10	8	10	9	12	12	10	11	13	13	11	15	13	16	8	9	9	16	16	13	9
4	8	6	4	3	4	5	5	6	11	9	7	9	8	10	11	10	9	10	12	14	13	17	14	18	8	11	17	14	10	6
5	8	6	5	4	2	3	3	6	9	8	6	7	6	8	10	9	7	8	11	13	13	17	14	18	9	10	16	13	9	6
6	9	7	7	5	3	3	3	5	10	8	4	6	4	6	8	8	6	8	11	11	13	17	15	19	10	10	14	12	7	5
7	7	4	6	5	3	3	2	4	8	6	4	5	5	7	7	7	5	6	10	11	12	16	13	17	9	8	13	11	8	8
8	6	3	8	3	6	5	4	2	6	4	4	5	7	9	10	9	7	5	8	9	10	15	11	15	9	6	13	13	11	10
9	4	4	10	11	9	10	8	6	2	5	7	8	10	12	13	12	10	8	7	6	8	11	7	10	9	1	8	10	14	14
10	6	3	10	9	8	8	6	4	5	2	4	5	7	10	10	9	7	5	5	7	10	14	11	14	11	5	10	12	11	12
11	8	5	8	7	6	4	4	4	7	4	3	3	4	6	7	6	4	4	8	9	12	16	13	16	10	7	13	10	8	9
12	8	6	10	9	7	6	5	5	8	5	3	2	5	6	6	5	3	4	8	8	13	14	17	16	12	8	11	9	9	11
13	10	8	9	8	6	4	5	7	10	7	4	5	3	4	5	7	6	8	11	11	15	19	16	19	11	10	14	11	5	8
14	12	11	12	10	8	6	7	9	12	10	6	6	4	3	2	7	6	9	11	11	17	21	18	19	13	13	14	12	7	11
15	13	11	12	11	10	8	7	10	13	10	7	6	5	2	3	7	6	9	12	12	18	22	18	19	14	13	15	12	9	12
16	12	10	12	10	9	8	7	9	12	9	6	5	7	7	7	4	2	5	9	8	17	18	14	16	13	10	11	8	11	12
17	11	8	10	9	7	6	5	7	10	7	4	3	6	6	6	2	3	4	7	6	15	16	13	14	12	9	9	7	10	11
18	9	7	11	10	8	8	6	5	8	5	4	4	8	9	9	5	4	3	7	6	14	16	12	14	13	8	9	9	11	13
19	9	7	13	12	11	11	10	8	7	5	8	8	11	12	12	9	7	7	3	3	12	13	9	10	13	5	7	9	15	16
20	8	8	13	14	13	11	10	9	6	7	9	8	11	11	12	8	6	6	3	3	11	12	9	10	12	5	5	6	15	16
21	6	8	11	13	13	12	10	8	10	12	13	15	17	18	17	15	14	12	11	5	6	5	8	10	7	12	14	19	17	17
22	11	13	15	17	17	17	16	15	11	14	16	17	19	21	22	18	16	16	13	12	6	5	6	3	15	10	12	15	23	21
23	7	9	13	14	14	15	13	11	7	11	13	14	16	18	18	14	13	12	9	9	5	6	5	5	11	6	10	12	20	18
24	11	13	16	18	18	19	17	15	10	14	16	19	19	19	16	14	14	10	10	8	3	5	3	15	9	10	15	12	22	22
25	7	8	8	8	9	10	9	9	9	11	10	12	11	13	14	13	12	13	13	12	10	14	11	15	6	8	15	16	15	13
26	4	5	9	11	10	10	8	6	1	5	7	8	10	13	13	10	9	8	5	5	7	10	6	9	8	2	7	8	15	15
27	10	12	16	17	16	14	13	13	8	10	13	11	14	14	15	11	9	9	7	5	12	12	10	10	15	7	5	5	18	19
28	12	13	16	14	13	12	11	13	10	12	10	9	11	12	12	8	7	9	9	6	14	15	12	12	16	18	5	4	15	16
29	14	12	13	10	9	7	8	11	14	11	8	9	5	7	9	11	10	11	15	15	19	23	20	22	15	14	18	15	5	6
30	12	10	9	6	6	5	8	10	14	12	9	11	8	11	12	12	11	13	16	16	17	21	18	22	13	15	19	16	6	6

TABLE 20
ZONE TO ZONE TRAVEL TIME MATRIX, IN MINUTES
1970 BUS TRAVEL TIMES

ZONE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	3	6	27	26	28	30	7	7	15	11	10	20	12	14	16	15	16	17	14	15	5	9	9	22	21	14	20	20	17	20
2	6	5	22	21	23	26	2	3	11	6	6	16	8	9	12	11	11	13	9	10	9	13	12	17	17	11	15	15	12	16
3	27	22	4	4	5	7	20	22	27	23	19	32	18	19	21	21	21	29	25	27	30	34	33	34	6	27	31	25	22	26
4	26	21	4	6	5	7	19	21	26	22	18	31	17	18	20	20	20	20	28	24	26	29	32	33	5	26	30	24	21	25
5	28	33	5	5	2	3	21	23	28	24	20	33	19	20	22	22	22	30	26	28	31	35	34	35	7	28	32	26	23	27
6	30	26	7	7	3	2	24	25	30	26	22	35	21	23	24	24	24	32	29	30	33	38	36	37	9	31	35	28	25	29
7	7	2	20	19	21	24	6	2	10	6	5	15	6	7	10	9	9	12	9	10	10	14	13	17	15	11	15	13	10	14
8	7	3	22	21	23	25	2	1	10	6	5	15	7	9	11	10	11	12	9	10	10	15	14	17	16	11	15	15	12	15
9	15	11	27	26	28	30	10	10	13	4	9	16	12	14	16	14	14	13	9	10	10	11	7	17	21	1	15	18	17	20
10	11	6	23	22	24	26	6	6	4	2	5	11	8	10	11	10	10	8	5	6	14	15	10	13	17	5	11	14	12	16
11	10	6	19	18	20	22	5	5	9	5	3	14	4	6	7	6	5	11	7	9	13	18	15	16	13	9	13	9	9	12
12	20	16	32	31	33	35	15	15	16	11	14	18	17	19	21	19	19	3	10	80	23	26	22	15	26	16	12	23	22	25
13	12	8	18	17	19	21	6	7	12	8	4	17	1	2	5	7	7	14	11	12	15	20	18	19	12	13	17	11	4	8
14	14	9	19	18	20	23	7	9	14	10	6	19	2	3	5	8	9	16	12	14	17	21	20	21	14	14	18	13	6	10
15	16	12	21	22	24	10	11	16	11	7	21	5	5	3	4	7	16	14	15	19	24	22	22	16	16	20	11	11	8	11
16	15	11	21	20	22	24	9	10	14	10	5	19	7	8	4	3	2	16	13	14	18	23	20	21	15	15	19	6	11	15
17	16	11	21	20	22	24	9	11	14	10	5	19	7	9	7	2	14	16	13	14	19	23	20	21	15	15	19	5	11	15
18	17	13	29	28	30	32	12	12	13	8	11	3	14	16	17	16	16	5	7	5	20	23	19	12	23	13	9	20	18	22
19	14	9	25	24	26	29	9	9	9	5	7	10	11	12	14	13	13	7	3	5	17	20	15	8	20	10	6	17	15	19
20	15	10	27	26	28	30	10	10	10	6	9	8	12	14	15	14	14	5	5	3	18	21	16	9	21	11	5	18	16	20
21	5	9	30	29	31	33	10	10	10	14	13	23	15	17	19	18	19	20	16	18	3	4	3	25	24	9	23	23	20	23
22	9	13	34	33	35	38	14	15	11	15	17	26	20	21	24	23	23	23	20	4	4	5	28	29	10	26	27	27	24	28
23	9	12	33	29	34	36	13	14	7	10	15	22	18	20	22	20	20	19	15	16	3	5	5	23	27	6	21	25	23	26
24	22	17	34	33	35	37	17	17	17	13	16	15	19	21	22	21	21	12	8	9	25	28	23	4	28	18	11	25	23	27
25	21	16	6	5	7	9	15	16	21	17	13	26	12	14	15	15	15	23	20	21	24	29	27	28	3	22	26	19	16	20
26	14	11	27	26	28	31	11	11	1	5	9	16	13	14	16	15	15	13	10	11	9	10	6	18	22	13	16	19	17	21
27	20	15	31	30	32	35	15	15	15	11	13	12	17	18	20	19	19	9	6	5	23	26	21	11	26	16	23	23	21	25
28	20	15	25	24	26	28	13	15	18	14	9	23	11	13	11	6	5	20	17	18	23	27	25	25	19	19	23	8	15	19
29	17	12	22	21	23	25	10	22	17	12	9	22	4	6	8	11	11	18	15	16	20	24	23	23	16	17	21	15	2	4
30	20	16	26	25	27	29	14	15	20	16	12	25	8	10	11	15	15	22	19	20	23	28	26	27	20	21	25	19	4	33

TABLE 21
ZONE TO ZONE TRAVEL TIME MATRIX, IN MINUTES
1980 BUS TRAVEL TIMES (PLAN ONE)

ZONE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	3	6	27	26	28	30	7	7	15	11	10	20	12	14	16	15	16	17	14	15	5	9	9	22	21	14	20	20	17	20
2	6	5	22	21	23	26	2	3	11	6	6	16	8	9	12	11	11	13	9	10	9	13	12	17	17	11	15	15	12	16
3	27	22	4	4	5	7	20	22	27	23	19	32	18	19	21	21	21	29	25	27	30	34	33	34	6	27	31	25	22	26
4	26	21	4	6	5	7	19	21	26	22	18	31	17	18	20	20	20	20	28	24	26	29	32	33	5	26	30	24	21	25
5	28	23	5	5	2	3	21	23	28	24	20	33	19	20	22	22	22	30	26	28	31	35	34	35	7	28	32	26	23	27
6	30	26	7	7	3	2	24	25	30	26	22	35	21	23	24	24	42	32	29	30	33	38	36	37	9	31	35	28	25	29
7	7	2	20	19	21	24	6	2	10	6	5	15	6	7	10	9	9	12	9	10	10	14	13	17	15	11	15	13	10	14
8	7	3	22	21	23	25	2	1	10	6	5	15	7	9	11	10	11	12	9	10	10	15	14	17	16	11	15	15	12	15
9	15	11	27	26	28	30	10	10	13	4	9	16	12	14	16	14	14	13	9	10	10	11	7	17	21	1	15	18	17	20
10	11	6	23	22	24	26	6	6	4	2	5	11	8	10	11	10	10	8	5	6	14	15	10	13	17	5	11	14	12	16
11	10	6	19	18	20	22	5	5	9	5	3	14	4	6	7	6	5	11	7	9	13	18	15	16	13	9	13	9	9	12
12	20	16	32	31	33	35	15	15	16	11	14	18	17	19	21	19	19	3	10	8	23	26	22	15	26	16	12	23	22	25
13	12	8	18	17	19	21	6	7	12	8	4	17	1	2	5	7	7	14	11	12	15	20	18	19	12	13	17	11	4	8
14	14	9	19	18	20	23	7	9	14	10	6	19	2	3	5	8	9	16	12	14	17	21	20	21	14	14	18	13	6	10
15	16	12	21	22	24	10	11	16	11	7	21	5	5	3	4	7	17	14	15	19	24	22	22	16	16	20	11	11	8	11
16	15	11	21	20	22	24	9	10	14	10	5	19	7	8	4	3	2	16	13	14	18	23	20	21	15	15	19	6	11	15
17	16	11	21	20	22	24	9	11	14	10	5	19	7	9	7	2	14	16	13	14	19	23	20	21	15	15	19	5	11	15
18	17	13	29	28	30	32	12	12	13	8	11	3	14	15	17	16	16	5	7	5	20	23	19	12	23	13	9	20	18	22
19	14	9	25	24	26	29	9	9	9	5	7	10	11	12	14	13	13	7	3	5	17	20	15	8	20	10	6	17	15	19
20	15	10	27	26	28	30	10	10	10	6	9	8	12	14	15	14	14	5	5	3	18	21	16	9	21	11	5	18	16	20
21	5	9	30	29	31	33	10	10	10	14	13	23	15	17	19	18	19	20	17	18	3	4	3	25	24	9	23	23	20	23
22	9	13	34	33	35	38	14	15	11	15	17	26	20	21	24	23	23	23	20	4	4	5	28	29	10	26	27	27	24	28
23	9	12	33	29	34	36	13	14	7	10	15	22	18	20	22	20	20	19	15	16	3	5	5	23	27	6	21	25	23	26
24	22	17	34	33	35	37	17	17	17	13	16	15	19	21	22	21	21	12	8	9	25	28	23	4	28	18	11	25	23	27
25	21	16	6	5	7	9	15	16	21	17	13	26	12	14	15	15	15	23	20	21	24	29	27	28	3	22	26	19	16	20
26	14	11	27	26	28	31	11	11	1	5	9	16	13	14	16	15	15	13	10	11	9	10	6	18	22	13	16	19	17	21
27	20	15	31	30	32	35	15	15	15	11	13	12	17	18	20	19	19	9	6	5	23	26	21	11	26	16	23	23	21	25
28	20	15	25	24	26	28	13	15	18	14	9	23	11	13	11	6	5	20	17	18	23	27	25	25	19	19	23	8	15	19
29	17	12	22	21	23	25	10	12	17	12	9	22	4	6	8	11	11	18	15	16	20	24	23	23	16	17	21	15	2	4
30	20	16	26	25	27	29	14	15	20	16	12	25	8	10	11	15	15	22	19	20	23	28	26	27	20	21	25	19	4	33

TABLE 22
DEMOGRAPHIC INDICATORS

ZONE	USE DENSITIES		TOTAL	EMPLOYMENT		POPULATION		STUDENTS		AVERAGE	TOTAL
NO.	RES.	EMPL.	FAMILIES	PRESENT	FUTURE	PRESENT	FUTURE	PRESENT	FUTURE	INCOME	DENSITY
1	3.5	.4	1471	534	1083	4648	4810	930	962	11536	3.7
2	4.1	.9	1210	642	1004	4224	3958	845	792	11077	6.7
3	3.7	.9	1855	651	1250	5701	6069	1140	1214	12013	10.4
4	3.6	1.5	2162	1059	1849	6495	7071	1299	1414	12235	8.6
5	4.4	3.4	2088	2280	3357	6679	6829	1336	1366	11385	13.3
6	2.2	6.4	1525	7021	9641	2627	4989	525	998	12016	8.9
7	6.6	12.6	1475	5128	5966	5986	4823	1197	965	9262	27.3
8	4.9	5.5	879	1553	1977	3298	2875	660	5751	10195	17.2
9	1.6	3.6	1018	3059	4416	2001	3328	400	666	11764	5.9
10	12.0	3.7	1913	2544	3435	6578	6257	1316	1251	10833	13.3
11	5.6	97.5	285	12874	15145	720	931	144	186	11413	103.0
12	7.7	15.2	1489	5924	7341	5082	4871	1016	974	9982	28.2
13	6.6	6.8	1466	2719	4377	3918	4795	1184	959	9661	21.6
14	4.9	1.9	1082	897	1546	3917	3540	7831	708	10430	10.3
15	2.3	.5	1256	494	897	3459	4106	692	821	11601	3.7
16	2.6	1.8	2103	1718	2264	5937	6878	1187	1376	14559	8.1
17	2.0	2.1	1093	1697	2401	2346	3575	469	715	15055	5.1
18	4.8	2.7	1437	1058	1568	4914	4700	983	940	11979	15.0
19	4.8	.6	1658	337	821	6177	5423	1235	1085	11556	11.7
20	3.3	.5	1834	355	5568	5989	5999	1200	1201	13668	9.1
21	1.8	.9	2109	1589	3156	4655	6897	931	1379	12227	3.7
22	2.0	.4	2453	691	1096	5630	8023	1126	1605	13327	4.1
23	3.0	3.4	2244	5791	10112	5360	7437	1072	1487	11878	6.5
24	2.2	.2	2121	432	946	5353	6937	1073	1387	12487	3.3
25	2.0	.1	8216	931	6149	18118	26872	3624	5374	12806	2.2
26	2.2	1.0	1379	1657	3614	4145	4509	829	902	13122	3.4
27	2.0	.1	3910	427	1505	10033	12789	2007	2558	14900	2.8
28	2.6	.4	2424	953	2588	7057	7927	1411	1585	13343	3.5
29	3.0	.4	2143	670	2091	6679	7007	1336	1401	11661	4.2
30	1.5	.0	2146	376	2096	4423	7017	885	1403	12255	.5

TABLE 23

FAMILY INCOME SEGREGATION, INCOME RANGES IN $1,000

	OPTIMAL DISTRIBUTION				SLACK				SURPLUS			
ZONE	0-5	5-10	10-15	15-UP	0-5	5-10	10-15	15-UP	0-5	5-10	10-15	15-UP
1	55	374	618	423	12	0	0	132	0	113	31	0
2	45	308	508	348	0	0	0	138	34	88	17	0
3	70	473	779	534	0	0	2	48	4	46	0	0
4	81	551	908	622	34	46	0	138	0	0	218	0
5	78	532	877	601	0	0	0	199	4	172	23	0
6	57	388	641	439	16	0	0	67	0	48	35	0
7	55	376	619	424	0	0	176	261	196	240	0	0
8	33	224	369	253	0	0	88	114	54	148	0	0
9	38	259	428	293	0	1	0	65	22	0	45	0
10	72	487	804	551	0	0	39	208	104	142	0	0
11	11	73	120	82	0	0	13	9	19	3	0	0
12	56	379	626	429	0	0	174	192	129	237	0	0
13	55	373	616	422	0	0	214	223	111	326	0	0
14	41	276	455	311	0	0	53	163	23	192	0	0
15	47	320	527	361	6	0	0	119	0	67	59	0
16	79	536	883	605	20	287	321	0	0	0	0	627
17	41	278	459	314	17	72	71	0	0	0	0	160
18	54	366	604	413	0	0	0	46	0	44	2	0
19	62	422	697	477	0	0	0	137	1	104	32	0
20	69	467	771	528	43	151	74	0	0	0	0	268
21	79	537	886	607	21	0	0	47	0	22	46	0
22	92	625	1031	706	39	229	0	0	0	0	68	201
23	85	579	955	654	0	0	0	116	4	63	49	0
24	80	540	891	610	40	0	22	0	0	28	0	33
25	308	2092	3451	2364	221	374	0	0	0	0	563	32
26	52	351	579	397	39	106	0	0	0	0	101	45
27	147	996	1643	1125	102	665	403	0	0	0	0	1171
28	91	617	1018	697	62	217	0	0	0	0	110	169
29	80	546	900	616	0	0	0	144	14	98	32	0
30	80	546	901	617	45	32	0	137	0	0	214	0

Total Slack	7251
Total Surplus	7251
Difference	14502

optimal, and 3) the number of families of each type by which each zone is in surplus of the optimal. The total number of slack and surplus families and the sum of the two are summarized at the bottom of the table.

The last six tables of the information display are the transportation outputs of QUADATT II for the region. This information can be divided temporally into present (1970) and future (1980) transportation inputs, and each of these divisions can be broken down into auto and transit. Present (1970) transportation input data are presented in Tables 24-26. Table 27 is a tabulation of future trip production and attractiveness estimates by purpose. Three trip purposes are recorded: 1) home to work, 2) home to non-work, and 3) non-home based and truck trips. Table 28 contains the interzonal trip matrix for future auto trips, while Table 29 contains the interzonal trip matrix for future transit trips.

TABLE 24

1970 TRIP GENERATION DATA

ZONE NO.	RESIDENTIAL TRIP GEN.	TOTAL ATTRACTIVENESS INDEX HOME TO WORK	HOME TO NON-WORK	NON-HOME + TRUCKS	ACTUAL TRIP PRODUCTIONS HOME TO WORK	HOME TO NON-WORK	NON-HOME + TRUCKS
1	9513	534	583	241	3044	4566	828
2	8527	642	559	232	2729	4093	794
3	11700	651	724	272	3744	5616	934
4	11368	1059	844	401	4310	6564	1376
5	13601	2280	951	717	4352	6529	2460
6	5261	7021	744	2219	1683	2525	7612
7	11530	5128	961	1721	3690	5534	5903
8	6517	1553	527	520	2085	3128	1785
9	3947	3059	468	883	1263	1895	3031
10	13077	2544	924	730	4185	6277	2504
11	1391	12874	1076	3231	445	668	11084
12	9883	5924	982	1122	3163	4744	3849
13	11639	2719	864	651	3725	5587	2235
14	7851	897	537	233	2512	3769	799
15	7046	494	456	171	2255	3382	587
16	26366	1718	839	511	4043	6064	1752
17	4913	1697	416	512	1572	2358	1758
18	10112	1058	675	339	3236	4854	1163
19	12672	337	735	185	4055	6082	634
20	12682	355	725	200	4058	6087	686
21	9486	1598	630	765	3036	4553	2623
22	11802	691	689	297	3777	5665	1019
23	10805	5791	943	1369	3458	5186	4698
24	11114	432	662	156	3556	5335	534
25	37989	931	2136	552	12156	18235	1893
26	8747	1657	542	395	2799	4199	1355
27	21772	427	288	967	6977	10451	989
28	14965	953	861	316	4789	7183	1085
29	13633	670	806	269	4363	6444	922
30	9153	376	539	174	2930	4394	597

Total Number of Trips - 337,435

TABLE 25

ZONE TO ZONE TRIP MATRIX
PRESENT DAILY VEHICLE TRIPS / 10

ZONE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	37	31	26	16	14	21	31	17	37	32	16	20	11	3	1	5	3	5	8	4	32	9	41	7	77	22	8	1	3	3
2	31	35	16	14	15	25	30	34	28	64	17	24	14	5	1	7	4	10	13	10	16	6	21	3	51	24	5	3	5	4
3	26	16	86	69	54	42	52	17	9	19	22	21	18	8	2	6	4	5	4	3	17	1	97	1	97	7	2	1	8	6
4	16	14	69	109	81	74	74	25	10	21	29	28	33	12	4	9	6	8	7	5	8	22	13	1	85	9	3	21	12	10
5	14	15	54	81	164	124	129	25	11	22	44	33	56	22	11	18	10	12	8	7	9	4	14	3	77	10	6	6	27	30
6	21	25	42	74	124	168	159	40	23	39	97	51	113	45	27	34	20	22	20	18	24	12	31	9	113	19	23	19	61	64
7	31	30	52	74	129	159	223	51	28	55	92	61	64	34	16	39	22	25	26	18	22	10	32	7	134	21	21	18	47	39
8	17	34	17	25	25	40	51	48	17	43	30	36	22	9	4	13	7	18	14	11	12	5	16	4	34	18	11	6	12	10
9	37	28	9	10	11	23	28	17	69	39	26	19	10	4	3	8	5	9	11	10	26	16	49	13	46	122	21	8	6	5
10	32	64	19	21	22	39	55	43	39	55	43	39	163	49	67	20	7	7	23	13	33	43	35	21	9	28	21	13	9	10
11	16	17	22	29	44	97	92	30	26	49	129	88	53	22	19	45	29	35	23	18	23	12	35	9	73	19	26	29	35	19
12	20	24	21	28	33	51	61	36	19	67	88	182	47	21	34	106	51	94	34	36	17	8	23	7	55	20	41	54	30	15
13	11	14	18	33	56	113	64	22	10	20	52	47	92	67	33	28	14	19	8	7	7	4	11	3	45	7	7	13	79	29
14	3	5	8	12	22	45	34	9	4	7	22	21	67	46	27	10	5	7	2	2	2	1	4	2	17	3	2	2	36	13
15	1	1	2	4	11	16	4	3	7	19	34	33	27	56	19	11	8	2	3	1	2	4	2	3	1	1	5	51	11	3
16	5	7	6	9	18	34	39	13	8	23	45	106	28	10	19	95	67	36	25	26	5	3	15	2	17	6	28	61	11	4
17	3	4	4	6	10	20	22	7	5	13	29	51	14	5	11	67	34	33	14	19	4	3	12	3	12	4	23	34	7	3
18	5	10	5	8	12	22	25	18	9	33	35	94	19	7	8	36	33	63	30	31	5	2	15	2	11	6	26	33	8	4
19	8	13	4	7	8	20	26	14	11	43	23	34	8	2	2	24	14	30	94	96	11	5	334	5	6	10	63	14	1	1
20	4	10	3	5	7	18	18	11	10	35	18	36	7	2	3	26	19	7	2	3	26	19	31	96	97	11	8	26	1	0
21	32	16	11	8	9	24	22	12	26	21	23	17	7	2	1	4	5	5	11	11	131	46	117	36	51	22	26	7	3	2
22	9	6	2	3	4	12	10	5	16	9	12	8	4	1	2	3	3	2	5	8	46	88	140	184	14	16	18	4	4	2
23	41	21	17	13	14	31	32	16	49	28	35	23	11	4	4	15	12	12	15	34	146	140	184	114	79	56	88	32	6	5
24	7	3	3	1	1	3	9	7	4	13	7	4	13	2	22	2	3	2	5	8	36	184	114	21	8	13	12	3	5	3
25	77	51	97	85	77	131	134	34	46	60	73	55	45	17	3	17	12	11	6	4	51	14	79	8	477	30	5	5	13	10
26	22	24	7	9	10	19	21	18	122	44	19	20	7	3	1	6	4	6	10	11	22	16	56	13	30	41	27	7	3	2
27	8	5	2	3	6	23	21	11	21	32	26	41	7	2	1	28	23	26	63	86	26	18	88	12	5	27	251	139	3	2
28	1	3	1	2	6	19	18	6	13	29	54	13	3	5	61	34	33	14	26	7	4	32	3	5	7	139	7	191	2	1
29	3	5	8	13	27	61	47	12	6	9	35	30	79	36	11	11	7	8	1	1	3	4	6	5	13	2	2	1	53	12
30	3	4	6	10	30	64	39	10	5	10	19	15	29	13	3	4	3	4	1	0	2	2	5	3	10	2	3	2	123	53

TOTAL NUMBER OF DAILY AUTO TRIPS - 244,840

TABLE 26
ZONE TO ZONE TRIP MATRIX

PRESENT DAILY PERSON TRIPS BY TRANSIT

ZONE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	0	0	0	0	0	0	4	0	0	2	111	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	8	0	0	3	119	2	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	2	0	0	0	1	141	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	2	171	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	2	0	0	0	5	201	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
6	0	0	2	0	2	0	0	0	0	13	191	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
7	4	8	0	0	0	0	26	20	6	43	357	23	32	13	3	6	3	9	16	9	2	0	3	0	0	1	0	3	1	0
8	0	0	0	0	0	0	20	6	2	17	152	7	10	3	1	2	1	2	5	2	0	0	1	0	0	0	0	0	0	0
9	0	0	0	0	0	0	6	2	0	22	83	5	5	2	0	0	0	3	7	0	0	0	0	0	0	0	0	0	0	0
10	2	3	1	2	5	13	43	17	22	82	345	47	19	6	2	8	5	12	16	9	3	1	9	1	1	7	2	1	2	0
11	111	119	141	171	201	192	357	152	83	345	881	348	336	175	136	277	121	226	231	168	103	70	135	72	422	91	200	218	245	118
12	1	2	0	0	0	1	23	7	5	47	348	15	18	7	0	1	0	41	23	17	0	0	2	3	0	1	1	0	0	0
13	2	3	1	1	1	0	32	10	5	19	336	18	54	19	3	8	4	6	7	4	0	0	2	0	0	1	0	2	2	0
14	0	1	0	0	0	0	13	3	2	6	175	7	19	3	0	3	1	1	1	1	0	0	1	0	0	0	0	0	0	0
15	0	0	0	0	0	0	3	1	0	2	136	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	6	2	0	8	277	1	8	3	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	3	1	0	5	121	0	4	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	9	2	3	12	226	41	6	1	0	0	0	4	4	3	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	1	2	16	5	7	16	231	23	7	1	0	2	1	4	1	0	0	0	2	0	0	1	0	0	0	0
20	0	0	0	0	0	0	9	2	0	9	168	17	4	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	2	0	0	3	103	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	1	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	3	1	0	9	135	2	2	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	1	72	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	1	422	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	1	0	0	7	91	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	2	200	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	3	0	0	1	218	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	1	0	0	2	245	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	118	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TOTAL NUMBER OF DAILY TRANSIT TRIPS - 13,584

TABLE 27
FUTURE TRIP GENERATION DATA

ZONE NO.	RESIDENTIAL TRIP GEN.	TOTAL ATTRACTIVENESS INDEX HOME TO WORK	HOME TO NON-WORK	NON-HOME + TRUCKS	ACTUAL TRIP PRODUCTIONS HOME TO WORK	HOME TO NON-WORK	NON-HOME + TRUCKS
1	11784	1067	649	395	3771	5656	1260
2	9731	1025	574	328	3114	4671	1045
3	14270	1123	784	388	4566	6849	1236
4	16613	1702	932	562	5316	7974	1790
5	15267	3101	980	910	4886	7328	2898
6	10306	9273	1078	2797	3298	4947	8912
7	11131	5952	871	1956	3562	5343	6233
8	7059	2008	538	637	2259	3389	2029
9	8744	4536	766	1367	2798	4197	4356
10	15338	3519	979	951	4908	7362	3030
11	2194	15148	1345	3832	702	1053	12212
12	10448	7186	1106	1397	3343	5015	4452
13	11301	3506	795	820	3616	5424	2613
14	8633	1593	558	377	2763	4144	1200
15	10315	978	589	317	3301	4951	1009
16	18307	2406	1061	656	5858	8787	2089
17	9362	2463	642	757	2996	4494	2412
18	11214	1524	687	445	3588	5383	1419
19	13919	947	726	302	4454	6681	961
20	16003	740	809	275	5121	7681	876
21	17604	3199	1030	1256	5633	8450	4001
22	20650	1178	1038	443	6608	9912	1286
23	19123	10211	1496	2319	6119	9179	7391
24	17254	991	900	275	5521	8282	877
25	61676	5604	3229	2002	19736	29604	6379
26	13230	3909	806	947	4234	6350	3016
27	33308	1614	1634	679	10658	15988	2164
28	20475	2661	1101	774	6552	9828	2465
29	17085	2188	943	645	5467	8201	2054
30	16233	1986	891	643	5194	7792	2048

TOTAL NUMBER OF TRIPS - 468,572

TABLE 28

ZONE TO ZONE TRIP MATRIX
FUTURE DAILY VEHICLE TRIPS / 10

ZONE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	39	29	29	18	19	25	27	17	50	32	20	23	10	4	3	7	6	10	11	15	51	14	59	10	121	50	26	11	5	9
2	29	31	17	24	23	33	42	31	35	60	24	26	12	5	4	10	9	12	15	12	24	6	27	4	74	12	6	6	7	13
3	29	17	102	79	59	53	49	14	16	16	27	21	18	5	5	10	11	8	4	4	18	5	20	2	119	5	4	4	9	27
4	18	24	79	123	85	92	68	26	14	23	36	28	25	10	8	20	15	11	7	4	13	3	10	2	137	13	5	9	24	71
5	19	23	59	85	162	150	113	31	17	28	43	32	39	18	12	26	24	15	11	7	15	6	22	3	114	16	10	15	34	74
6	25	33	53	92	150	222	166	46	32	55	120	71	95	44	33	54	46	30	20	22	35	16	42	10	159	28	38	38	89	143
7	27	42	49	68	113	166	174	43	31	48	80	66	53	25	30	49	43	34	21	18	28	12	38	8	140	24	31	32	52	51
8	17	31	14	26	31	46	43	45	22	34	33	16	16	7	7	14	13	22	12	10	17	5	21	4	65	22	12	9	12	15
9	50	35	16	14	17	32	31	22	121	52	40	29	15	7	6	14	12	18	28	38	48	26	85	23	113	196	73	31	12	11
10	32	60	16	23	28	55	48	42	52	165	59	64	30	11	12	27	24	43	53	32	31	12	38	9	72	53	47	20	21	16
11	20	24	27	36	43	120	80	34	40	59	116	84	50	24	25	49	46	42	21	19	33	16	47	11	114	35	32	38	45	38
12	23	26	21	28	32	71	66	33	29	64	84	166	55	34	42	87	78	61	29	41	23	11	29	9	79	29	51	52	44	28
13	10	12	18	25	39	95	53	16	15	30	50	55	79	45	40	38	26	17	9	10	10	5	14	3	64	14	16	22	87	38
14	4	5	5	10	18	44	25	7	7	11	24	34	45	48	83	27	20	9	4	6	4	2	7	1	24	5	9	11	22	9
15	3	4	5	8	12	33	30	7	6	12	25	42	40	83	63	31	23	10	5	5	3	3	7	1	17	6	5	11	35	12
16	7	10	10	20	26	54	49	14	14	27	49	87	36	27	31	125	140	53	20	28	7	4	23	4	42	20	36	56	22	16
17	6	9	11	15	24	46	43	13	12	24	46	78	26	20	23	140	48	38	20	28	8	5	19	6	39	14	40	44	18	14
18	10	12	8	11	15	30	34	22	18	43	42	61	17	9	10	53	38	58	20	29	7	3	20	4	2	17	38	25	13	7
19	11	15	4	7	11	20	21	12	28	53	21	29	9	4	5	20	20	20	82	87	12	8	44	15	25	48	70	28	4	3
20	15	12	4	4	7	22	18	10	38	32	19	31	10	6	5	28	28	29	87	91	17	11	47	15	35	51	133	78	4	3
21	51	24	18	13	15	35	28	17	48	31	33	23	10	4	3	7	8	12	17	156	121	239	25	125	52	57	36	17	6	7
22	14	6	5	3	6	16	12	5	26	12	16	11	5	2	3	4	5	8	11	121	164	200	244	35	31	30	10	10	7	4
23	59	27	19	22	42	38	21	85	38	47	29	14	7	7	23	19	20	44	239	200	347	192	172	102	109	49	113	39	13	14
24	10	4	2	2	3	10	8	4	23	9	11	9	3	1	1	4	6	4	15	52	244	192	182	19	27	28	44	18	4	4
25	121	74	119	137	114	159	140	65	113	72	114	79	64	24	17	42	39	25	25	35	125	35	172	19	106	137	73	25	27	35
26	50	27	19	13	16	28	24	22	196	53	35	29	14	5	6	20	14	17	48	51	57	31	102	28	137	124	91	47	6	5
27	26	12	5	5	10	38	31	12	73	47	32	51	16	9	5	36	40	38	70	133	36	30	109	42	37	91	347	243	6	5
28	11	6	4	9	15	38	32	9	31	20	38	52	22	11	11	56	44	25	28	67	17	10	49	18	25	47	243	226	10	7
29	5	7	9	24	34	89	52	12	12	21	45	44	87	35	22	22	18	13	4	4	6	7	13	4	27	10	6	10	133	96
30	9	13	27	71	74	143	51	15	11	16	38	28	38	12	9	16	14	7	3	3	7	4	14	4	35	8	5	7	96	31

Total Number of Daily Auto Trips - 344,660

TABLE 29

ZONE TO ZONE TRIP MATRIX
FUTURE DAILY PERSON TRIPS BY TRANSIT

ZONE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	0	0	0	0	0	0	3	0	0	3	118	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	4	0	0	4	139	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	2	0	0	1	163	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	3	199	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	2	0	0	5	192	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
6	0	0	2	0	2	0	0	0	0	13	268	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
7	3	4	0	0	0	0	20	17	6	37	304	18	27	12	1	5	2	7	12	7	2	0	3	0	1	2	0	1	1	0
8	0	0	0	0	0	0	17	6	2	16	168	6	9	3	0	2	0	1	4	2	0	0	2	0	0	0	0	0	0	0
9	0	0	0	0	0	0	6	2	0	26	131	5	6	3	0	0	0	3	6	0	0	0	0	0	0	0	0	0	0	0
10	3	4	1	3	5	13	16	26	37	84	390	43	24	8	3	8	8	13	17	9	5	1	12	1	3	12	4	3	4	1
11	118	139	163	199	192	268	304	168	131	390	808	322	305	172	160	312	183	248	187	160	141	97	181	81	566	131	221	234	273	189
12	0	0	0	0	0	0	18	6	5	43	322	13	15	6	0	1	0	34	19	15	0	0	3	3	0	2	2	0	0	0
13	2	3	1	1	1	0	27	9	6	24	305	15	48	19	3	9	5	5	7	4	1	0	3	0	0	2	0	2	3	1
14	0	1	0	0	0	0	12	3	3	8	172	6	19	4	0	3	1	1	2	1	0	0	1	0	0	0	0	0	0	0
15	0	0	0	0	0	0	1	0	0	3	160	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	5	2	0	8	312	1	9	3	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	2	0	0	8	183	0	5	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	7	1	3	13	248	34	5	1	0	0	0	4	5	3	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	12	4	6	17	187	19	7	2	1	5	1	0	0	0	3	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	7	2	0	9	160	15	4	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	2	0	0	5	151	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	1	97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	3	2	0	12	181	3	3	1	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	1	81	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	1	0	0	3	566	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	2	0	0	12	131	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	4	221	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	1	0	3	234	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	1	0	3	273	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	1	189	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TOTAL NUMBER OF DAILY TRANSIT TRIPS = 14,828

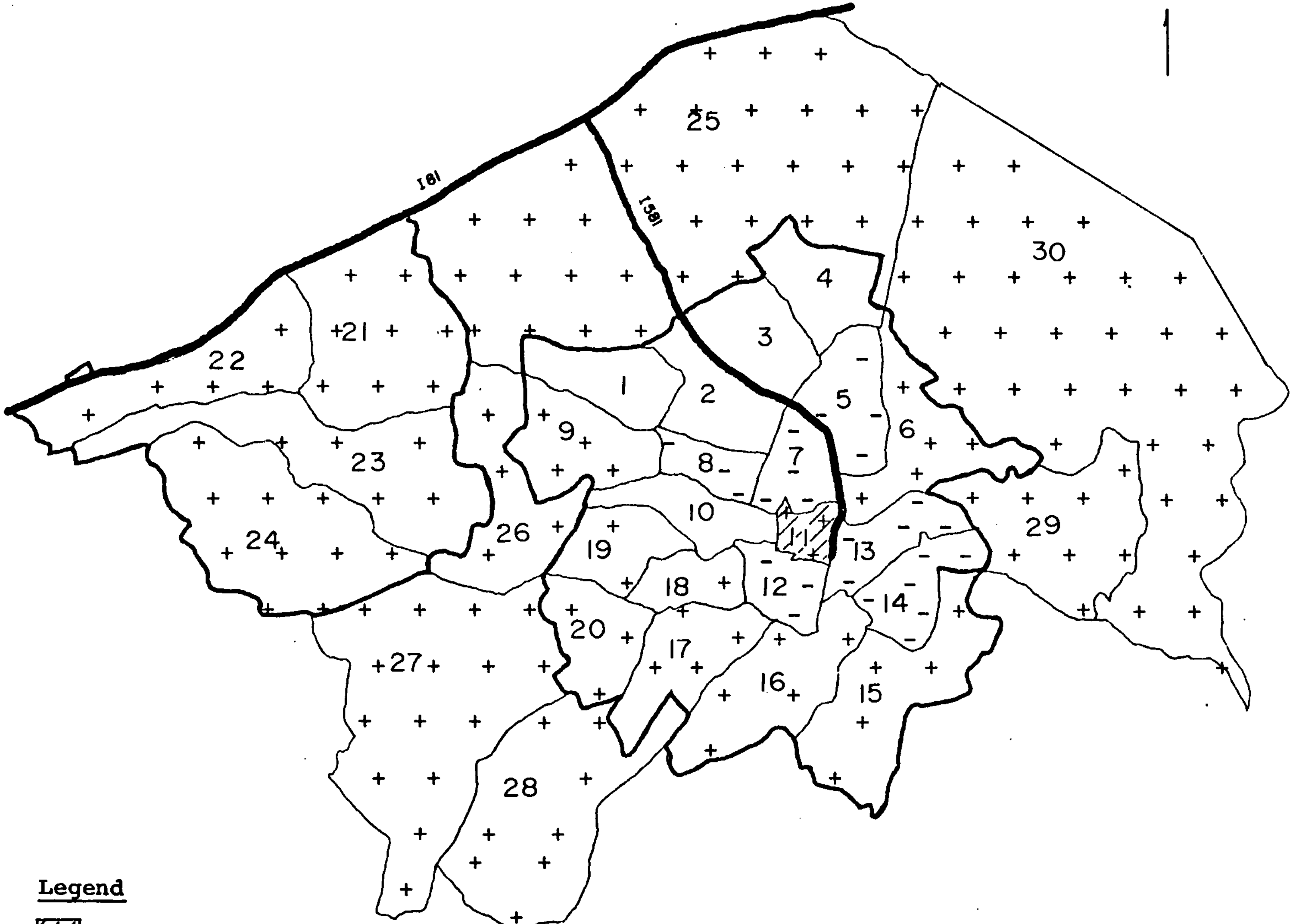
CHAPTER VI

Evaluation of QUADATT II Output and Conclusions

The evaluation of QUADATT II output for the Roanoke Metropolitan Area may be conveniently divided into two categories: activity distributions and transportation measures. Both of these output categories, as well as general conclusions, are discussed in the paragraphs which follow.

Activity Distributions

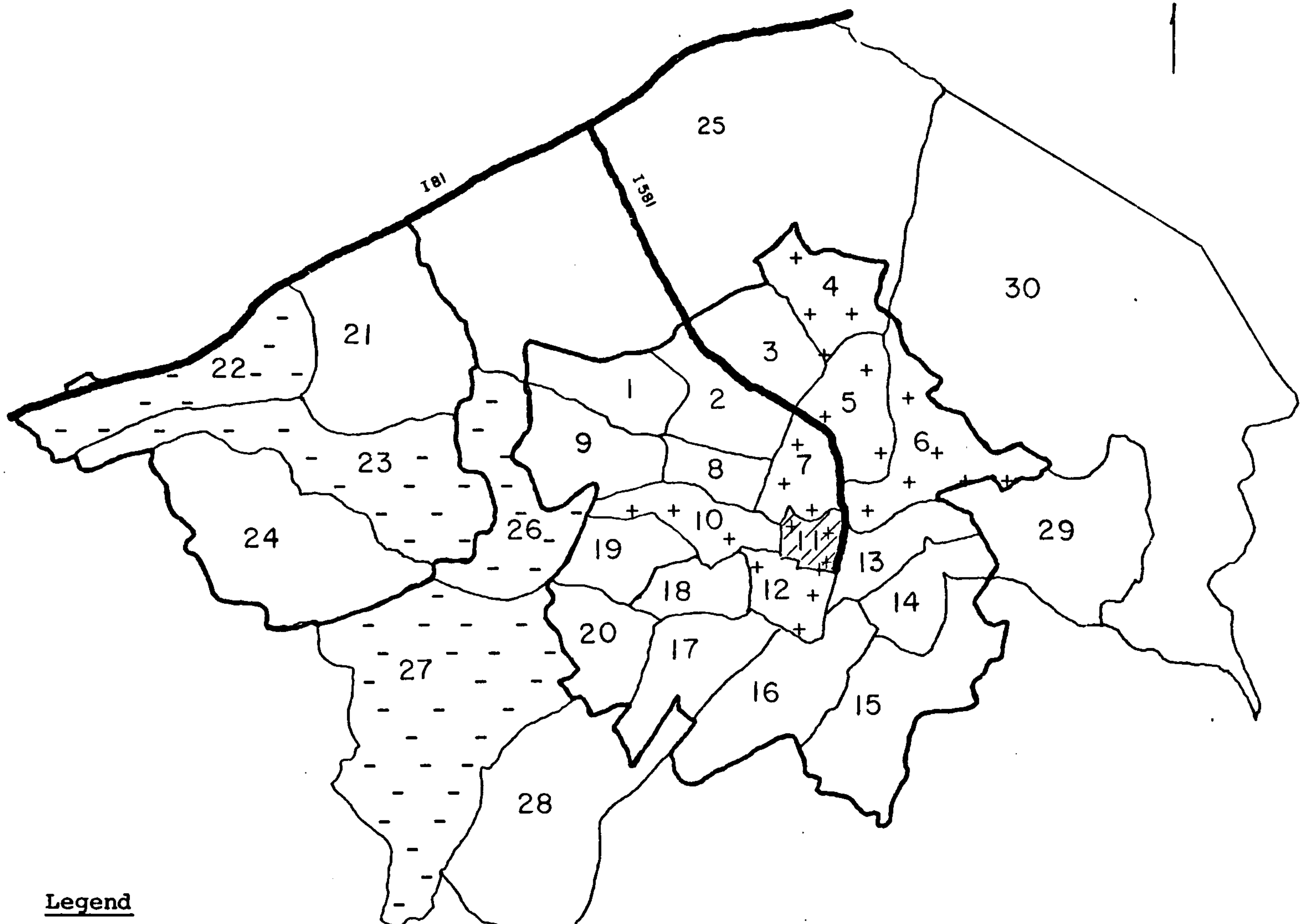
The 1970 and the 1980 no-build distributions of activity were compared with the impacts of the three other 1980 transit plans in order to evaluate the differences between future transit alternatives. Figures 11 through 14 indicate changes in population distributions due to changes in transit accessibility. Figure 11 indicates the changes in population distribution which would occur if no improvements were made in the transit system between 1970 and 1980 (Plan 1). Figures 12 through 14 demonstrate the changes in distributions which would be introduced by changing transit service (Plans 2, 3, 4) from the level of the 1980 null alternative (Plan 1). (The location of employment is not as sensitive to transit system changes as is population, but follows similar distributional patterns for each of the alternative plans.) As Figures 11 through 14 indicate, increasing the level of transit service to the fringes of the city and beyond (Plan 4) causes a slight shift in population and employment toward the suburbs. This pressure is primarily exerted on higher income groups, since the



Legend

Indicates CBD
+'s Indicate a gain of at least five percent
-'s Indicate a loss of at least five percent

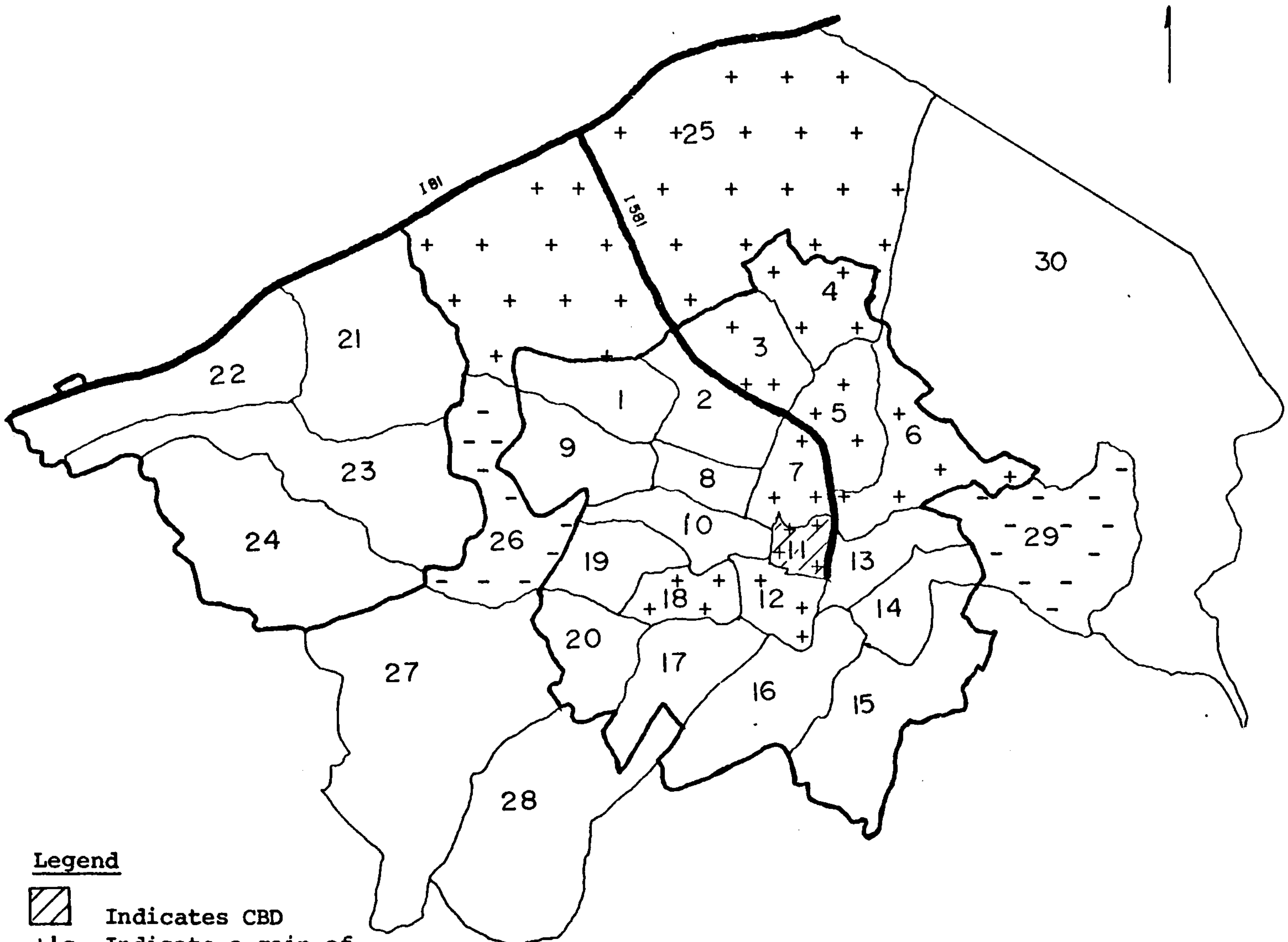
Figure 11
CHANGES IN POPULATION DISTRIBUTION
(Plan 1 versus 1970)



Legend

Indicates CBD
+'s Indicate a gain of at least five percent
-'s Indicate a loss of at least five percent

Figure 12
CHANGES IN POPULATION DISTRIBUTION
(Plan 2 versus Plan 1)



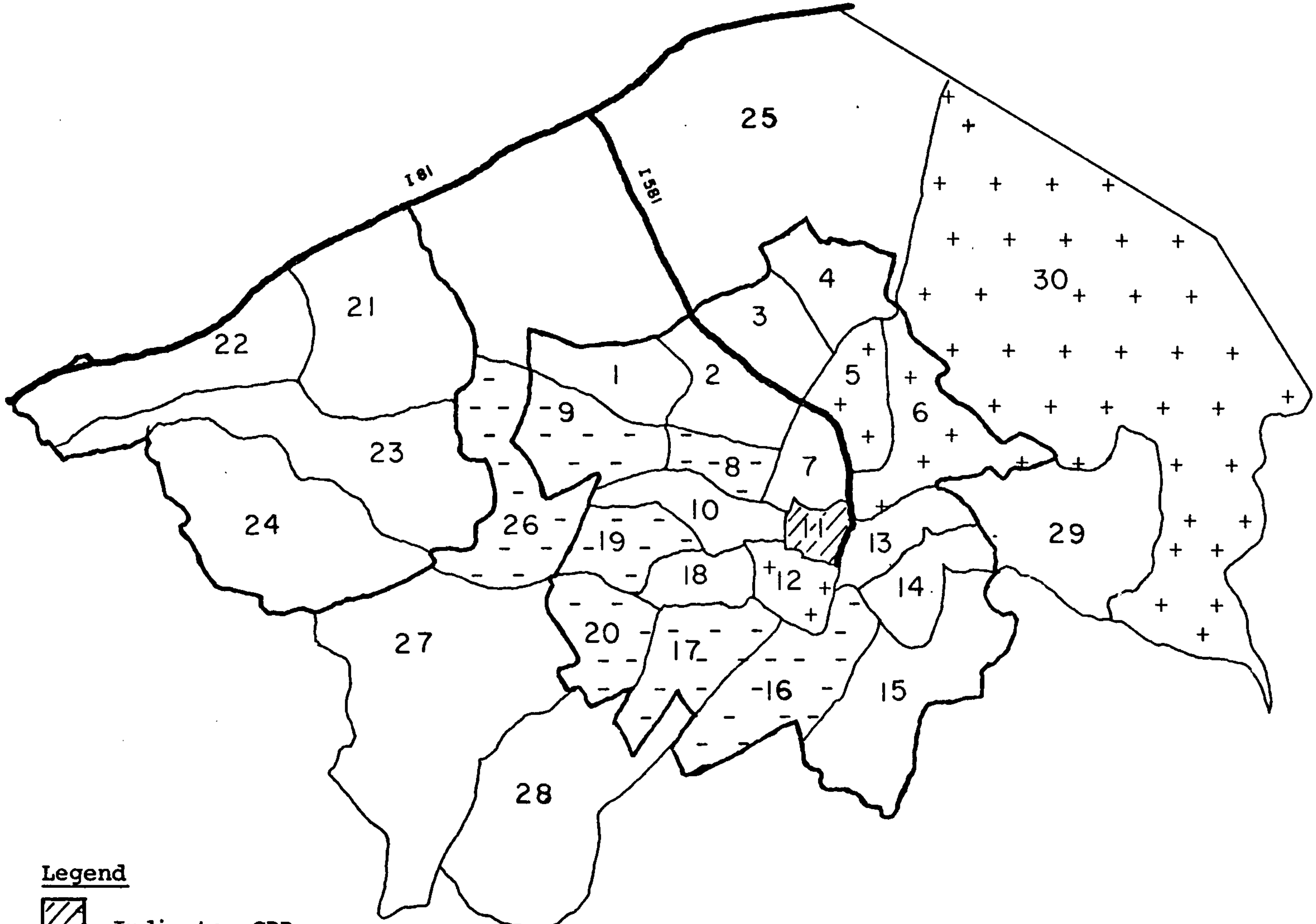
Legend

[hatched box] Indicates CBD

+'s Indicate a gain of at least five percent

-'s Indicate a loss of at least five percent

Figure 13
CHANGES IN POPULATION DISTRIBUTION
(Plan 3 versus Plan 1)



Legend

Indicates CBD
+'s Indicate a gain of at least five percent
-'s Indicate a loss of at least five percent

Figure 14
CHANGES IN POPULATION DISTRIBUTION
(Plan 4 versus Plan 1)

median family income increases in the newly accessible zones. Conversely, the no-build and limited accessibility options (Plans 1, 2 and 3) characterized by more centralized transit systems, effect slight increases in activity in the downtown zones and in the income of the resident population.

Since higher income groups move outward with increased transit mobility, segregation by income is most prevalent in Plan 4. The transit alternative which provides the least accessibility to the suburbs (Plan 3) therefore presents the best mix of income groups (for the solution set which was examined).

Transportation Measures

Table 30 presents regional transportation measures pertinent in evaluating the differences between alternative transit systems. The statistics presented in that table reveal a logical pattern in terms of relative differences between alternatives and are also consistent with previous studies of the Roanoke Area (Wilbur Smith, 1970). The absolute number of transit riders increases with increasing levels of service (Plan 4), but the percent of transit ridership does not reach the 1970 percentage levels, because increasing incomes encourage a greater volume of automobile trips.

Table 30 also focuses on the transportation characteristics of the CBD, Zone 11. As would be expected, the transit system with the best service (Plan 4) draws the greatest number of trip ends into the CBD.

TABLE 30

SUMMARY OF STATISTICS

	1970	Plan 1	Plan 2	Plan 3	Plan 4
Roanoke Region					
Percent Trips by Transit	4.02	3.17	2.8	2.9	3.29
Percent Increase in Transit Ridership Over 10 Year Period	-	8.5	.1	.2	13.0
Daily Transit Ridership	13,584	14,828	13,592	13,613	15,393
Daily Auto Trips	244,840	344,660	345,970	345,590	344,140
Population	164,159	194,643	194,643	194,643	194,643
Indicators of Segregation by Income		$14,462	$14,472	$14,427	$14,502
City of Roanoke					
Population	92,115	98,899	103,846	103,685	99,228
Mean Income	$9,429	$11,200	$11,200	$11,200	$11,200
Roanoke County					
Population	50,062	65,377	61,062	61,169	66,121
Mean Income	$11,466	$13,100	$13,100	$13,100	$13,100
City of Salem					
Population	21,982	30,367	29,735	29,789	29,294
Mean Income	$10,172	$12,600	$12,600	$12,600	$12,600
CBD (Zone 11)					
Population	720	908	1,161	1,090	931
Mean Income	$6,092	$11,344	$11,807	$11,744	$11,413
Employment	12,874	15,148	15,203	15,169	15,145
Daily Transit trip ends	6,395	7,053	6,719	6,678	7,146
Daily Auto Trip Ends	11,630	13,680	14,320	14,190	13,690
Percent Trips by Transit	30	28.4	26.6	26.8	28.6
Percent of Transit Trips with One End in CBD	87.6	89.7	92.5	92.	87.4

General Conclusions

Since the paradigm of the transportation planner and/or decision-maker who might evaluate QUADATT II output is not predetermined, there is no attempt here to select "good" or "bad" alternatives. Rather the intent of this analysis has been to validate that the relative trends in both activity distributions and transportation measures are a reasonable basis for comparison of alternative impacts. Comparison of QUADATT II output with a previous study of the Roanoke region (Wilbur Smith and Associates, 1970) has confirmed that the 1980 trends are indeed reasonable.

In addition to the test for output "reasonableness", QUADATT II execution time and cost were compared with those of more comprehensive modeling processes. The QUADATT II procedure for each of the transit alternatives required less than thirty seconds of execution time on a UNIVAC 1108. Therefore, at a standard market price for CPU time of $1000 per hour, QUADATT II execution for a single alternative costs less than $10. Each of the transit alternatives was processed via remote teletype terminal with an average turnaround time of five minutes. In contrast, the standard land use modeling-trip generation-trip assignment-modal split-capacity restraint procedures for a transportation study may require hours of "batched job" turnaround time for each alternative - and tens of thousands of dollars. These statistics support the hypothesis that the processing of alternative transportation plans may be accomplished quickly and inexpensively with the QUADATT II package.

Summary

The application of QUADATT II to the study of alternative transit plans in Roanoke has demonstrated the following advantages associated with the package:

- modularity of models
- limited expenditure of time and money on data collection and computer processing
- highly interpretable output for evaluation purposes.

The prime disadvantage associated with QUADATT II is the:

- sacrifice of accuracy.

Each of these advantages and disadvantages is summarized in the paragraphs below.

Modularity of Models

The modular nature of the QUADATT models was an asset in the development of Version II. The Cohort Survival technique and Input-Output model were easily incorporated into the package due to the independent structure of the QUADATT models. Their inclusion in the QUADATT II package improved the level of accuracy attainable in forecasting activity distributions for the Roanoke region.

Limited Expense

The Roanoke application demonstrated that QUADATT II is relatively inexpensive and time saving in terms of data collection and computer processing. Because of the many data assumptions, (such as the non-area specific calibration of the gravity model), even a large scale study would be less expensive using QUADATT II than traditional transportation planning processes.

Interpretable Output

The output of QUADATT II is summarized in formats which are amenable to efficient evaluation of activity distributions, transportation measures, and socioeconomic impacts. This attribute was affirmed in the analysis of QUADATT II output for the Roanoke transit alternatives.

Sacrifice of Accuracy

The major drawback in the use of QUADATT II involves the inaccuracies which are introduced by "short-cut" assumptions. For example, the derivation of coefficients and constants from previous studies in many of the models contributes to errors in projections for the Roanoke region. However, if the purpose of a transportation study is to evaluate the relative differences between alternative plans, then inaccuracies introduced by QUADATT II assumptions may be tolerable. Since many studies currently being conducted are principally concerned with relative differences between alternatives, QUADATT II provides a viable approach to the assessment of a broad array of alternative transportation plans.

CHAPTER VII

Recommendations for Future Research

Use of the QUADATT II procedure has suggested the need for future investigation of the following areas: measures of uncertainty, presentation of output, and inclusion of additional models. Each of these areas is discussed in the following sections.

Improvement of Measures of Uncertainty

An important area for further research involves the establishment of measures of uncertainty for planning models in general. QUADATT II suffers along with other planning models in the lack of quantitative techniques for measuring the risk of forecasting results. As forecast year data become available, the QUADATT II forecasts should be compared with them.

A sensitivity analysis of QUADATT II would yield valuable information in evaluating model output. Such an analysis might be conducted at two levels of detail for the transit study undertaken here:

1) A trend, maximum, and minimum number of transit trips might be projected for each alternative. The maximum and minimum scenarios would be obtained by varying the socioeconomic input to QUADATT II to extreme but possible levels. The trend scenario would reflect similar socioeconomic conditions to those of the present. A subsequent

evaluation of the activity levels and transportation measures associated with each scenario would indicate more clearly the relative differences between alternatives.

2) A detailed sensitivity analysis might be undertaken in which each input variable is varied to its feasible limits, and the QUADATT II output is compared with a "control" run, such as Plan 1.

Improvement of Output Presentation

Although QUADATT II as it now exists presents a clear and concise output display, there are methods available which could increase the utility of the technique to decisionmakers. These methods range from mapping packages such as SYMAP, SYMVIEW, and CALFORM* to interactive devices such as CRT (Cathode ray tube) computer terminals. Mapping techniques would be beneficial in presenting a geographic representation of relative levels for each land use variable, for output for the Segregation by Income Model, or for results of the proposed environmental analysis models. Another useful mapping function already included in some transportation planning packages is a display of transportation links with varying widths to indicate the density of interzonal traffic (Federal Highway Administration, 1972). Such mapping displays are useful to the decisionmaker in evaluating the impacts of future policies.

Interactive devices are the most expensive and responsive output

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* Developed by the Harvard Laboratory of Computer Design and Spatial Analysis.

media presently available. The planner may test alternative transportation plans in a single brief session with a teletype terminal or CRT. Interactive devices provide an opportunity for evaluation of a greater number of alternatives, which is a primary concern of the QUADATT II approach.

Inclusion of Environmental Impact and Other Relevant Models

Mobile-source air pollution and infrastructure (water and sewer levels of service) models could be incorporated into QUADATT II without violating the objectives of simplicity and low cost (Voorhees, 1972).

At the simplest level these models might estimate:

1) Carbon monoxide, nitrogen oxide, hydrocarbons, sulfur oxides, and particulate emission rates for automobiles and buses, given the average speed and the number of trips for each mode within each zone.
2) Exposure levels by pollutant for each resident by income and employee by type in each zone.
3) Sewer and water capacity of each zone in millions of gallons per day for each resident by income and employee by type.

Other models which would broaden the evaluation criteria of QUADATT II output include:

1) A construction cost model which would provide measures of construction costs for highways. If zones were allocated to four categories, such as CBD, fringe business, residential, and rural, differing construction costs might be associated

with each category. The number of miles of proposed highway in each zone would then be multiplied by the district construction cost per mile to obtain a measure of highway construction cost.

2) A model which simulates government expenditures and their relationship to transportation outlays (Miller, 1973).

3) A model of peak period trips to assist the transportation planner in pinpointing future overloaded transportation facilities.

4) A model to predict immigration rates, birth rates, and death rates as input for the cohort survival model.

As new influential factors emerge in the urban system, other models could be developed to reflect changes. For example, fuel prices may become an important factor affecting the modal split model in the future. The need for such models will become more explicit as attitudes and the environment change over time.

Summary

It should be emphasized that QUADATT II has been created as a heuristic and sketch planning tool and not as an accurate forecasting aid. Research has indicated that the cost of comprehensive transportation planning studies is not excessive in view of their forecasting objectives. More complex planning models often require a data collection period of as much as two years (Creighton, Hamburg Planning Consultants, 1971). In comparison, QUADATT II requires a minimal cost and time allocation for data collection, and is most useful in evaluating the relative differences between alternatives, not as a predictive tool.

Although recommendations have been made in this chapter for expansion of the QUADATT II model capabilities, inclusion of more components in a model generates the illusion that refinements are being added and uncertainty eliminated. Yet in practice, "Every additional component introduces less that is known than is not known" (Lee, 1972).

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QUADATT II: A TRANSPORTATION PLANNING TOOL

by

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ABSTRACT

There is an increasing need for a methodology which will provide quick and inexpensive forecasts of inputs from a variety of alternative transportation plans. QUADATT II (Quick And Dirty Analysis Techniques for Transportation - Version II) is a set of simplified models which has been compiled in order to fulfill this need.

The QUADATT II procedure was applied for this analysis to thirty transportation zones in the metropolitan area of Roanoke, Virginia. Five transit configurations were designed as input to QUADATT II, and the resultant impacts were evaluated. Based on the results of this application it was determined that QUADATT II provides reasonable trends in activity distributions and transportation characteristics related to a given set of alternative transportation plans, and does so at a much reduced level of cost and time over that of the typical large scale studies.