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A SYSTEM DYNAMICS MODEL TO TEST URBAN
TRANSPORTATION POLICY ALTERNATIVES

BY

JOHN PAUL BURTLE
B.S., UNIVERSITY OF TENNESSEE, 1963

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the Graduate Studies Program of
Florida Technological University

Orlando, Florida
1974

*Original
Designated Library copy*

To Molly and the kids
for their many
weekends of patience

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CHAPTER I

INTRODUCTION

This study investigates the structure of urban transportation systems, the bases of commuter mode selection, and the effects of alternate transportation system management policies. The study was based on the hypothesis that changes in transportation system management policies are possible which will significantly increase the demand for public transportation in urban areas.

The Problem

American urban transportation since World War II has been characterized by a rapid increase in the use of private automobiles coupled with the decreased use of public transportation. While urban populations have grown rapidly during this post-war period, annual passenger totals for public transportation have fallen from 23.5 billion passengers in 1945 to 8.019 billion passengers in 1968.¹ While national population has been increasing at an annual rate of 1.7 percent, automobile population has been increasing at an annual rate of 5.7 percent.²

The trend away from public transportation is due, in part, to the move of the commuters to the suburbs and to the dispersion of industry. In greater part, the trend is attributable to a national prosperity which has allowed the great majority of employed persons to afford the comfort and convenience of a private automobile.

To most commuters the option of using public transportation represents exposure to the weather while awaiting a carrier which is commonly late, uncomfortable, and often overcrowded during rush hours. Increasing public transportation fares coupled with declining service are added deterrents to electing to use public transportation. Public transportation is generally slower than commuting by private automobile since the competing modes normally share the roadways and the public transport must make stops along the way. Rapid transit systems offer a meaningful alternative only in heavily traveled corridors and do not fully satisfy the needs of the commuter who must travel by other modes to and from the rapid transit corridor.

For public transportation to compete favorably with the private automobile, public transportation systems must satisfy the commuters' needs for timely service, convenient service, comfortable facilities, all at a cost which does not exceed (and should be less than) automobile commuting.³

To maintain smooth traffic flow, planners feel they need 300 miles of roadway for every 100,000 added automobiles. Commonly 100 miles of roadway are actually built for every 100,000 added automobiles.⁴ Construction of sufficient roadway to meet demands is inhibited by available tax revenues and by competition for land. Each mile of roadway removes 40 to 50 acres of taxable property from the local tax rolls and from other useful employment.⁵ When necessary funds and land have been available so that sufficient roadway to meet current and projected demand were constructed, the attractive new roadway has consistently upset the demand forecast by generating a

population surge which rapidly overloads the new roadway.⁶ A saturation point is being approached where urban planners in the most developed areas realize that urban communities cannot continue indefinitely to relinquish valuable land to transport the flood of private automobiles.

The extensive use of automobiles, through exhaust emissions, land consumed by roadway and parking spaces, and by the production of automobiles and fuels, has become an increasing menace to the quality of the environment.

Dwindling oil supplies reinforce the growing awareness that current commuter trends must be changed. In the United States in 1972, more than 15 million barrels of oil per day were consumed, 40% for gasoline primarily for automobiles. The more than six million barrels of oil a day now consumed for gasoline is projected to grow to ten million barrels a day in another 10 years. In 1972 the United States imported \$3.5 billion in oil. This figure is projected to grow to \$20 billion by 1980, further aggravating the national balance of payments deficit and increasing our national dependency on oil-rich nations.⁷

In some large metropolitan areas with well-defined traffic corridors, new or revitalized rapid transit systems such as the highly publicized and very expensive Bay Area Rapid Transit System may ease the urban transportation problem. But for most of the nation's urban areas, where such expensive systems cannot be funded or where significant corridorization does not exist, methods must be found to improve existing bus systems to make these systems more responsive to

the needs of commuters. Transportation Secretary John Volpe commented: "In the vast majority of urban centers, better public transportation will have to come from better buses on better schedules making better utilization of rights-of-way already in place." ⁸

Approach to the Problem

The urban transportation problem defies piecemeal reform. Auto demand is influenced not only by the cost and time associated with auto travel, but also by the cost and time associated with public transportation. Likewise, the demand for public transportation is related to the time and cost of auto travel. Construction of roadway is a function of projected auto demand, but it is also constrained by the availability of land and by the increasing costs associated with increasing population density. And what is the effect of increasing roadway construction costs on transit demand? Decreasing the rate of constructing new roadway may make auto driving less appealing, but what is the effect of this reduction on transit demand when public transportation must use the same increasingly congested roadways? Will a tax levied on auto users to support public transportation cause auto ownership to decline significantly, reducing the revenues derived from the tax?

It is clear from the questions above that a macroscopic model of the total urban transportation system could be a powerful tool to aid urban planners test and evaluate transportation policy alternatives. It is the purpose of this study to develop a macroscopic model of the urban transportation system and to apply the model to test several transportation policy alternatives as they might be applied in Orange

County, Florida.

A modeling effort similar to that undertaken herein was reported at the 1974 Winter Simulation Conference, 14-16 January, 1974, Washington, D.C., in the paper "Urban Transportation Strategies Model" by S. G. Shanks, R. R. Hippler, and P. N. Formica of the Research Corporation of New England.

Other related works include Free Transit⁹ by T. A. Domencich and G. Kraft and "An Econometric Model of Urban Bus Transit Operations" included in Economic Characteristics of the Urban Transportation Industry.¹⁰

CHAPTER II

SYSTEM DYNAMICS AND DYNAMO

Introduction to System Dynamics

System Dynamics was developed by J. W. Forrester at the Massachusetts Institute of Technology as a means to study industrial systems.¹¹ The techniques have been extended by Forrester^{12,13} and by the Meadows group¹⁴ to modeling other socioeconomic systems. The primary objective of a System Dynamics study is to understand how the organization of a system affects system performance. Alternate management policies are tested by simulation. The simulation is not an effort to predict specific events with accuracy, but rather aims to demonstrate the characteristic behavior of the system and to indicate how that characteristic behavior will be changed under varying management policies.

Fundamental to the structure of a System Dynamics model is the representation of the flow of assets such as material, orders, money, people, equipment, and the like. Flow is modeled as a series of rates and levels with an origin (source) and a sink. The rates describe the continuous inputs to and outputs from the levels. The differences between the input and output rates are integrated to determine the levels. The rates are related to the levels by rate equations (also called decision functions). Equations in the System Dynamics model other than rate and level equations are called auxiliary equations.

Schematically, rates are represented as valves, levels are represented as rectangles, and auxiliaries are represented as circles. Schematic symbols are illustrated in Figure 1.

A significant factor in determining the response of socio-economic systems is the delay that occurs in transmitting assets and information and in making decisions. Two orders of delay are commonly used: the first order delay and the third order delay. Figure 2 illustrates the first and third order delay responses to step and impulse inputs.

Particular emphasis is given to modeling feedback phenomena. Forrester describes socioeconomic systems as characteristically multiloop, nonlinear feedback systems. He maintains that planners are unable to interpret adequately such systems without an assist from a System Dynamics model or some similar aid. The behavior of socioeconomic systems, in Forrester's terms, are "counterintuitive" so that planners' intuitive solutions are often counterproductive. Finally, Forrester writes: "The (System Dynamics) approach is easy to understand but difficult to practice. Few people have a high level of skill; but preliminary work is developing all over the world. Some European countries and especially Japan have begun centers of education and research."¹⁵

Introduction to Dynamo

Dynamo (DYNamic MOdels) was developed at the Massachusetts Institute of Technology by Dr. Phyllis Fox and Alexander L. Pugh, III, based on earlier work by Richard K. Bennett. Dynamo is a user-oriented higher-level language specifically developed to facilitate

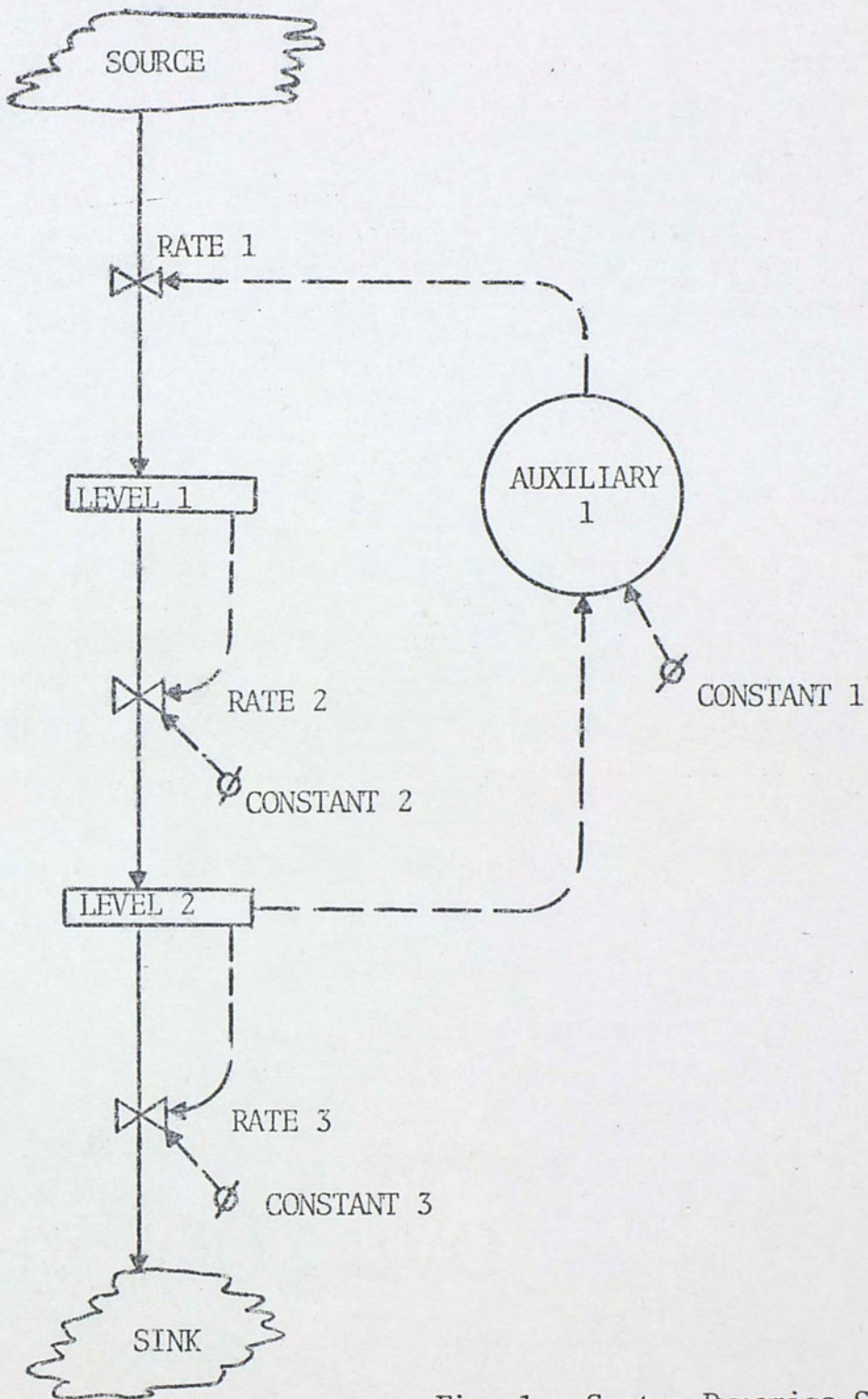
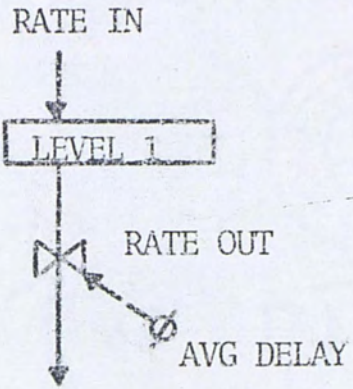
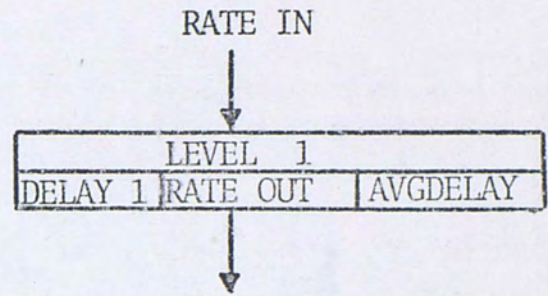


Fig. 1.--System Dynamics Schematic Example.

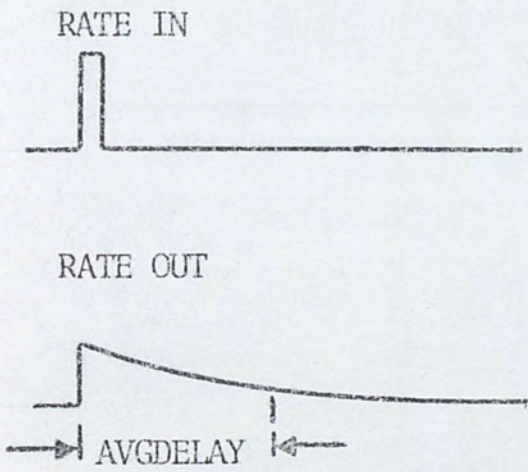
SCHEMATIC OF FIRST ORDER DELAY



ALTERNATE SCHEMATIC



RESPONSE TO IMPULSE INPUT



RESPONSE TO STEP INPUT

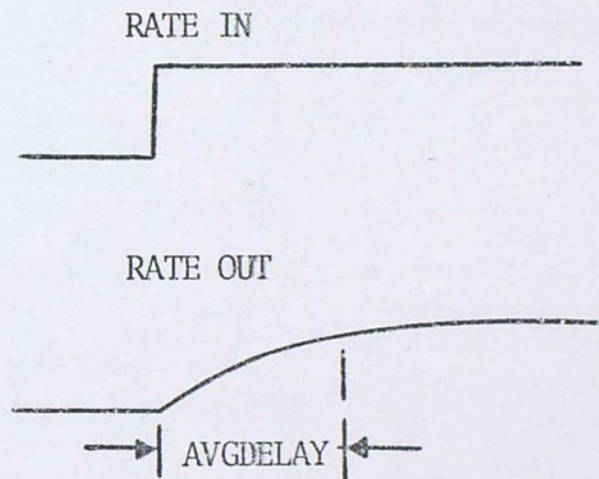
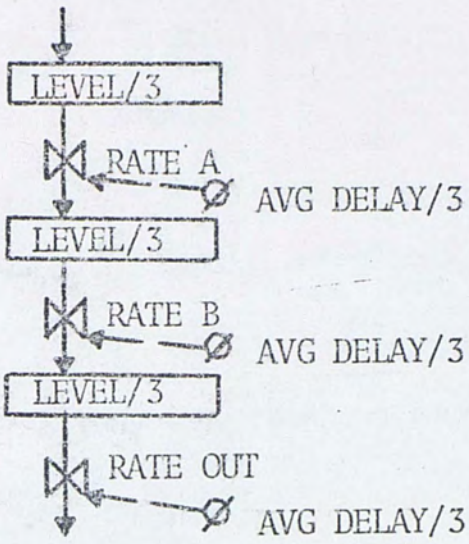
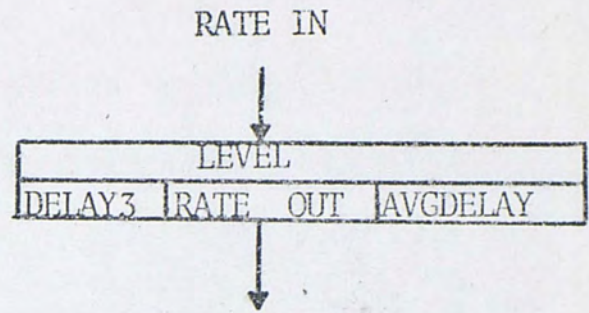


Fig. 2a.--The First Order Delay

SCHEMATIC OF THIRD ORDER DELAY



ALTERNATE SCHEMATIC



RESPONSE TO IMPULSE INPUT

RATE IN

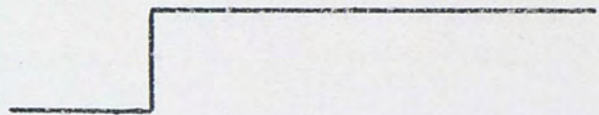


RATE OUT



RESPONSE TO STEP INPUT

RATE IN



RATE OUT

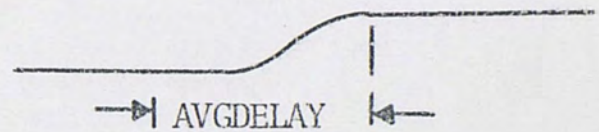


Fig. 2b.--The Third Order Delay

programming System Dynamics studies but which may be applied to any dynamic system simulation.¹⁶

Fundamental to any dynamic simulation technique is the numerical method of integration. Dynamo employs the simple Euler's Method of integration (rectangular integration). The stability and computational efficiency of rectangular integration are well suited to System Dynamics models which are characteristically not well defined. Because Dynamo employs only rectangular integration, the language may not be appropriate for simulating well-defined physical systems where high precision is meaningful and sometimes necessary.

Rectangular integration is defined as follows:

$$\text{If } y' = f(x,y)$$

$$\text{Then } y_{n+1} = y_n + hf(x,y).$$

To convert this definition into Dynamo, set:

$$y_{n+1} = Y.K \text{ (i.e., } Y \text{ at time } K)$$

$$y_n = Y.J \text{ (i.e., } Y \text{ at time } J)$$

$$h = DT$$

$$f(x,y) = \text{INPUT.JK} - \text{OUTPUT.JK}$$

(i.e., the difference between
input and output rates during
time interval J to K).

Then the Dynamo level (L) statement for integration is:

$$L \quad Y.K = Y.J + DT*(\text{INPUT.JK}-\text{OUTPUT.JK}).$$

To facilitate modeling, Dynamo includes trigonometric functions (such as SIN, LOG, EXP), value selection functions (such as MAX, MIN, TABLE), time triggered functions (such as PULSE, RAMP), random number generators, and built in macros (such as DELAY3 and SMOOTH). The Dynamo program includes extensive error analysis,

comprehensive error messages, and attempts to interpret errors to allow programs to run without resubmission.

CHAPTER III

DYNAMIC MODEL OF THE URBAN TRANSPORTATION SYSTEM

Applicability of the System Dynamics Approach

The urban transportation system is composed of two major sectors: the private automobile sector and the public transportation sector. The functional diagram, Figure 3, depicts the eleven functional blocks of the model. Blocks 2 through 6 describe the private automobile sector while blocks 7 through 11 describe the public transportation sector. Block 1 represents the commuter response to changes in the automobile and public transportation sectors.

Auto and transit demand computations are accomplished in block 1 representing the commuter response to changing auto commuting cost, auto commuting time, transit commuting cost, transit commuting time, and transit accessibility. Demand is computed in terms of peak hour auto and transit demand, total area auto ownership, and total monthly transit users.

Auto demand trends are projected in block 2 to allow planning new roads and evaluating user tax rates.

In block 3 projected peak hour demand is analyzed and construction of new roadway is initiated as required. The model considers construction rates and expected road life to continuously update statistics regarding roadway availability.

Roadway available and planned is compared with current and pro-

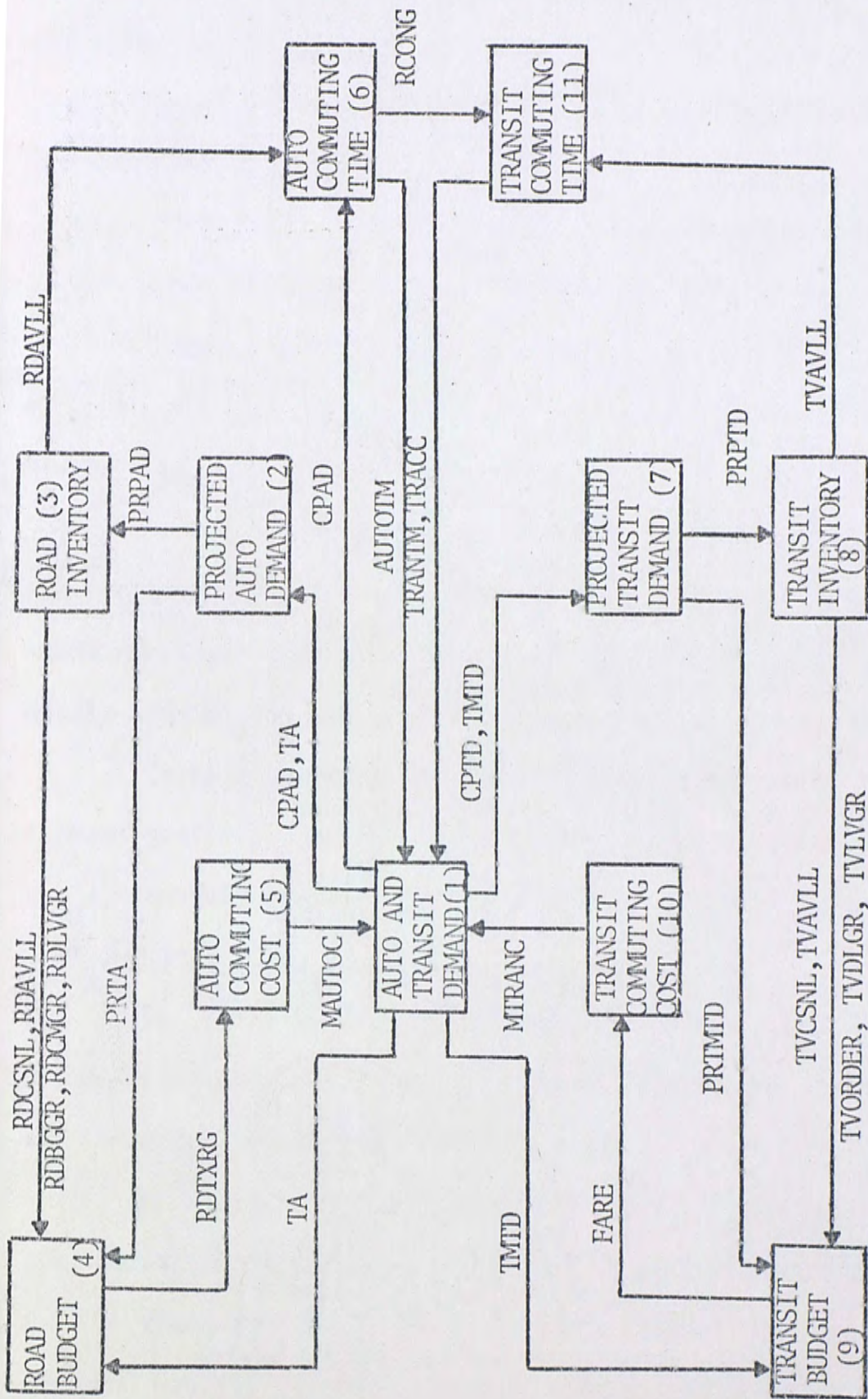


Fig.3.--Urban Transportation System Functional Diagram

jected auto ownership in block 4 to determine the required gasoline tax rate.

Fixed and variable costs associated with automobile commuting are compiled in block 5.

In block 6, auto demand and roadway availability are compared to determine the time required to commute by auto.

Transit demand trends are projected in block 7 to allow planning the purchase of new transit vehicles and evaluating the adequacy of the transit fare.

In block 8, the projected peak hour transit demand is analyzed and procurement of transit vehicles is initiated as required. The model considers procurement rate and expected vehicle life to continuously update statistics regarding transit vehicle availability.

Transit system projected costs are compared in block 9 with transit system projected income to determine the required transit fare.

Monthly transit commuting cost is computed from the transit fare in block 10.

In block 11, transit vehicle availability and road congestion are considered in determining the time required to commute by transit and the accessibility of transit.

By examination of Figure 3, it can be seen that the urban transportation system is a complex, multiloop feedback system involving the flow of assets. The prime objective of this study is to understand how the organization of the system affects performance and to evaluate alternative management policies. The description of the system and the objectives of the study are consistent with the capabili-

ties of the System Dynamics approach.

Detailed Description of the Model

Auto and Transit Demand, Block 1. - The design of this block is based on the postulate that demand for a particular transportation system is dependent on the cost, time, comfort and convenience of the system as compared with these same attributes for competing systems. To compute peak hour demands for two competitive transportation systems, private automobiles and public transit, let:

PAD = PEAK HOUR AUTO DEMAND
 PTD = PEAK HOUR TRANSIT DEMAND
 MAUTOC = MONTHLY AUTO USER COST
 MTRANC = MONTHLY TRANSIT USER COST
 AUTOTM = ONE WAY TIME FOR AUTO COMMUTER
 TRANM = ONE WAY TIME FOR TRANSIT COMMUTER
 ACOMFT = AUTO COMFORT
 TCOMFT = TRANSIT COMFORT
 ACONV = AUTO CONVENIENCE
 TCONV = TRANSIT CONVENIENCE

Then the equations for peak hour auto and transit demand are of the form:

$$PAD = f_1 (MAUTOC, MTRANC, AUTOTM, TRANM, ACONV, TCONV, ACOMFT, TCOMFT) \quad (1.1)$$

$$PTD = f_2 (MAUTOC, MTRANC, AUTOTM, TRANM, ACONV, TCONV, ACOMFT, TCOMFT) \quad (1.2)$$

Applying the chain rule for partial derivatives:

$$\begin{aligned} dPAD = & \frac{\partial PAD}{\partial MAUTOC} \frac{dMAUTOC}{dt} + \frac{\partial PAD}{\partial MTRANC} \frac{dMTRANC}{dt} + \frac{\partial PAD}{\partial AUTOTM} \frac{dAUTOTM}{dt} \\ & + \frac{\partial PAD}{\partial TRANM} \frac{dTRANM}{dt} + \frac{\partial PAD}{\partial ACOMFT} \frac{dACOMFT}{dt} + \frac{\partial PAD}{\partial TCOMFT} \frac{dTCOMFT}{dt} \\ & + \frac{\partial PAD}{\partial ACONV} \frac{dACONV}{dt} + \frac{\partial PAD}{\partial TCONV} \frac{dTCONV}{dt} \end{aligned} \quad (1.3)$$

$$\begin{aligned}
\frac{dPTD}{dt} = & \frac{\partial PTD}{\partial MAUTOC} \frac{dMAUTOC}{dt} + \frac{\partial PTD}{\partial MTRANC} \frac{dMTRANC}{dt} + \frac{\partial PTD}{\partial AUTOTM} \frac{dAUTOTM}{dt} \\
& + \frac{\partial PTD}{\partial TRANIM} \frac{dTRANIM}{dt} + \frac{\partial PTD}{\partial ACOMFT} \frac{dACOMFT}{dt} + \frac{\partial PTD}{\partial TCOMFT} \frac{dTCOMFT}{dt} \\
& + \frac{\partial PTD}{\partial ACONV} \frac{dACONV}{dt} + \frac{\partial PTD}{\partial TCONV} \frac{dTCONV}{dt}
\end{aligned} \tag{1.4}$$

Equations 1.3 and 1.4 may be further definitized by employment of the concept of demand elasticity. As applied to a travel demand model, demand elasticity represents the percent change in demand for a given system in response to a one percent change in one of the variables giving rise to the travel demand, assuming all other variables in the equation are held constant. Elasticities with respect to the variables for the subejct mode are called direct elasticities while elasticities with respect to the variables associated with competing modes are called cross elasticities. Mathematically, elasticity is defined as:

$$n_x = \frac{x}{n} \frac{\partial N}{\partial x}$$

where n_x is the elasticity of travel demand N with respect to variable x .¹⁷ Inverting the elasticity definition:

$$\frac{\partial N}{\partial x} = \frac{N}{x} n_x \tag{1.5}$$

This study assumes that auto and transit comfort and auto convenience are not varying with time. Transit convenience is represented by transit access time (TRACC). Applying equation 1.5 to equations 1.3 and 1.4:

$$\begin{aligned} \frac{dPAD}{dt} = & \frac{(PAD)(DE1)}{FMAUTOC} (MAUTOCC) + \frac{(PAD)(CE1)}{FMTRANC} (MTRANCC) \\ & + \frac{(PAD)(DE2)}{FAUTOTM} (AUTOTMC) + \frac{(PAD)(CE2)}{FTRANIM} (TRANIMC) \\ & + \frac{(PAD)(CE5)}{FTRACC} (TRACC) \end{aligned} \quad (1.6)$$

$$\begin{aligned} \frac{dPTD}{dt} = & \frac{(PTD)(CE3)}{FMAUTOC} (MAUTOCC) + \frac{(PTD)(DE3)}{FMTRANC} (MTRANCC) \\ & + \frac{(PTD)(CE4)}{FAUTOTM} (AUTOTMC) + \frac{(PTD)(DE4)}{FTRANIM} (TRANIMC) \\ & + \frac{(PTD)(DE5)}{FTRACC} (TRACC), \end{aligned} \quad (1.7)$$

where:

DE1 = ELASTICITY RELATING PAD TO MAUTOCC
 DE2 = ELASTICITY RELATING PAD TO AUTOTMC
 DE3 = ELASTICITY RELATING PTD TO MTRANCC
 DE4 = ELASTICITY RELATING PTD TO TRANIMC
 DE5 = ELASTICITY RELATING PTD TO TRACC
 CE1 = ELASTICITY RELATING PAD TO MTRANCC
 CE2 = ELASTICITY RELATING PAD TO TRANIMC
 CE3 = ELASTICITY RELATING PTD TO MAUTOCC
 CE4 = ELASTICITY RELATING PTD TO AUTOTMC
 CE5 = ELASTICITY RELATING PTD TO TRACC
 MAUTOCC = dMAUTOC/dt
 MTRANCC = dMTRANC/dt
 AUTOTMC = dAUTOTM/dt
 TRANIMC = dTRANIM/dt
 TRACC = dTRACC/dt
 FMAUTOC = MAUTOC PRIOR TO MAUTOCC
 FMTRANC = MTRANC PRIOR TO MTRANCC
 FAUTOTM = AUTOTM PRIOR TO AUTOTMC
 FTRANIM = TRANIM PRIOR TO TRANIMC
 FTRACC = TRACC PRIOR TO TRACC

Equations 1.6 and 1.7 may be programmed in Dynamo as follows:

NOTE BLOCK 1 PART 1

```
R MAUTOCC.KL=MAUTOC.K-FMAUTOC.K
L FMAUTOC.K=FMAUTOC.J+DT*MAUTOCC.JK
R AUTOTMC.KL=AUTOTM.K-FAUTOTM.K
L FAUTOTM.K=FAUTOTM.J+DT*AUTOTMC.JK
R MTRANCC.KL=MTRANC.K-FMTRANC.K
L FMTRANC.K=FMTRANC.J+DT*MTRANCC.JK
R TRANIMC.KL=TRANIM.K-FTRANIM.K
```



```

L  FTRANIM.K=FTRANIM.J+DT*TRANIMC.JK
R  TRACCC.KL=TRACC.K-FTRACC.K
L  FTRACC.K=FTRACC.J+DT*TRACCC.JK
A  ADCHNG1.K=PAD.K*DE1*MAUTOCC.JK/FMAUTOC.K
A  ADCHNG2.K=PAD.K*DE2*AUTOTMC.JK/FAUTOTM.K
A  ADCHNG3.K=PAD.K*CE1*MTRANCC.JK/FMTRANC.K
A  ADCHNG4.K=PAD.K*CE2*TRANIMC.JK/FTRANIM.K
A  ADCHNG5.K=PAD.K*CE5*TRACCC.JK/FTRACC.K
L  PAD.K=PAD.J+DT*(ADCHNG1.J+ADCHNG2.J+ADCHNG3.J +
X  ADCHNG4.J+ADCHNG5.J
A  TDCHNG1.K=PTD.K*DE3*MTRANCC.JK/FMTRANC.K
A  TDCHNG2.K=PTD.K*DE4*TRANIMC.JK/FTRANIM.K
A  TDCHNG3.K=PTD.K*DE5*TRACCC.JK/FTRACC.K
A  TDCHNG4.K=PTD.K*CE3*MAUTOCC.JK/FMAUTOC.K
A  TDCHNG5.K=PTD.K*CE4*AUTOTMC.JK/FAUTOTM.K
L  PTD.K=PTD.J+DT*(TDCHNG1.J+TDCHNG2.J+TDCHNG3.J +
X  TDCHNG4.J+TDCHNG5.J)

```

The block 1, part 1 Dynamo schematic is depicted in Figure 4.

The peak hour auto and transit demands computed in block 1, part 1, do not consider the effects of the urban area population trends. These effects are considered by the calculations in block 1, part 2.

Peak hour auto commuters (PAC) is determined as the product of the peak hour auto demand (PAD) and the average commuters per auto (ACPA). Then the total peak hour demand (uncorrected to reflect population trends) is given by the sum of peak transit demand (PTD) and peak hour auto commuters (PAC).

The peak hour transit fraction (PKHTRTF) is found by dividing peak hour transit demand (PTD) by the uncorrected total peak hour demand (TOTPHD). Similarly, the peak hour auto fraction (PKHRAF) is the quotient peak hour auto commuters (PAC) divided by TOTPHD.

The daily peak hour commuters in the modeled area is represented by the level PKHRCOM and the rate MCOMCR, the monthly commuter change rate which may be positive or negative. For this study, MCOMCR is modeled as a constant equal to MCMCRA, the monthly commuter change rate average.

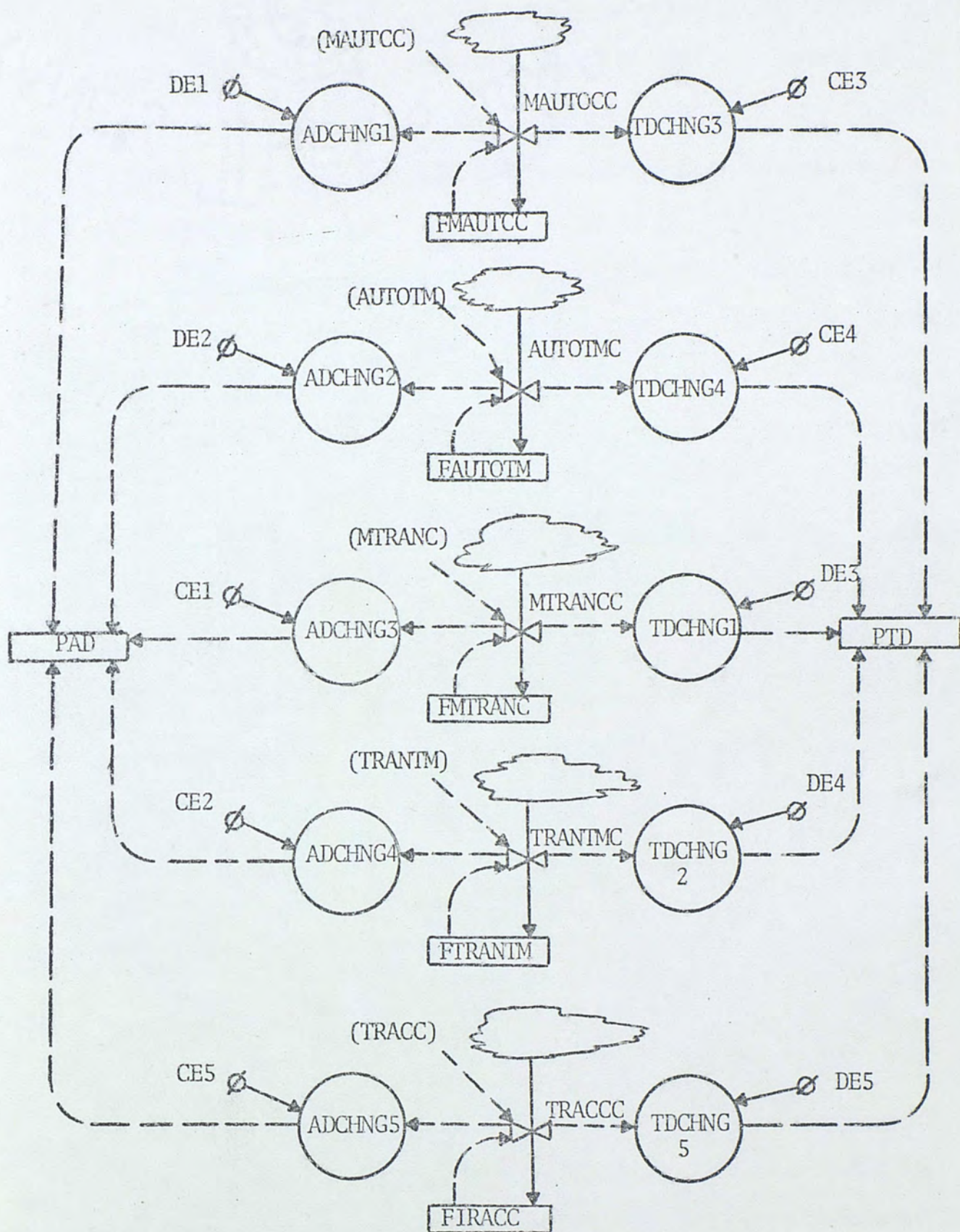


Fig. 4.--Auto and Transit Demand Block 1, Part 1

The corrected peak hour auto commuter total is determined as the product of the peak hour auto fraction (PKHRAF) and the total peak hour commuters (PKHRCOM). Similarly, the corrected peak hour transit demand (CPTD) is the product of PKHRCOM and the peak hour transit fraction (PKHRTRF).

The corrected peak hour auto demand (CPAD) is the quotient of corrected peak hour auto commuters (CPAC) divided by the average commuters per auto (ACPA). Total area autoownership (TA) is computed by dividing CPAD by the peak hour auto demand fraction (PADF) of the total area autos.

Total monthly transit demand (TMTD) is found as a function of corrected peak hour transit demand (CPTD) and the peak hour transit demand fraction (PTDF) of the total transit demand. The auto fraction (AUTOF) and transit fraction (TRANF) of peak hour commuters are determined from CPTD and CPAC. See Figure 5. The Dynamo coding is:

```

A  PAC.K=PAD.K*ACPA
A  TOTPHD.K=PAC.K+PTD.K
A  PKHRAF.K=PAC.K/TOTPHD.K
A  PKHRTRF.K=PTD.K/TOTPHD.K
L  PKHRCOM.K=PKHRCOM.J+DT*MCOMCR.JK
R  MCOMCR.KL=MCMCRA
A  CPAC.K=PKHRAF.K*PKHRCOM.K
A  CPAD.K=CPAC.K/ACPA
A  TA.K=CPAD.K/PADF
A  CPTD.K=PKHRTRF.K*PKHRCOM.K
A  TMTD.K=CPTD.K/PTDF
A  AUTOF.K=CPAC.K/(CPAC.K+CPTD.K)
A  TRANF.K=1-AUTOF.K

```

Projected Auto Demand, Block 2. - Projected auto demand is determined by: (1) computing the rate of change in peak hour auto demand; (2) exponentially smoothing the rate of change in peak hour auto demand; (3) determining the smoothed rate of change in total auto

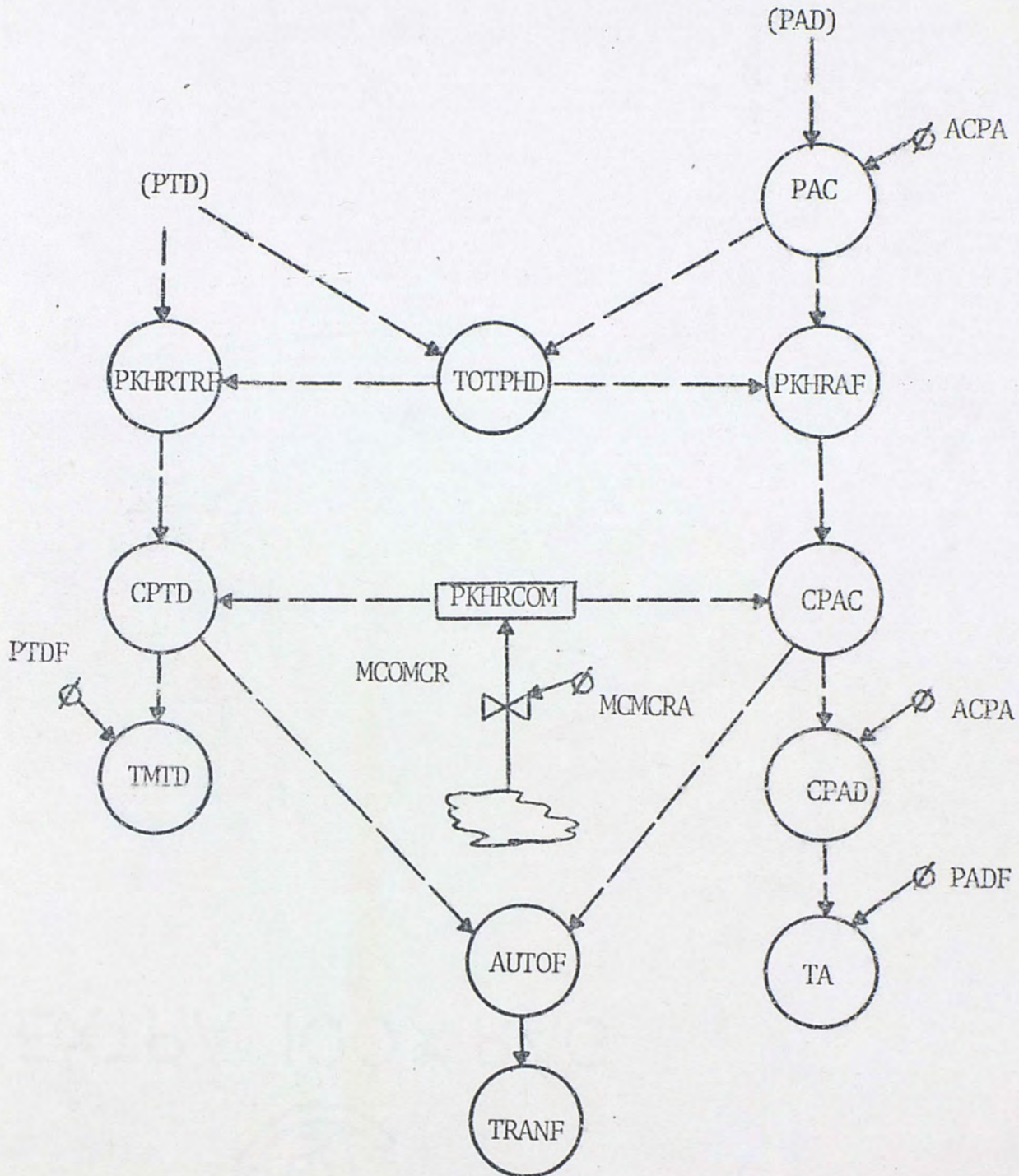


Fig. 5.--Auto and Transit Demand Block 1, Part 2

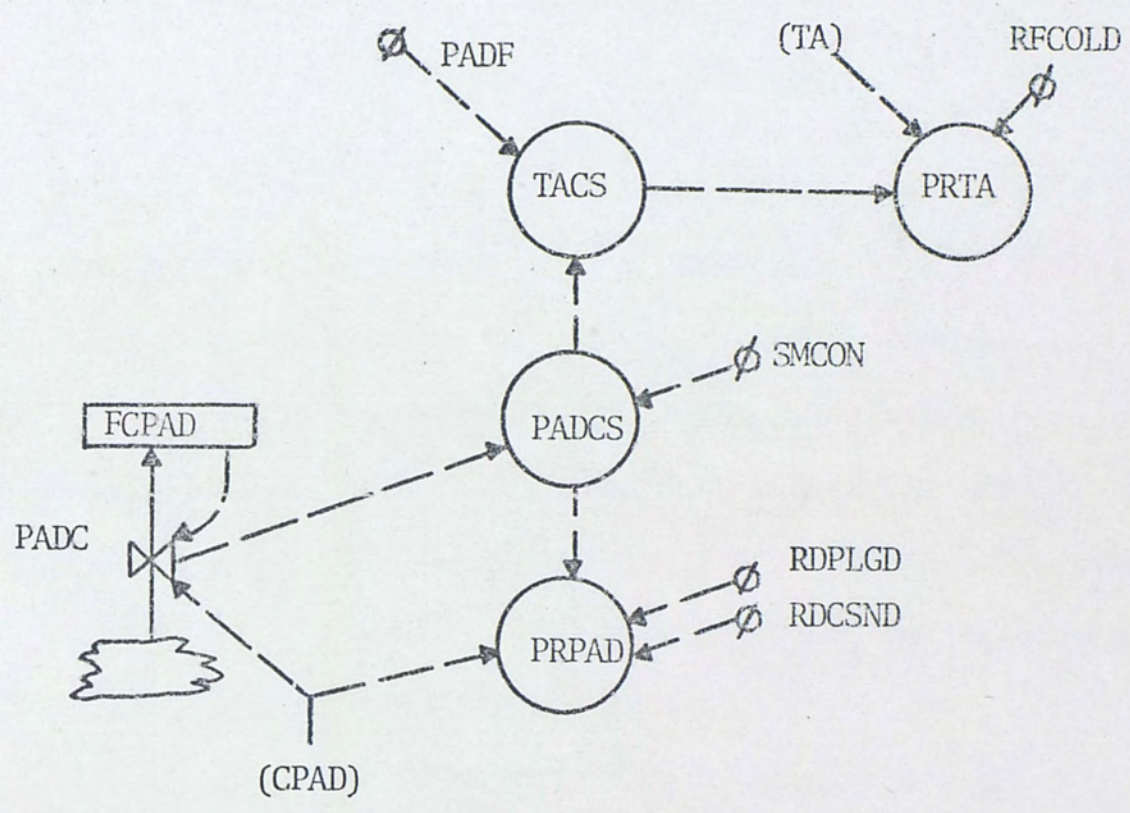


Fig. 6.--Projected Auto Demand, Block 2

ownership in the modeled area; (4) computing the projected peak hour auto demand; and (5) computing the projected total auto ownership.

In order that he may project future roadway needs, the manager must be aware of changes occurring in the peak hour auto demand. If CPAD is the corrected peak hour auto demand, and FCPAD is the former peak hour auto demand, then the change in auto demand, PADC, is determined by the following Dynamo statements:

```
R  PADC.KL=CPAD.K-FCPAD.K
L  FCPAD.K=FCPAD.J+DT*PADC.JK
```

The flow rates in socioeconomic systems are often irregular. However, management actions must respond smoothly. Exponential smoothing is employed in the model to facilitate smooth management responses. Smoothing is a method of interpreting a series of irregular past information values to determine the significant underlying trends. Exponential smoothing assigns progressively less weight to older information values. If T is the smoothing time constant, the exponential average of the data points S is given by:

$$\text{Exponential Avg.} = \frac{1}{T} (S_1 + (1 - \frac{1}{T}) S_2 + \dots + (1 - \frac{1}{T})^n S_{n+1})$$

In planning the amount of new roadway which must be constructed, management will normally attempt to perceive the underlying trend in peak hour auto demand rather than reacting only to the latest data. This attempt to react to the underlying trend is represented by employing the exponential smoothing macro provided by the Dynamo language. If PADC is the peak hour auto demand change and SMCON is the smoothing time constant, then the smoothed peak hour auto demand change, PADCS, is given by:

```
A  PADCS.K=SMOOTH(PADC.JK,SMCON)
```


Then, if PADF is the peak hour auto demand fraction of the total area autos, the smoothed change in total auto ownership, TACS, is given by:

$$A \quad TACS.K = PADCS.K / PADF$$

In planning the amount of new roadway which must be constructed, management must estimate the future peak hour auto demand. The model represents this projection by multiplying the smoothed monthly change in auto demand, PADCS, by the number of months in the planning horizon and adding this product to the corrected peak hour auto demand, CPAD. In this model, the planning horizon is taken to be the sum of the average time required to plan new roadway (RDPLGD) and the average time required to construct new roadway (RDCSND). The Dynamo statement for the projected peak hour auto demand, PRPAD, is:

$$A \quad PRPAD.K = CPAD.K + (RDPLGD + RDCSND) (PADCS.K)$$

In determining the appropriate user tax rates, the manager must estimate the future total auto ownership in the area. The model represents this projection by multiplying the smoothed monthly change in auto ownership, TACS, by the number of months in the planning horizon and adding this product to the current total auto ownership, TA. In this model the tax rate planning horizon is chosen to be the average time required for taxes collected to progress from the collection point (gasoline service station) to the account for roads, RFDCOLD. The Dynamo statement for the projected total auto ownership, PRTA, is:

$$A \quad PRTA.K = TA.K + RFDCOLD * TACS.K$$

Road Inventory, Block 3. - Block 3 represents the planning, construction, availability and scrapping of major roads. Major roads are defined as expressways, highways, arterials and central business

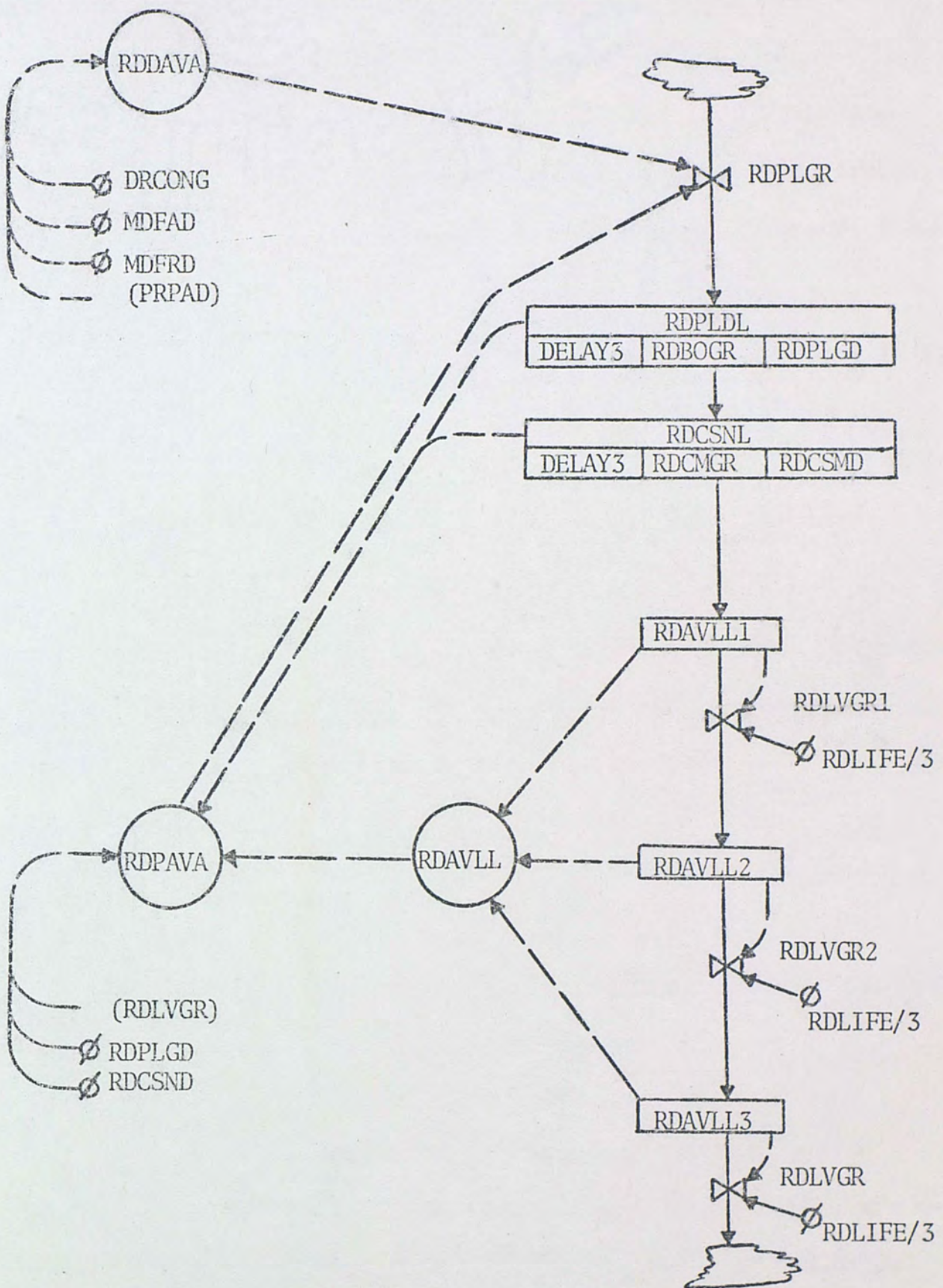


Fig. 7.--Road Inventory Block 3

district streets.

Road planning is accomplished by comparing the projected availability of roads with the projected demand for roads. If RDPAVA is the projected availability of roads and RDDAVA is the desired availability of roads, then the rate at which new roadway is planned, RDPLGR, is:

$$\begin{aligned} \text{RDPLGR} &= \text{RDDAVA} - \text{RDPAVA} && \text{If } \text{RDDAVA} > \text{RDPAVA} \\ &= 0 && \text{If } \text{RDDAVA} \leq \text{RDPAVA} \end{aligned} \quad (3.1)$$

The Dynamo language MACRO "CLIP" accomplishes the function described by equation 3.1 in the following statement:

```
R RDPLGR.KL=CLIP(RDDAVA.K-RDPAVA.K,0,RDDAVA.K,RDPAVA.K)
```

Road construction will begin an average of RDPLGD (the road planning delay) months after the planning decision is made. The road beginning rate, RDBGGR, response to the road planning rate input, RDPLGR, is represented as a third order delay as follows:

```
R RDBGGR.KL=DELAY3(RDPLGR.JK,RDPLGD)
```

Roadway will be completed an average of RDCSND (the road construction delay) months after construction is begun. The road completing rate, RDCMGR, response to the road beginning rate input, RDBGGR, is represented as a third order delay as follows:

```
R RDCMGR.KL=DELAY3(RDBGGR.JK,RDCSND)
```

The amount of roadway planned but not under construction (RDPLDL) and the amount of roadway under construction (RDCSNL) are determined by integrating the difference between the input and output rates:

```
L RDPLDL.K=RDPLDL.J+DT*(RDPLGR.JK-RDBGGR.JK)
L RDCSNL.K=RDCSNL.J+DT*(RDBGGR.JK-RDCMGR.JK)
```


Roadway will be scrapped an average of RDLIFE (the expected life of roadway) months after construction is completed. The rate of scrapping roadway, RDLVGR, response to the road completing rate (RDCMGR) input is represented as a third order delay. In this case the model includes the explicit Dynamo statements comprising a third order delay to allow the user the opportunity to apportion the initial roadway availability among (1) lane-miles of roadway available in the first third of the expected road life (RDAVLL1), (2) lane-miles of roadway available in the second third of expected road life (RDAVLL2), and (3) lane-miles of roadway available in the final third of expected road life (RDAVLL3). If RDLVGR1, RDLVGR2, and RDLVGR are the rates at which roadway completes the first, second, and final thirds, respectively, of the expected life, then:

```

L  RDAVLL1.K=RDAVLL1.J+DT*(RDCMGR.JK-RDLVGR1.JK)
R  RDLVGR1.KL=RDAVLL1.K/(RDLIFE/3)
L  RDAVLL2.K=RDAVLL2.J+DT*(RDLVGR1.JK-RDLVGR2.JK)
R  RDLVGR2.KL=RDAVLL2.K/(RDLIFE/3)
L  RDAVLL3.K=RDAVLL3.J+DT*(RDLVGR2.JK-RDLVGR.JK)
R  RDLVGR.KL=RDAVLL3.K/(RDLIFE/3)

```

and, the total roadway available, RDAVLL, is:

```

A  RDAVLL.K=RDAVLL1.K+RDAVLL2.K+RDAVLL3.K

```

The projected availability of roads, RDPAVA, is determined in the model for a planning horizon equal to the total time required to plan and construct new roadway (RDPLGD+RDCSND):

```

A  RDPAVA.K=RDAVLL.K+RDCSNL.K+RDPLDL.K-(RDPLGD+RDCSND)
X  *RDLVGR.JK)

```

The desired future availability of roads, RDDAVA, is based upon the projection of peak hour auto demand, PRPAD, and the management desired degree of road congestion, DRCONG, in peak hour autos per lane-

mile. If MDFAD is the fraction of the peak hour auto demand moving in the major direction of flow, and MDFRD is the fraction of the available roadway carrying peak hour traffic in the major direction, then:

$$A \quad RDDAVA.K = (MDFAD * PRPAD.K) / (MDFRD * DRCONG)$$

Road Budget, Block 4. - The modeling accomplished in Block 4 consists of (1) determining the rate at which road funds are collected and received, (2) determining the rate at which road funds are committed and expended, and (3) determining the auto user tax rate.

Funds for roads are collected from two sources: receipts from users, MRURPT, and receipts from non-user sources, MNRURPT. If RFDDIVF is the fraction of MRURPT diverted for other than road uses, then the Dynamo statement defining the road fund collection rate (RFDCOLR) is:

$$R \quad RFDCOLR.KL = MRURPT.K * (1 - RFDDIVF) + MNRURPT.K$$

The time lag between collection of funds for roads and the receipt of the funds at a central point for disbursement is represented by a first order delay with an average delay time of RFDCOLD months. If RFDDUEL is the level of road funds which have been collected but not received at the central receiving point and if RFDRPTR is the rate at which collected funds are received at the central receiving point, then the appropriate Dynamo statements are:

$$L \quad RFDDUEL.K = RFDDUEL.J + DT * (RFDCOLR.JK - RFDRPTR.JK)$$

$$R \quad RFDRPTR.KL = RFDDUEL.K / RFDCOLD$$

Road fund commitments are divided into two general categories: roadway total monthly operation and maintenance costs (RDTMOM) and road-

way total monthly capital outlay (RDTMCO)* RDTMOM is given by the sum of the products of the categories of roadway availability and the corresponding unit monthly operating and maintenance costs:

$$\begin{aligned} A \quad RDTMOM.K &= RD1UMOM * RDAVLL1.K + RD2UMOM * RDAVLL2.K + \\ X \quad RD3UMOM &* RDAVLL3.K \end{aligned}$$

RDTMCO is determined as a function of the cost of roadway per lane mile, the amount of roadway constructed or under construction, and the capital recovery factor for roads. Cost of roadway per land mile is a function of population density.¹⁸ Population is modeled as a multiple of total peak hour commuters. If POP is the population of the modeled area, PKHRCOM is the total number of peak hour commuters, and PHCPOPR is the ratio of peak hour commuters to population, then:

$$A \quad POP.K = PKHRCOM.K / PHCPOPR$$

If AREA is the total land area served by the modeled network, and POPDENS is the population density, then:

$$A \quad POPDENS.K = POP.K / AREA$$

If the cost of roadway per lane mile in an unpopulated area is MNCRPLM and the increase in unit cost per unit increase in population density is CRPLMRI then the cost of roadway per lane mile (CRPLM) is given by:

$$A \quad CRPLM.K = MNCRPLM + CRPLMRI * POPDENS.K$$

The monthly capital outlay for major roads is computed using the annual

* The model makes the assumption that costs associated with major roads (expressways, highways, arterials and central business district streets) are primarily supported through user tax collections (MRURPT) at the local, state and federal levels. Inclusion of non-user receipts (MNURPT) is representative of the reality that some roads in the modeled network may be supported by property taxes or other non-user sources. Inclusion of the road fund diverted fraction (RFDDIVF) allows for the diversion of user receipts to other applications such as maintaining shoulders, subsidy of mass transit, or support of rural highways.

cost method¹⁹ modified for monthly cost. If RDAVLL is the roadway available, RDCSNL is the roadway under construction, CRFR is the annual capital recovery factor for constructing roads (based on the prevailing interest rate and expected road life), then:

$$A \quad RDTMCO.K = (RDAVLL.K + RDSCNL.K) * CRPLM.K * (CRFR/12)$$

The rate at which road funds are committed (RFDCOMR) is given by the sum:

$$R \quad RFDCOMR.KL = RDTMOM.K + RDTMCO.K$$

The amount of road funds (RFDL) which have been received at the central receiving point but which have not been committed is given by:

$$L \quad RFDL.K = RFDL.J + DT * (RFDPRTR.JK - RFDCOMR.JK)$$

The time lag between commitment of road funds and the expenditure of those funds is represented by a first order delay with an average delay time of RFDEXPD months. If RFDEXPR is the rate at which road funds are expended, and if RFDCMDL is the amount of funds which have been committed but not expended, then:

$$L \quad RFDCMDL.K = RFDCMDL.J + DT * (RFDCOMR.JK - RFDEXPR.JK)$$

$$R \quad RFDEXPR.KL = RFDCMDL.K / RFDEXPD$$

Determination of the appropriate road user tax rate requires (1) projecting the future levels of roadway availability and roadway under construction, (2) estimating the future monthly costs of operation and maintenance and of capital outlay, (3) estimating the future monthly road revenue requirement, (4) apportioning the revenue requirement between user and non-user sources, and (5) determining the portion of the revenue requirement to be born by each auto based on the projected total automobile ownership. The planning horizon selected for use in this model is equal to the road fund collection delay, RFDCOLD.

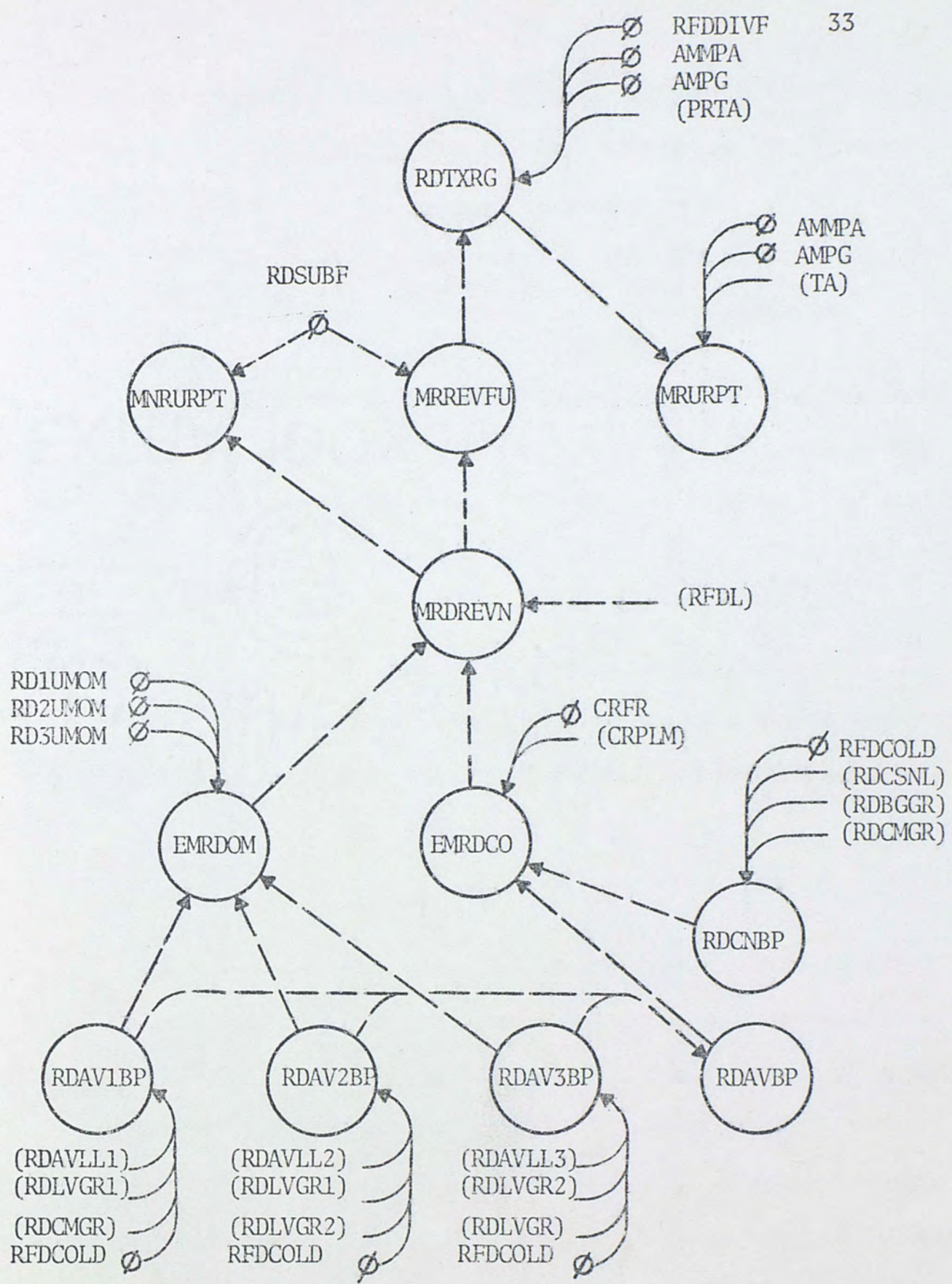


Fig. 9.--Road Budget Block 4, Part 2

The budgetary prediction of roadway availability (RDAVBP) for the planning horizon RFDCOLD is a function of roadway availability, roadway completing rate, and roadway attrition rate:

$$\begin{aligned} A \quad RDAV1BP.K &= RDAVLL1.K + RFDCOLD * (RDCMGR.JK - RDLVGR1.JK) \\ A \quad RDAV2BP.K &= RDAVLL2.K + RFDCOLD * (RDLVGR1.JK - RDLVGR2.JK) \\ A \quad RDAV3BP.K &= RDAVLL3.K + RFDCOLD * (RDLVGR2.JK - RDLVGR.JK) \\ A \quad RDAVBP.K &= RDAV1BP.K + RDAV2BP.K + RDAV3BP.K \end{aligned}$$

The budgetary prediction of roadway under construction (RDCNBP) for the planning horizon RFDCOLD is determined as a function of the current roadway construction level (RDCSNL), the rate at which roadway is being constructed (RDCMGR), and the rate at which new construction is begun (RDBGGR):

$$A \quad RDCNBP.K = RDCSNL.K + RFDCOLD * (RDBGGR.JK - RDCMGR.JK)$$

The estimated monthly road operating and maintenance costs (EMRDOM) is the sum of the products of RDAViBP and RD_iUMOM where i = 1,2,3 depending on the road age category:

$$\begin{aligned} A \quad EMRDOM.K &= RD1UMOM * RDAV1BP.K + RD2UMOM * RDAV2BP.K + \\ X \quad &RD3UMOM * RDAV3BP.K \end{aligned}$$

The estimated monthly road capital outlay (EMRDCO) is determined in the same manner as RDTMCO except that roadway availability is replaced by RDAVBP and roadway under construction is replaced by RDCNBP:

$$A \quad EMRDCO.K = (RDAVBP.K + RDCNBP.K) * CRPLM.K * (CRFR/12)$$

The monthly road revenue needed (MRDREVN) is determined from the estimated monthly road capital outlay, the estimated monthly road operating and maintenance cost, and the current road fund level.

$$A \quad MRDREVN.K = EMRDCO.K + EMRDOM.K - RFDL.K$$

If RDSUBF is the fraction of roadway revenue requirements to be satisfied by other than road user taxes, then the monthly road re-

venue required from users (MRREVFU) is given by:

$$A \text{ MRREVFU.K} = (1 - \text{RDSUBF}) * \text{MRDREVN.K}$$

and the monthly non-user receipts (MNRURPT) is:

$$A \text{ MNRURPT.K} = \text{RDSUBF} * \text{MRDREVN.K}$$

Road user taxes are represented exclusively in the model by state and federal gasoline taxes (The U.S. Department of Transportation, Highway Statistics 1970, tabulation of federal revenue from auto user taxes indicates that a total of \$3,809,203,000 was collected in 1970, of which \$3,611,445,000 was attributed to federal gasoline taxes.).²⁰ The road tax rate per gallon (RDTXRG) is determined as a function of the monthly revenue required from users (MRREVFU), the average monthly miles per auto (AMMPA), the average miles per gallon (AMPG), the projected total auto ownership (PRTA), and the fraction of the road funds which will be diverted for other uses (RFDDIVF):

$$A \text{ RDTXRG.K} = (\text{MRREVFU.K} * \text{AMPG}) / ((\text{PRTA.K} * \text{AMMPA}) * (1 - \text{RFDDIVF}))$$

The monthly road user receipts for the current month (MRURPT) is modeled as a function of the road tax rate (RDTXRG), the current total auto ownership (TA), the average monthly miles per auto (AMMPA), and the average miles per gallon of gasoline (AMPG). The Dynamo statement is:

$$A \text{ MRURPT.K} = \text{RDTXRG.K} * \text{TA.K} * (\text{AMMPA} / \text{AMPG})$$

Auto Commuting Cost, Block 5. - The only auto commuting cost variable intrinsically determined by the model is the road tax rate per gallon (RDTXRG). All other factors contributing to the monthly auto commuting cost are represented as constants (which may of course be varied by the user of the model). Factors included in computing

the monthly auto commuting cost are: one-way commuter trips per month (COMTPM), average one-way commuting distance (COMDIS), auto maintenance cost per mile (AMTM), auto gas and oil cost per gallon of gasoline (AGSOILG), auto miles per gallon of gasoline (AMPG), auto insurance cost per mile (AINSURM), auto parking and tolls cost per mile (APKTLSM), auto capital outlay per mile (ACOPM), and auto commuters per auto (ACPA). If MAUTOC is the monthly auto commuting cost, then:

$$\begin{aligned} A \quad & \text{MAUTOC.K} = (\text{COMTPM} * \text{COMDIS}) * (\text{AMTM} * (\text{AGSOILG} / \text{AMPG}) + \text{AINSURM} + \\ X \quad & \text{APKTLSM} + \text{ACOPM} + (\text{RDTXRG.K} / \text{AMPG})) / \text{ACPA} \end{aligned}$$

Auto Commuting Time, Block 6. - Auto commuting time, AUTOTM,

is the peak hour auto line-haul time in minutes per mile. AUTOTM is the reciprocal of the peak hour auto speed, ASPEED. ASPEED is determined as a function of the peak hour road congestion, RCONG. If CPAD is the corrected peak hour auto demand, RDAVLL is the total lane-miles of roadway available, MDFAD is the fraction of peak hour auto demand traveling in the major direction, and MDFRD is the fraction of available roadway available for traffic traveling in the major direction, then:²¹

$$\begin{aligned} A \quad & \text{RCONG.K} = (\text{MDFAD} * \text{CPAD.K}) / (\text{MDFRD} * \text{RDAVLL.K}) \\ A \quad & \text{ASPEED.K} = 45 - 0.375 * \text{RCONG.K} \\ A \quad & \text{AUTOTM.K} = 60 / \text{ASPEED.K} \end{aligned}$$

Projected Transit Demand, Block 7. - Projected transit demand

is determined by: (1) computing the rate of change in peak hour transit demand; (2) exponentially smoothing the rate of change in peak hour demand; (3) determining the smoothed rate of change in total monthly transit demand in the modeled area; (4) computing the projected peak hour transit demand; and (5) computing the projected total monthly transit demand.

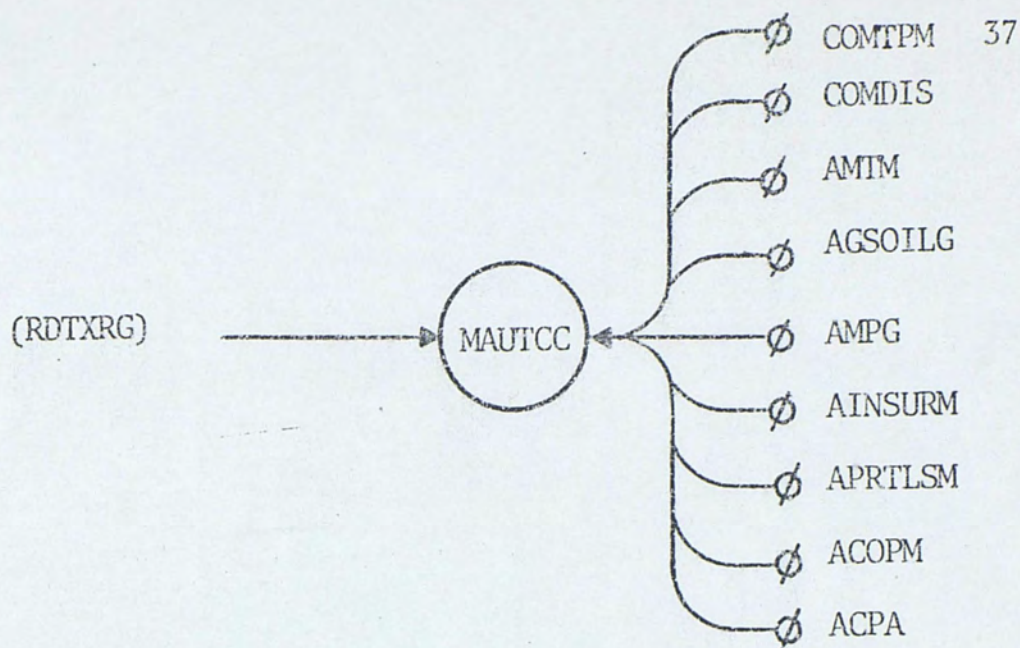


Fig.10.--Auto Commuting Cost Block 5

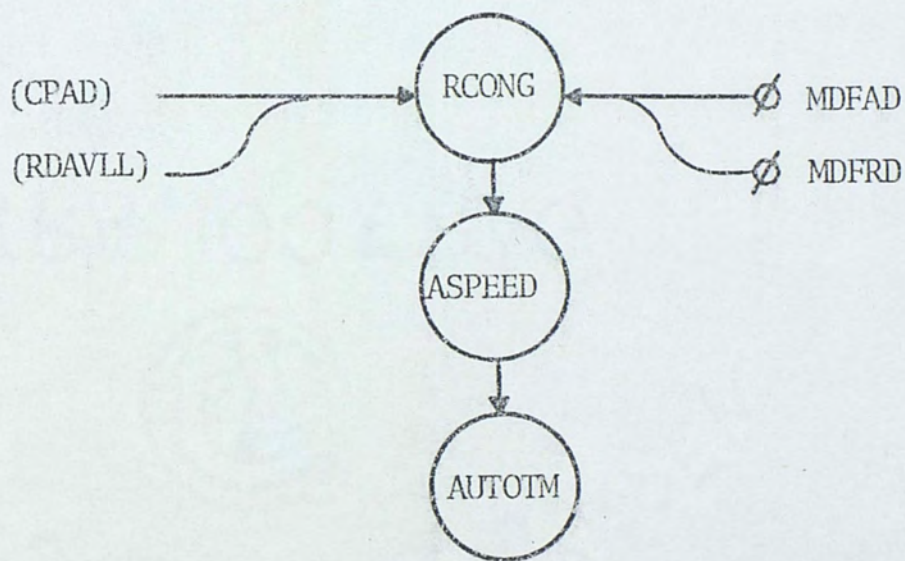


Fig.11.--Auto Commuting Time Block 6

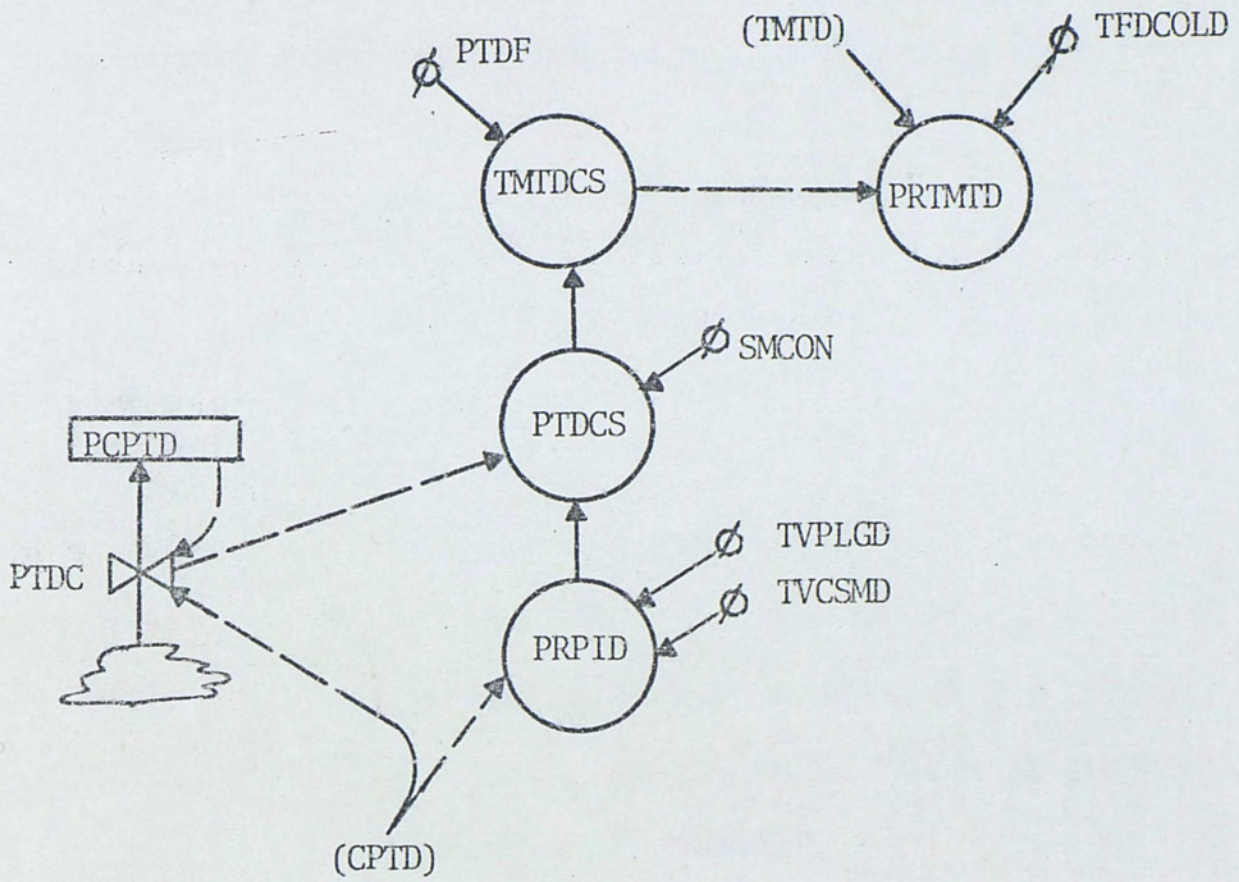


Fig.12.--Projected Transit Demand Block 7

In order that he may project future transit vehicle needs, the manager must be aware of changes occurring in the peak hour transit demand. If CPTD is the corrected peak hour transit demand, and FCPTD is the former corrected peak hour demand, then the change in transit demand, PTDC, is:

$$\begin{aligned} R \quad PTDC.KL &= CPTD.K - FCPTD.K \\ L \quad FCPTD.K &= FCPTD.J + DT * PTDC.JK \end{aligned}$$

In planning the number of new transit vehicles which must be ordered, management will normally attempt to perceive the underlying trend in peak hour transit demand rather than reacting only to the latest data. This attempt is represented by employing the exponential smoothing macro provided by the Dynamo language. If PTDC is the peak hour transit demand change and SMCON is the smoothing time constant, then the smoothed peak hour transit demand change, PTDCS, is given by:

$$A \quad PTDCS.K = SMOOTH(PTDC.JK, SMCON)$$

Then, if PTDF is the peak hour transit demand fraction of total monthly transit demand, the smoothed change in total monthly transit demand, TMTDCS, is given by:

$$A \quad TMTDCS.K = PTDCS.K / PTDF$$

To determine the number of new transit vehicles required, the projected peak hour transit demand, PRPTD, is determined by multiplying the smoothed change in peak hour transit demand, PTDCS, by the number of months in the planning horizon and adding this product to the corrected peak hour transit demand, CPTD. In this model, the planning horizon is taken to be the sum of the average time required to plan purchase of new transit vehicles (TVPLGD) and the average elapsed time between ordering and delivery (TVCSND). The Dynamo statement for the

projected peak hour transit demand, PRPTD, is:

$$A \quad PRPTD.K = CPTD.K + (TVPLGD + TVCSND) (PTDCS.K)$$

In determining the appropriate transit fare, the manager must estimate the future total monthly transit demand in the modeled area. This projection is determined by multiplying the smoothed monthly change in total monthly transit demand, TMTDCS, by the number of months in the planning horizon and adding this product to the current total monthly transit demand, TMTD. In this model, the transit fare planning horizon is chosen to be the average time required for fare receipts to be credited to the operating account, TFDCOLD. The Dynamo statement for the projected total monthly transit demand, PRMTD, is:

$$A \quad PRMTD.K = TMTD.K + TFDCOLD * TMTDCS.K$$

Transit Vehicle Inventory, Block 8. - Block 8 represents the planning, construction, availability, and scrapping of transit vehicles.

Transit vehicle planning is accomplished by comparing the projected availability of transit vehicles with the projected demand for transit vehicles. If TVPAVA is the projected availability of transit vehicles and TVDAVA is the desired availability of transit vehicles, then the rate at which new transit vehicles are planned, TVPLGR, is:

$$R \quad TVPLGR.KL = CLIP(TVDAVA.K - TVPAVA.K, 0, TVDAVA.K, TVPAVA.K)$$

Transit vehicle construction will begin an average of TVPLGD (the transit vehicle planning delay) months after the planning decision is made. The transit vehicle ordering rate, TVORDER, response to the transit vehicle planning rate input, TVPLGR, is represented as a third order delay:

$$R \quad TVORDER.KL = DELAY3(TVPLGR.JK, TVPLGD)$$

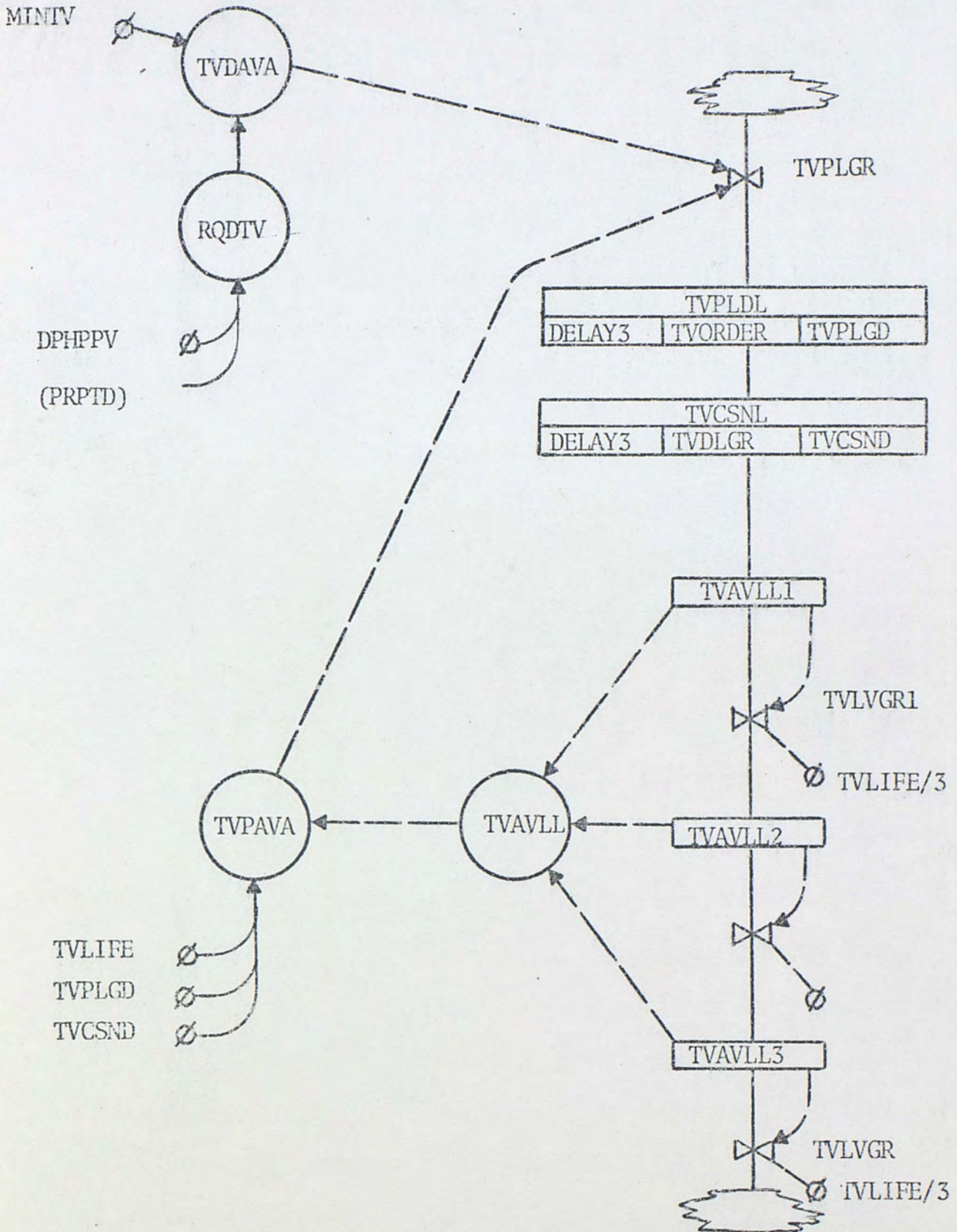


Fig.13.--Transit Vehicle Inventory Block 8

Transit vehicles will be delivered an average of TVCSND (the transit vehicle construction delay) months after ordering. The transit vehicle delivering rate, TVDLGR, response to the transit vehicle ordering rate input, TVORDER, is represented as a third order delay:

$$R \quad TVDLGR.KL = \text{DELAY3}(TVORDER.JK, TVCSND)$$

The number of transit vehicles planned but not yet ordered (TVPLDL) and the number of transit vehicles ordered but not yet delivered (TVCSNL) are determined by integrating the difference between the input and output rates:

$$\begin{aligned} L \quad TVPLDL.K &= TVPLDL.J + DT * (TVPLGR.JK - TVORDER.JK) \\ L \quad TVCSNL.K &= TVCSNL.J + DT * (TVORDER.JK - TVDLGR.JK) \end{aligned}$$

Transit vehicles will be scrapped an average of TVLIFE (the expected life of transit vehicles) months after delivery. The rate of scrapping transit vehicles, TVLVGR, response to the transit vehicle delivering rate, TVDLGR, is represented as a third order delay. In this case the model includes the explicit Dynamo statements for a third order delay rather than the macro to allow the user the opportunity to apportion the initial transit vehicle availability among (1) number of transit vehicles available in the first third of the expected vehicle life (TVAVLL1), (2) number of transit vehicles available in the second third of expected vehicle life (TVAVLL2), and (3) number of transit vehicles available in final third of expected road life (TVAVLL3). If TVLVGR1, TVLVGR2, and TVLVGR are the rates at which vehicles complete the first, second, and their segments, respectively, the expected vehicle life, then:

$$\begin{aligned} L \quad TVAVLL1.K &= TVAVLL1.J + DT * (TVDLGR.JK - TVLVGR1.JK) \\ R \quad TVLVGR1.KL &= TVAVLL1.K / (TVLIFE / 3) \\ L \quad TVAVLL2.K &= TVAVLL2.J + DT * (TVLVGR1.JK - TVLVGR2.JK) \end{aligned}$$

$$\begin{aligned} R \quad & \text{TVLVGR.2KL} = \text{TVAVLL2.K} / (\text{TVLIFE} / 3) \\ L \quad & \text{TVAVLL3.K} = \text{TVAVLL3.J} + \text{DT} * (\text{TVLVGR2.JK} - \text{TVLVGR.JK}) \end{aligned}$$

and the total vehicles available, TVAVLL, is:

$$A \quad \text{TVAVLL.K} = \text{TVAVLL1.K} + \text{TVAVLL2.K} + \text{TVAVLL3.K}$$

The projected availability of transit vehicles, TVPAVA, is determined in the model for a planning horizon equal to the total time required to plan and construct new transit vehicles (TVPLGD+TVCSND).

$$\begin{aligned} A \quad & \text{TVPAVA.K} = \text{TVAVLL.K} + \text{TVCSNL.K} + \text{TVPLDL.K} - ((\text{TVPLGD} + \text{TVCSND}) \\ X \quad & * \text{TVLVGR.JK}) \end{aligned}$$

The desired future availability of transit vehicles, TVDAVA, is the larger of required transit vehicles (RQDTV) or minimum transit vehicles (MINTV). RQDTV is a function of projected peak hour transit demand (PRPTD) and the desired peak hour passengers per transit vehicle (DPHPPV):

$$\begin{aligned} A \quad & \text{RQDTV.K} = \text{PRPTD.K} / \text{DPHPPV} \\ A \quad & \text{TVDAVA.K} = \text{MAX}(\text{RQDTV.K}, \text{MINTV}) \end{aligned}$$

Transit Budget, Block 9. - The modeling accomplished in Block 9 consists of (1) determining the rate at which transit funds are collected and received, (2) determining the rate at which transit funds are committed and expended, and (3) determining the transit fare.

Funds for transit are collected from two sources: receipts from users, MIURPT, and monthly transit subsidy receipts, MTSBRPT. The transit fund collection rate, TFDCOLR, is given by:

$$R \quad \text{TFDCOLR.KL} = \text{MIURPT.K} + \text{MTSBRPT.K}$$

The time lag between collection of funds for transit and the crediting of funds to the operating account is represented by a first order delay with an average delay time of TFDCOLD. If TFDDUEL is the level of transit funds which have been collected but not credited and

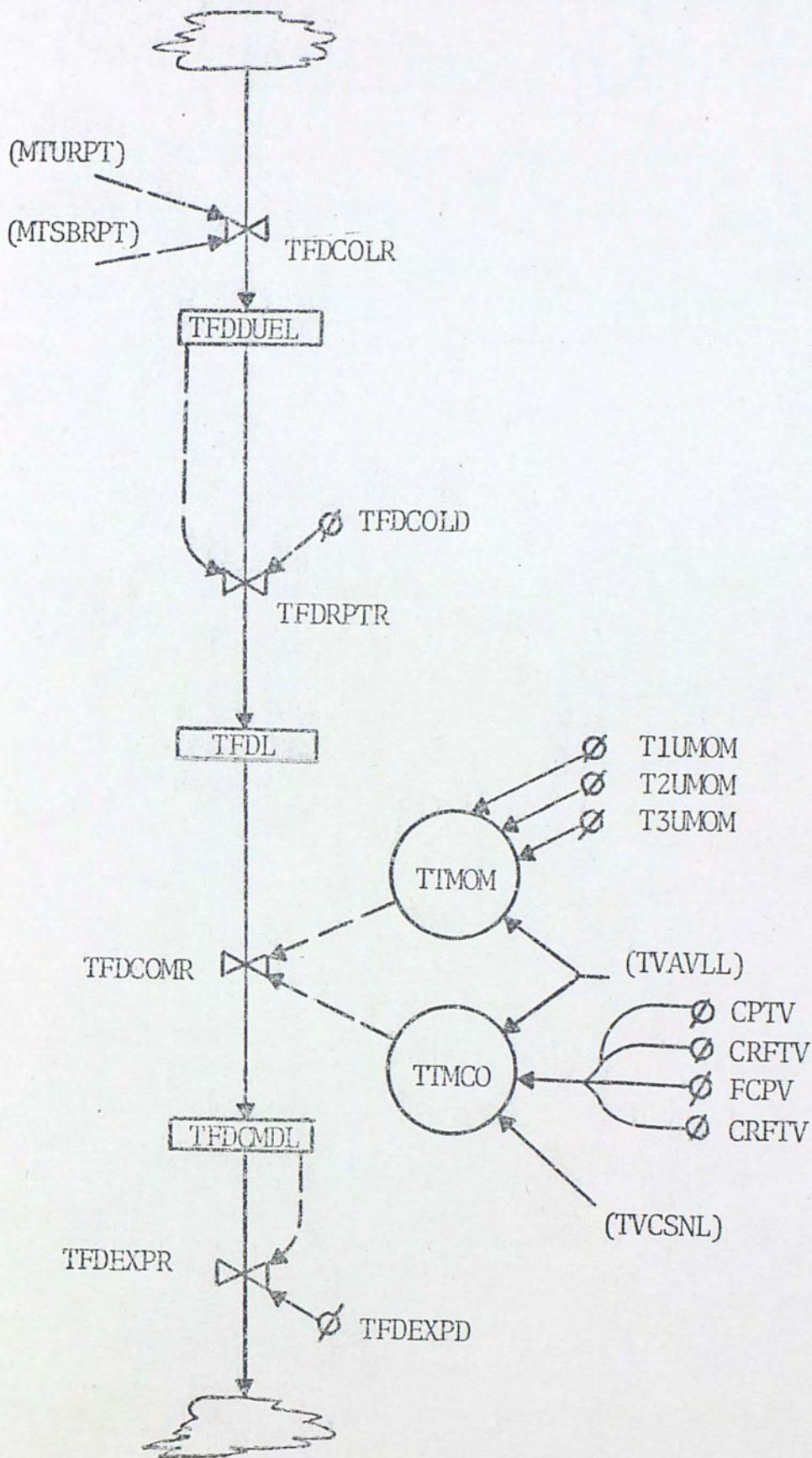


Fig. 14.--Transit Budget, Block 9, Part 1

if TFDRPTR is the rate at which transit funds are credited, then:

$$\begin{aligned} \text{L } \text{TFDDUEL.K} &= \text{TFDDUEL.J} + \text{DT} * (\text{TFDCOLR.JK} - \text{TFDRPTR.JK}) \\ \text{R } \text{TFDRPTR.KL} &= \text{TFDDUEL.K} / \text{TFDCOLD} \end{aligned}$$

Transit fund commitments are divided into two general categories:

transit total monthly operation and maintenance costs (TIMOM) and transit total monthly capital outlay (TTCMO). TIMOM is given by the sum of the products of the categories of transit vehicle availability and the corresponding unit monthly operating and maintenance costs:

$$\begin{aligned} \text{A } \text{TIMOM.K} &= \text{T1UMOM} * \text{TVAVLL1.K} + \text{T2UMOM} * \text{TVAVLL2.K} + \\ \text{X } \text{T3UMOM} &* \text{TVAVLL3.K} \end{aligned}$$

TTCMO is determined as a function of the cost of a single transit vehicle (CPTV), the number of vehicles available (TVAVLL), the number of vehicles on order (TVCSNL), the capital recovery factor for transit vehicles (CRFTV), the facility cost per vehicle (FCPV), and the capital recovery factor for transit facilities (CRFTF):

$$\begin{aligned} \text{A } \text{TTCMO.K} &= (\text{TVAVLL.K} + \text{TVCSNL.K}) * (((\text{CPTV} * \text{CRFTV}) / 12) + \\ \text{X } &((\text{FCPV} * \text{CRFTF}) / 12)) \end{aligned}$$

The given rate at which transit funds are committed, TFDCOMR, is given by the sum:

$$\text{R } \text{TFDCOMR.KL} = \text{TIMOM.K} + \text{TTCMO.K}$$

The amount of transit funds (TFDL) which have been credited to the transit account but which have not yet been committed is given by:

$$\text{L } \text{TFDL.K} = \text{TFDL.J} + \text{DT} * (\text{TFDRPTR.KL} - \text{TFDCOMR.JK})$$

The time lag between commitment of transit funds and the expenditure of those funds is represented by a first order delay with an average delay time of TFDEXPD months. If TFDEXPR is the rate at which transit funds are expended, and if RFDCMDL is the amount of funds which

have been committed but not expended, then:

$$\begin{aligned} L \quad TFDCMDL.K &= TFDCMDL.J + DT * (TFDCOMR.JK - TFDEXPR.JK) \\ R \quad TFDEXPR.KL &= TFDCMDL.K / TFDEXPD \end{aligned}$$

Determination of the appropriate transit fare requires (1) projecting the future levels of transit vehicle availability and transit vehicles on order, (2) estimating the future monthly costs of operation and maintenance and for capital outlay, (3) estimating the future transit revenue requirement, (4) determining the portion of transit revenue needs which will be subsidized, and (5) determination of the necessary transit fare. The planning horizon selected for use in this portion of the model is equal to the transit fund collection delay, TFDCOLD.

The budgetary prediction of transit vehicle availability (TVAVBP) for the planning horizon TFDCOLD is a function of transit vehicle availability, transit vehicle delivery rate, and transit vehicle attrition rate:

$$\begin{aligned} A \quad TVAV1BP.K &= TVAVLL1.K + TFDCOLD * (TVDLGR.JK - TVLVGR1.JK) \\ A \quad TVAV2BP.K &= TVAVLL2.K + TFDCOLD * (TVLVGR1.JK - TVLVGR2.JK) \\ A \quad TVAV3BP.K &= TVAVLL3.K + TFDCOLD * (TVLVGR2.JK - TVLVGR.JK) \\ A \quad TVAVBP.K &= TVAV1BP.K + TVAV2BP.K + TVAV3BP.K \end{aligned}$$

The budgetary prediction of transit vehicles on order (TVCNBP) is determined as a function of the current number of transit vehicles on order (TVCSNL), the rate at which new vehicles are being delivered (TVDLGR), and the rate at which new vehicles are ordered (TVORDER):

$$A \quad TVCNBP.K = TVCSNL.K + TVCOLD * (TVORDER.JK - TVDLGR.JK)$$

The estimated monthly transit operating and maintenance costs (EMTOM) is the sum of the products of TVAViBP and TiUMOM where $i = 1, 2, 3$ depending on the vehicle age group:

$$\begin{aligned} &A \text{ EMTOM.K} = T1UMOM * TVAV1BP.K + T2UMOM * TVAV2BP.K + \\ &X \text{ T3UMOM} * TVAV3BP.K \end{aligned}$$

The estimated monthly transit capital outlay (EMTCO) is determined in the same manner as TTMCO except that vehicle availability is replaced by TVAVBP and vehicles on order is replaced by TVCNBP:

$$\begin{aligned} &A \text{ EMTCO.K} = (TVAVBP.K + TVCNBP.K) * (((CPTV * CRFTV) / 12) + \\ &X ((FCPV * CRFTF) / 12)) \end{aligned}$$

The monthly transit revenue needed (MTREVN) is determined from the estimated monthly transit capital outlay (EMTCO), the estimated monthly transit operating and maintenance cost (EMTOM), and the current transit fund level (TFDL):

$$A \text{ MTREVN.K} = \text{EMTCO.K} + \text{EMTOM.K} - \text{TFDL.K}$$

If TCOSBF is the fraction of the transit capital outlay supported by subsidy and if TOMSBF is the fraction of the transit operating and maintenance costs supported by subsidy, then the monthly transit subsidy receipts* (MTSBRPT) is determined by:

$$A \text{ MTSBRPT.K} = \text{TCOSBF} * \text{EMTCO.K} + \text{TOMSBF} * \text{EMTOM.K}$$

Then the monthly transit revenue required from users, MTREVFU, is given by:

$$A \text{ MTREVFU.K} = \text{MTREVN.K} - \text{MTSBRPT.K}$$

If PRIMTD is the projected total monthly transit demand, then the required fare, FARE, is the quotient:

$$A \text{ FARE.K} = \text{MTREVFU.K} / \text{PRIMTD.K}$$

Completing the feedback loop in this block of the model, the monthly transit user receipts (MTURPT) are now computed as the product

* The model assumes that predicted monthly transit subsidy receipts are satisfied by actual monthly transit subsidy receipts.

of the transit fare and the current total monthly transit demand (TMTD):

$$A \quad MTURPT.K = FARE.K * TMTD.K$$

Transit Commuting Cost, Block 10. - The monthly line-haul cost of commuting by transit is determined as the product of transit fare (FARE) and one-way commuter trips per month (COMTPM). If MTRANC is the monthly transit cost, then:

$$A \quad MTRANC.K = COMTPM * FARE.K$$

Transit Commuting Time, Block 11. - Transit commuting time is determined in two components: the transit line-haul time in minutes per mile and the accessibility of transit in the modeled area.

Transit line-haul speed is determined as a function of road congestion, RCONG. The maximum transit line-haul speed, with no road congestion, is selected to be 25 miles per hour. The Dynamo expression for transit speed, TSPEED, is programmed as a switch function so that the user may decouple the transit speed from road congestion (to simulate rapid transit conditions). If RTRAN is set to zero, transit speed is coupled with road congestion. If RTRAN is set to one, then TSPEED is the preset rapid transit speed, RTSPEED:*

$$A \quad TSPEED.K = SWITCH(25 - 0.375 * RCONG.K, RTSPEED, RTRAN)$$

The transit line-haul time (TRANM) in minutes per mile is the reciprocal of TSPEED multiplied by 60 minutes per hour:

$$A \quad TRANM.K = 60 / TSPEED.K$$

Transit service (TRANS) is determined as the product of the number of transit vehicles available (TVAVLL) and the average daily

* This approximation is based on the form of the ASPEED equation modified to reflect slower speeds associated with transit modes which share streets with auto traffic.



Fig. 16.--Transit Commuting Cost, Block 10

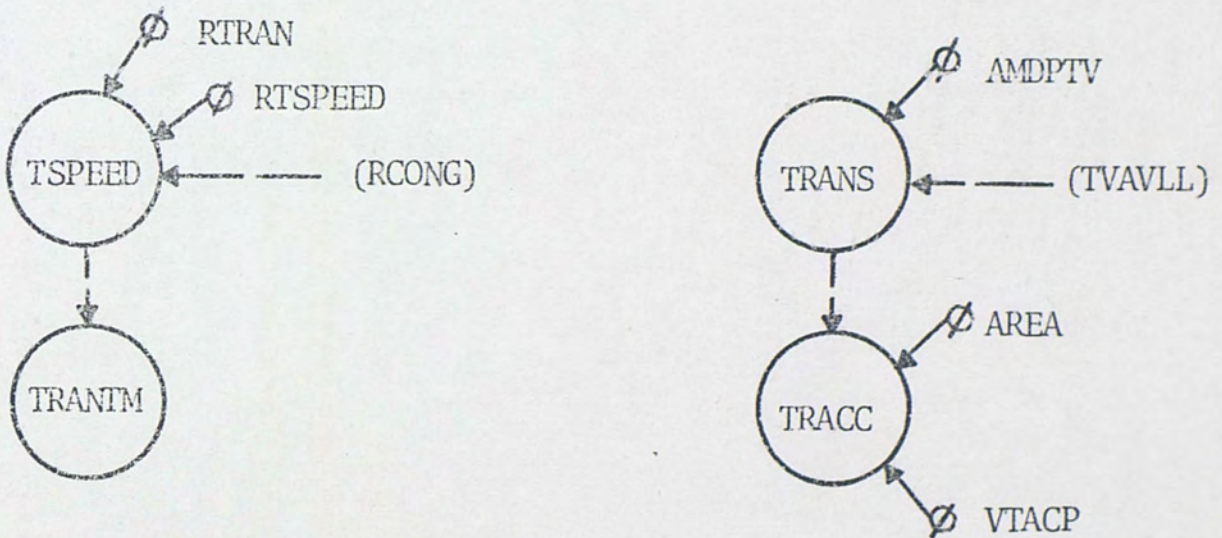


Fig. 17.--Transit Commuting Time, Block 11

miles per transit vehicle:

$$A \quad TRANS.K = TVAVLL.K * AMDPTV$$

The transit access time (TRACC) is inversely proportional to the transit service in bus-miles (TRANS) and directly proportional to the size of the service area (AREA). If the value selected for the transit access constant of proportionality is VTACP, then:

$$A \quad TRACC.K = (VTACP * AREA) / TRANS.K$$

Model Feedback. - Having computed new values of auto commuting time, auto commuting cost, transit commuting time, transit commuting cost, and transit access time, the model returns to Block 1 to determine new values of auto demand and transit demand.

CHAPTER IV

VALIDATION OF THE DYNAMO MODEL, RESULTS OF SIMULATION, AND ANALYSIS OF POLICIES

This chapter describes the selection of constants and initial conditions for the model, describes model behavior under varying conditions, describes simulation experiments under varying management policies and presents an analysis of the result of the experiments.

Validation of the Model

The model was validated by (1) surveying the literature to determine appropriate values for model constants, (2) collecting available data from Orange County, Florida, for initial conditions, (3) running the model under steady state conditions, and (4) comparing the results of the steady state simulation with observed results and results which might reasonably expected when current conditions are projected over the twenty year simulation period.

Selection of Constants. - A survey of the literature was conducted to determine realistic, nominal values of all constants in the private automobile sector and the public transportation sector. The results of the literature survey are described below.

The concept of employing demand elasticity in the transportation model was taken from Free Transit.²² The values for the direct elasticities and cross elasticities were taken from the same

source. Given the following definitions:

- DE1 = Direct elasticity relating peak hour auto demand to the change in monthly auto cost
- DE2 = Direct elasticity relating peak hour auto demand to the change in one-way auto commuter time
- DE3 = Direct elasticity relating peak hour transit demand to the change in monthly transit cost
- DE4 = Direct elasticity relating peak hour transit demand to the change in one-way transit commuter line-haul time
- DE5 = Direct elasticity relating peak hour transit demand to the change in transit access time
- CE1 = Cross elasticity relating peak hour auto demand to the change in monthly transit cost
- CE2 = Cross elasticity relating peak hour auto demand to the change in one-way transit commuter line-haul time
- CE3 = Cross elasticity relating peak hour transit demand to the change in monthly auto commuting cost
- CE4 = Cross elasticity relating peak hour transit demand to the change in one-way auto commuting time
- CE5 = Cross elasticity relating peak hour auto demand to the change in transit access time,

Then:

- C DE1 = -0.5
- C DE2 = -0.8
- C DE3 = -0.1
- C DE4 = -0.4
- C DE5 = -0.7
- C CE1 = 0.1
- C CE2 = 0.1
- C CE3 = 0.1
- C CE4 = 0.1
- C CE5 = 0.1

The number of auto commuters per commuter auto (ACPA) has typically been estimated about 1.6:²³

$$C \text{ ACPA} = 1.6$$

The National Academy of Engineering in 1972 reprinted statistics gathered between 1959 and 1962 in five major cities indicating that the percentage of daily volume during the maximum peak hour varies between seven and 13 percent.²⁴ Statistics gathered in the Orange County, Florida, area indicate an approximate equivalency between total daily traffic volume and total auto registration.²⁵ Based on these data, the model assigns a value of 0.10 to PADF, the peak hour auto demand fraction of total autos:

$$C \text{ PADF} = 0.10$$

The National Academy of Engineering statistics also reflect that during the 1959 to 1962 period the percentage of daily transit volume in Washington, D.C., during the maximum peak hour was 16 percent of the daily volume.²⁶ Based on this figure, the peak hour transit demand fraction of monthly transit demand (PTDF) is estimated to be 0.006:

$$C \text{ PTDF} = 0.006.$$

The statistics reprinted by the National Academy of Engineering indicate that the percentage of auto traffic flow in the minor direction during the maximum rush hour varied from 36.3 percent to 42.6 percent.²⁷ Thus, the fraction of auto demand traveling in the major direction (MDFAD) is estimated to be 0.60:

$$C \text{ MDFAD} = 0.60.$$

The fraction of available roadway available for traffic traveling in the major direction is normally 0.5. This factor could be varied by management decisions to designate one-way streets:

$$C \text{ MDFRD} = 0.5.$$

The Highway Research Board's Highway Capacity Manual²⁸

includes traffic speed-density relationship charts indicating that a density factor of 30 vehicles/mile/lane is a desirable design goal. To allow steady stability of the model, the desired road congestion is computed to be equal to the road congestion computed for the initial conditions:

$$N \text{ DRCONG} = \text{RCONG}.$$

Winfrey²⁹ states: "Since it often takes up to 10 years with 2 to 5 years most common, to move a project from its planning stage through design, right-of-way procurements, and construction, a program of construction needs to be not less than 3 years in advance and often up to 10 years." Based on Winfrey's statement, a road planning horizon of three years has been selected for the model, with the road planning delay (RDPLGD) set to 12 months and the road construction delay (RDCSND) set to 24 months:

$$\begin{aligned} C \text{ RDPLGD} &= 12 \\ C \text{ RDCSND} &= 24 \end{aligned}$$

Ritter and Paquette³⁰ write: "The period of time to be used for the computation of annual costs for each element of (roadway) capital expenditure is a matter for decision by the agency involved. Many organizations use a time of 50 or 60 years for right-of-way costs and 40 years for costs of grading, drainage, and structures. For structures a period of 20 years is frequently used." Because the model aggregates the elements of roadway capital expenditure, a road life (RDLIFE) figure of 30 years (360 months) is used in the model:

$$C \text{ RDLIFE} = 360.$$

The road fund collection delay (RFDCOLD) and the road fund expenditure delay (RFDEXPD) were estimated to be three months each:

$$\begin{aligned} C \text{ RFDCOLD} &= 3 \\ C \text{ RFDEXPD} &= 3 \end{aligned}$$

The ratio of peak hour commuters to total population was derived from estimated 1970 statistics gathered for Orange County, Florida. Orange County auto registration is 224,067.³¹ Having derived $PADF = 0.10$, the peak hour auto demand is 22,407. The auto commuters per auto has been approximated at 1.6. Therefore peak hour auto commuters are 35,851. Recent Orange County Transit Authority statistics indicate a daily ridership of about 7500. Using the approximation that 16 percent of the daily ridership occurs during the maximum peak hour, peak hour transit commuters are 1200 and total peak hour commuters are about 37050. The 1970 population of Orange County was 393,100.³² Thus the peak hour commuters to population ratio is 0.092:

$$C \text{ PHCPOPR} = 0.092.$$

About half of the federal gas taxes paid in Florida are not applied to Florida roads.³³ It is estimated that half the state four cent highway tax and one cent secondary road tax go to rural areas. It is also assumed that the three cent Florida gasoline tax for support of local streets and roads is distributed 50 percent for roads included in the modeled roadway network with the remaining 50 percent for roads and streets not modeled or for other uses.

$$C \text{ RFDDIVF} = 0.5.$$

Typical 1965 costs for roadway operation and maintenance averaged about \$130 per lane-mile per month.³⁴ The model uses this

\$130 figure for roads 0 to ten years old, and increases the cost by about 25 percent for each additional ten years of road life.

C RD1UMOM = 130
 C RD2UMOM = 160
 C RD3UMOM = 200

The rate of interest attributed to roadway capital outlay has been variously figured from zero to eight percent. A figure of seven percent has been selected for use in the model. Given a road life of 30 years the capital recovery factor for roads is 0.08059.³⁵

C CRFR = 0.08059.

A portion of the modeled network includes the central business district streets which generally are not supported through users taxes but rather through property taxes. That fraction of the road revenue required which is derived from other than user tax sources is termed the road subsid fraction (RDSUBF) and has been estimated at five percent:

C RDSUBF = 0.05.

The model assumption is that commuters travel to and from work an average of 20 times per month. That is, the one-way commuter trips per month (COMTPM) is set to 40:

C COMTPM = 40.

The structure of the model requires selection of an average commuting distance for the commuter choosing his transportation mode. A figure of ten miles, one way, was arbitrarily chosen.

C COMDIS = 10.

A 1972 study by the Federal Highway Administration³⁶ of the estimated average cost, in cents per mile, of operating a standard

size 1972 automobile over ten years and 100,000 miles in Baltimore suburbs served as the data base for the elements of automobile cost.

The automobile cost elements included in the model are as follows:

AMTM	Auto-maintenance cost per mile
AGSOILG	Average cost of gas and oil per gallon of gas
AINSURM	Average insurance cost per mile of driving
APKTLSM	Average parking and tolls cost per mile driven
ACOPM	Average capital outlay per mile of driving

The values inserted for each of these constants are:

C	AMTM	=	0.026
C	AGSOILG	=	0.21
C	AINSURM	=	0.014
C	APKTLSM	=	0.018
C	ACOPM	=	0.044

In order to allow experiments involving changes in AGSOILG, an initial value (AGSOILI) and a final value (AGSOILF) are specified:

C	AGSOILI	=	0.21
C	AGSOILF	=	0.21

Then, in subsequent runs, the value of AGSOILF may be varied. To facilitate the experiment, AGSOILG is expressed as a variable which is stepped twelve months into the simulation:

A	AGSOILG.K	=	AGSOILI + STEP (AGSINC.K,12)
A	AGSINC.K	=	AGSOILF - AGSOILI.

A typical auto miles per gallon figure of 10 was selected and monthly miles per auto, based on 10,000 miles per year, is 833:

C	AMPG	=	10
C	AMMPA	=	833

The minimum level of transit service is set equal to the normal weekday service provided by the Orange County, Florida, Transit Authority, which is the service provided by 33 buses:

$$C \text{ MINTV} = 33$$

The desired peak hour passengers per vehicle (DPHPV) is selected to be equal to the number of seats per transit vehicle. The new Orange County, Florida, buses seat 43.

$$C \text{ DPHPV} = 43.$$

The average daily miles per transit vehicle (AMDPTV) is based on statistics from the Orange County, Florida, Transit Authority, which is 150 miles (apportioning the total mileage over the 27 routes and the 6 back-up buses).

$$C \text{ AMDPTV} = 150.$$

The transit vehicle planning delay (TVPLGD) is chosen to be representative of the time required to prepare specifications, solicit bids, evaluate bids, complete negotiations, and award a transit vehicle procurement contract. For standard transit vehicles, a reasonable figure for the TVPLGD is chosen to be six months:

$$C \text{ TVPLGD} = 6.$$

When the Orange County, Florida, Transit Authority awarded a contract for 33 new buses in December, 1972, the transit vehicle construction delay (TVCSND) was nine months:

$$C \text{ TVCSND} = 9.$$

Selection of an expected transit vehicle life (TVLIFE) is based on the figure selected by Domencich and Kraft,³⁷ who chose a figure of 12 years (144 months). Choosing a six percent interest rate, Domencich and Kraft applied a capital recovery factor for transit vehicles (CRFTV) of 0.11928. Domencich and Kraft found that the average facility cost per transit vehicle (FCPV) is \$4500. Assuming a facility

life of 40 years and an interest rate of six percent, Domencich and Kraft derived a capital recovery factor for transit facilities (CRFTF) of 0.06646:

C	TVLIFE	=	144
C	CRFTV	=	0.11928
C	FCPV	=	4500
C	CRFTF	=	0.06646

The Orange County, Florida, Transit Authority have paid approximately \$39,000 per bus in 1973:

C CPTV = 39000.

The transit fund collection delay (TFDCOLD), representing the time lag between collecting fares on the individual vehicle and crediting the collections to the transit account was selected to be the minimum delay possible with a one-month update rate; that is, one month:

C TFDCOLD = 1.

The transit fund expenditure delay (TFDEXPD); that is, the average time elapsed between committing transit funds and expending transit funds, was estimated to be three months:

C TFDEXPD = 3.

The 1969 monthly transit operating and maintenance cost averaged about \$1500.³⁸ The model assumes current costs range from \$2125 to \$3050 depending on the vehicle age:

C	T1UMOM	=	2125
C	T2UMOM	=	2540
C	T3UMOM	=	3050.

Orange County, Florida, subsidizes the local transit system about six cents per passenger. Since the fare charged is thirty cents,

and since all capital outlay has been subsidized by various Government levels, the transit operation and maintenance subsidy fraction is $6/36 = 0.167$ and the transit capital outlay subsidy fraction is 1. To allow experiments involving changes in the transit operating and maintenance subsidy fraction (TOMSBF) and the transit capital outlay subsidy fraction (TCOSBF), initial and final values are provided with a switch at 12 months into the simulation:

```

A TOMSBF.K = TOMSBFI + STEP (TOMSBFC.K,12)
A TOMSBFC.K = TOMSBFF - TOMSBFI
C TOMSBFI = 0.167
C TOMSBFF = 0.167
A TCOSBF.K = TCOSBFI + STEP (TCOSBFC.K,12)
A TCOSBFC.K = TCOSBFF - TCOSBFI
C TCOSBFI = 1.00
C TCOSBFF = 1.00

```

To allow for an experiment involving express bus lanes, instituted by stepping RTRAN at month 12, the rapid transit speed (RTSPEED) is selected to be 30 miles per hour:

```

A RTRAN.K = RTRANI + STEP (RTRANF,12)
C RTRANI = 0
C RTRANF = 0
C RTSPEED = 0

```

The value of the transit access constant of proportionality (VTACP) was selected to be 53.17 so that the initial value of transit access time will be ten minutes:

```

C VTACP = 53.17.

```

The area included in the model is 900 square miles:

```

C AREA = 900.

```

Current projections indicated Orange County will grow by 1500 persons per month during the next ten years.³⁹ We have previously determined that the ratio of peak hour commuters to total population

is 0.091. Thus the average monthly change rate in numbers of peak hour commuters (MCMCRA) is 1500 times $0.092 = 138$.

C MCMCRA = 138.

The smoothing constant chosen for use in the model is six months and the update rate of the simulation is once every month:

C SMCON = 6

C DT = 1.

Statistics from 1963⁴⁰ indicate that the minimum cost of roadway per lane-mile was about \$125,000. The model estimates the current minimum cost at \$145,000. The rate at which cost increases per unit increase in population density was assumed to be the 1963 rate, 8.33:

C MNCRPLM = 145000

C CRPLMRI = 8.33.

Selection of Initial Conditions. - Initial conditions were selected to represent current conditions in Orange County, Florida.

Major roads included in the model are defined as expressways, highways, arterials, and central business district streets. The TOPICS network includes 360 centerline miles of roadway.⁴¹ It is estimated that the 360 centerline miles represent about 1000 lane-miles. Because of the accelerating growth of Orange County, the age distribution of the roadway is shifted toward newer roads:

N RDAVLL1 = 500

N RDAVLL2 = 300

N RDAVLL3 = 200.

The Orange County Transit Authority procured 33 new buses less than one year ago. Some old buses have been kept in the inventory for emergency uses, but for the purposes of this model are ignored. Because the total modeled transit vehicle inventory is new, the initial

conditions are:

```
N TVAVLL1 = 33
N TVAVLL2 = 0
N TVAVLL3 = 0
```

The rationale behind the selection of initial values of peak hour auto demand and peak hour transit demand has been explained on another page. The values are:

```
N PAD = 22407
N PTD = 1200.
```

Because the rate of road fund commitments should always match the rate of road fund receipts, the initial value selected for the road fund level is

```
N RFDL = 0
```

and similarly the initial value selected for the transit fund level is

```
N TFDL = 0
```

The remainder of the required initial conditions are computed in the following manner:

```
N RDPLGR = RDLVGR
N RDBGGR = RDLVGR
N RDCMGR = RDLVGR
N TVPLGR = TVLVGR
N TVORDER = TVLVGR
N TVDLGR = TVLVGR
N FAUTOTM = AUTOTM
N FMTRANC = MIRANC
N FTRANIM = TRANIM
N FMAUTOC = MAUTOC
N FTRACC = TRACC
N PADCS = 0
N PTDCS = 0
N PKHRCOM = PTD + PAD*ACPA
N CPAD = PAD
N FCPAD = PAD
N TA = PAD/PADF
N FCPTD = PTD
N TMTD = PTD/PTDF
```



```

N   RDAVLL = RDAVLL1 + RDAVLL2 + RDAVLL3
N   RDLVGR = RDAVLL3/(RDLIFE/3)
N   RDPLDL = RDLVGR*RDPLGD
N   RDCSNL = RDLVGR*RDCSND
N   POPDENS = POP/AREA
N   CRPLM = MNCRPLM + CRPLMRI*POPDENS
N   RDTMCO = (RDAVLL + RDCSNL)*CRPLM*(CRFR/12)
N   RDTMOM = RD1UMOM*RDAVLL1 + RD2UMOM*RDAVLL2 + RD3UMOM*
           RADVLL3
N   RFDCOMR = RDTMOM + RDTMCO
N   RFDDUEL = RFDCOMR*RFDCOLD
N   RFDCMDL = RFDCOMR*RFDEXPD
N   MRDREVN = RDTMCO + RDTMOM
N   MRREVFU = (1-RDSUBF)*MRDREVN
N   RDTXRG = (MRREVFU*AMPG)/(TA*AMPA)*(1-RFDDIVF))
N   RCONG = (MDFAD*CPAD)/(MDFRD*RDAVLL)
N   ASPEED = 45 - 0.375*RCONG
N   TVAVLL = TVAVLL1 + TVAVLL2 + TVAVLL3
N   TVLVGR = TVAVLL3/(TVLIFE/3)
N   TVPLDL = TVLVGR*TVPLGD
N   TVCSNL = TVLVGR*TVCSND
N   TTMOM = T1UMOM*TVAVLL1 + T2UMOM*TVAVLL2 + T3UMOM*TVAVLL3
N   TFDCOMR = TTMOM + TTMCO
N   TFDDUEL = TFDCOMR*TFDCOLD
N   TFDCMDL = TFDCOMR*TFDEXPD
N   MTREVN = TTMCO + TTMOM
N   MTSBRPT = TCOSBF*TMCO + TOMSBF*TTMOM
N   MTREVFU = MTREVN - MTSBRPT
N   FARE = MTREVFU/TMID
N   TSPEED = SWITCH(25 - 0.375*RCONG, RTSPEED, RTRAN)
N   TRANS = TVAVLL*AMDPTV
N   TTMCO = (TVAVLL + TVCSNL)*(((CPTV*CRFTV)/12) + ((FCPV*
           CRFTF)/12))
N   MAUTOC = (COMTPM*COMDIS)*(AMIM + (AGSOILG/AMPG) + AINSURM +
X   APKTLSPM + ACOPM + (RDTXRG/AMPG))/ACPA
N   AUTOTM = 60/ASPEED
N   MTRANC = COMTPM*FARE
N   TRANIM = 60/TSPEED
N   TRACC = (VTACP*AREA)/TRANS.

```

Steady State Experiment. - The model was run initially under

"steady state" conditions. That is, population was held steady at the 1970 level and gasoline prices were held constant at the 1972 level.

Not constant, however, was the age distribution of the roads and transit vehicles. Initially, these age distributions were skewed toward newer facilities. During the twenty year (240 month) simulation

the age distributions became more even causing increasing maintenance costs and increasing user costs. The effects of the shifting age distributions were more pronounced in the transit sector where, initially, all vehicles were new. The required transit fare increased from an initial 29.326 cents to a high of 36.929 cents. The tax rate per gallon of gasoline during the same period increased from 12.135 cents to a high of 12.460 cents. Thus an overall gain in the desirability of auto commuting occurred with the fraction of commuters using the transit system declining from 3.2388 percent to 3.0829 percent.

During the preparation period of this thesis (1972-1974) a significant change in the price of gasoline occurred. In 1972 the price of gasoline (less taxes) was about 21 cents per gallon. By early 1974 that price had increased to about 40 cents per gallon with minimal impact on the private auto/transit commuter split. A simulation run duplicating this shift in gasoline price resulted in an initial increase in the percent commuters using transit during peak hour from 3.2388 percent to 3.4891 percent two years after the price increase, then a gradual loss of passengers as the balance settled around 3.378 percent for transit commuting.

Results of Simulation

Simulation experiments were run to investigate the effects of changes in transit subsidy policies, the impact of decoupling transit vehicle movement from road congestion, and the effects of increasing gasoline prices. Because the effects caused by the rapid increase in

Orange County, Florida, tend to obscure the effects of policy changes, experiments were run under both steady-state population and increasing population conditions.

Steady-State Population, Increased Transit Subsidy. - The capital outlay to purchase the initial 33 vehicles included in the model of Orange County was totally subsidized. This experiment assumes a continuation of the policy of total subsidy of transit capital outlay. The existing level of subsidizing transit operation and maintenance is about 16.7 percent. In this experiment the operation and maintenance subsidy is increased to 50 percent. As a result the required transit fare was reduced to 18.815 cents. The percent of peak hour commuters using transit increased from 3.2388 percent to 4.1439 percent three years later then settled to about 3.626 percent.

Steady-State Population, Current Subsidy Levels, and Express Bus Lanes. - This experiment assumes present subsidy levels are continued (100 percent of capital outlay and 16.7 percent of operation and maintenance) and investigates the effects of decoupling transit vehicles from auto congestion (as by providing exclusive express transit traffic lanes). A transit speed of 30 miles per hour was assumed for this test, a substantial increase over the average speed of 12.135 miles per hour for transit vehicles sharing the roadways with autos. Under these conditions, the demand for new transit vehicles increased. The increased numbers of vehicles allowed for improved service which in turn increased demand. The results are illustrated in Figure 18. The fraction of commuters using transit during peak hour increased from 3.2388 percent to a high of 13.539 percent, then

settled at about 11.5 percent.

C RTRANF=1.

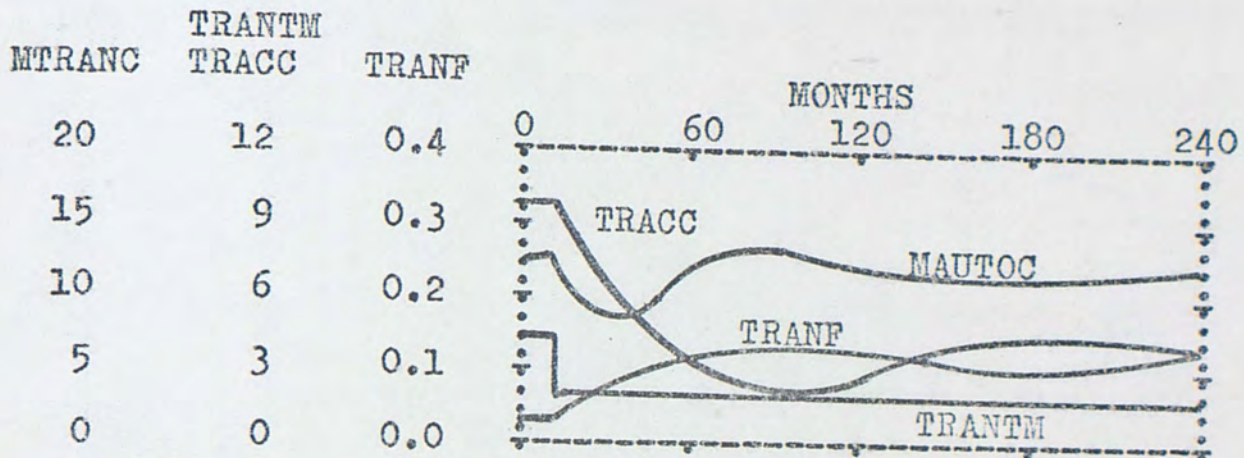


Fig. 18.--Results, Steady-State Population, Current Subsidy Levels, Express Bus Lanes

Steady-State Population, Current Subsidy Levels, Dollar

Gasoline. - This experiment investigates the effects of gasoline prices continuing to rise to ninety cents (over a dollar when taxes are included in the price). A steady-state population is assumed and a continuation of transit subsidies at present levels. The price increase was modeled as a step increase occurring twelve months into the simulation. The percent of peak hour commuters using transit increased from an initial 3.2388 percent to a high of 5.9121 percent sixty months into the simulation, then settled to about 4.65 percent. See Figure 19.

C AGSOILF=0.90

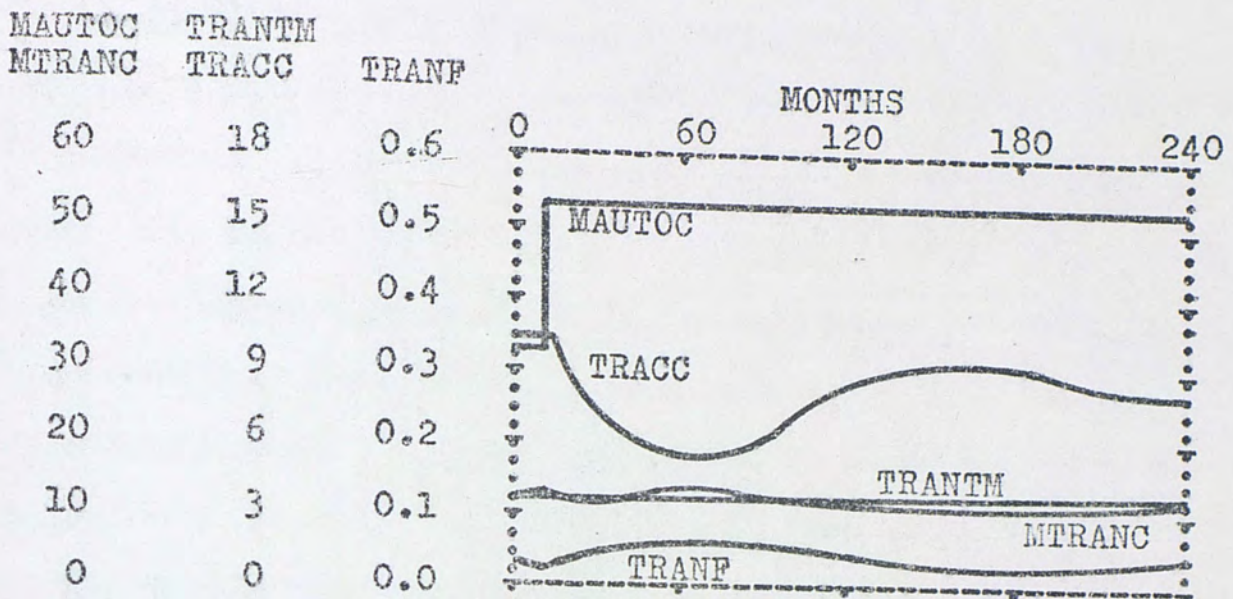


Fig. 19.--Steady-State Population,
Current Subsidy Levels, Dollar Gasoline

Steady-State Population, No Transit Subsidies. - The next group of experiments assume discontinuation of the existing levels of subsidizing transit capital outlay and operation and maintenance. In this experiment, with steady-state population conditions, and with all subsidies ended twelve months into the simulation, the required transit fare increased from 29.326 cents to a high of 55.537 cents, then settled to a fare of about 55.46 cents. The resultant decrease in transit desirability was reflected by a decrease in the percent of peak hour

commuters using the transit system from 3.2388 percent to about 2.88 percent.

Steady-State Population, No Transit Subsidies, Forty Cent Gasoline. - Because the basic automobile operating costs included in this model were significantly affected by the events of late 1973 and early 1974, the no transit subsidies experiment was rerun under current conditions of gasoline costing forty cents per gallon plus tax. Under these conditions the auto/transit split becomes more stable when transit subsidies are removed. Transit fare increased from an initial 29.326 cents to a high of 50.799 cents and a final 50.743 cents. The percent of peak hour commuters using the transit system declined from an initial 3.2388 percent to a final 3.1482 percent.

Steady-State Population, No Transit Subsidy, Dollar Gasoline. - The experiment in which gasoline prices were increased to over a dollar (with taxes included) was repeated to observe the interaction of the gasoline price increase with an ending of transit subsidies. The monthly cost of transit commuting increased from about 12 dollars to about 17 dollars while the monthly cost of auto commuting increased from about 35 dollars per month to over 50 dollars per month. Transit fare increased from 29.326 cents to a high of 43.704 cents and a final price of 42.769 cents. The percent of peak hour commuters selecting transit increased from 3.2388 percent to 3.7340 percent. Results are illustrated in Figure 20.

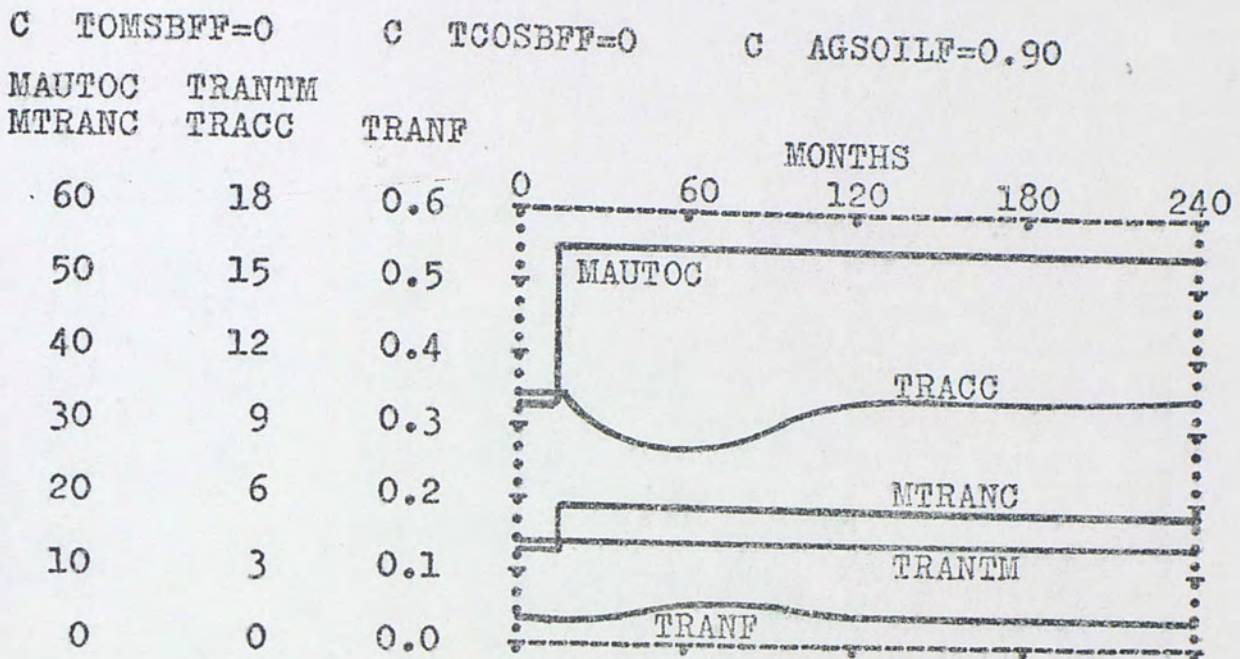


Fig. 20.--Steady-State Population,
No Transit Subsidies, Dollar Gasoline

Steady-State Population, No Transit Subsidy, Express Bus Lanes. -

The experiment in which the effects of decoupling transit vehicles from auto congestion were investigated was repeated under the discontinued subsidy conditions. A transit speed of 30 miles per hour was assumed for the test. The increase in transit desirability caused a demand for additional transit vehicles which, in turn, allows for improved transit service. However, in this case, the users must pay for the new transit vehicles. Transit fare increases from 29.326 cents

to a high of 44.124 when the switchover occurs, and a final cost of 41.678 cents. The percent of commuters using transit increases to a high of 11.452 percent and a final 9.576 percent. See Figure 21.

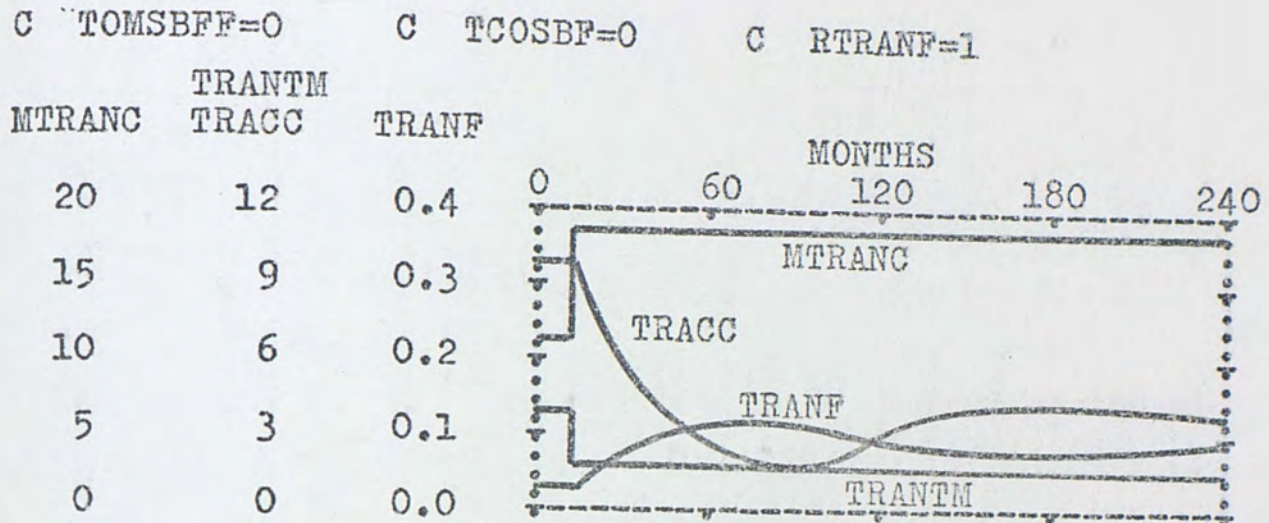


Fig. 21.--Steady-State Population,
No Transit Subsidies, Express Bus Lanes

Increasing Population, No Transit Subsidy. - In this experiment, and all succeeding experiments, the effects of the Orange County population continuing to increase at the present rate are included. It is estimated that 138 new peak hour commuters enter the system every month. An increased demand on both the roadway system and the transit system causes a requirement for increased roadway and transit vehicles. Roadway becomes increasingly expensive while transit service is reaching an increasing number of potential patrons. A significant shift toward transit commuting occurs without continuing transit

subsidies. Transit fare initially increases to 44.464 cents, then settles to 40.338 cents. The percent of commuters using transit climbs to 10.123. See Figure 22.

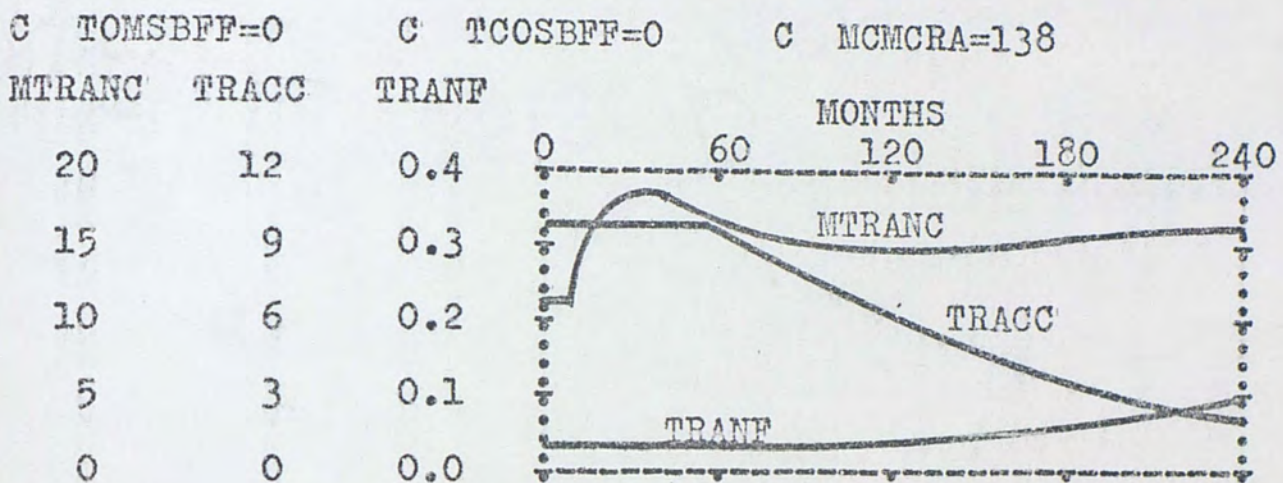


Fig. 22.--Population Increasing, No Transit Subsidies

Increasing Population, No Transit Subsidy, Express Bus Lanes. -

The experiment in which transit vehicle movement was decoupled from auto traffic was repeated under the conditions of no transit subsidies and increasing population. Introduction of express bus lanes re-enforces the strong tendency toward use of transit of the population density increases. The percent of peak hour commuters selecting the transit system increases from an initial 3.2388 percent to an impressive 27.738 percent. See Figure 23.

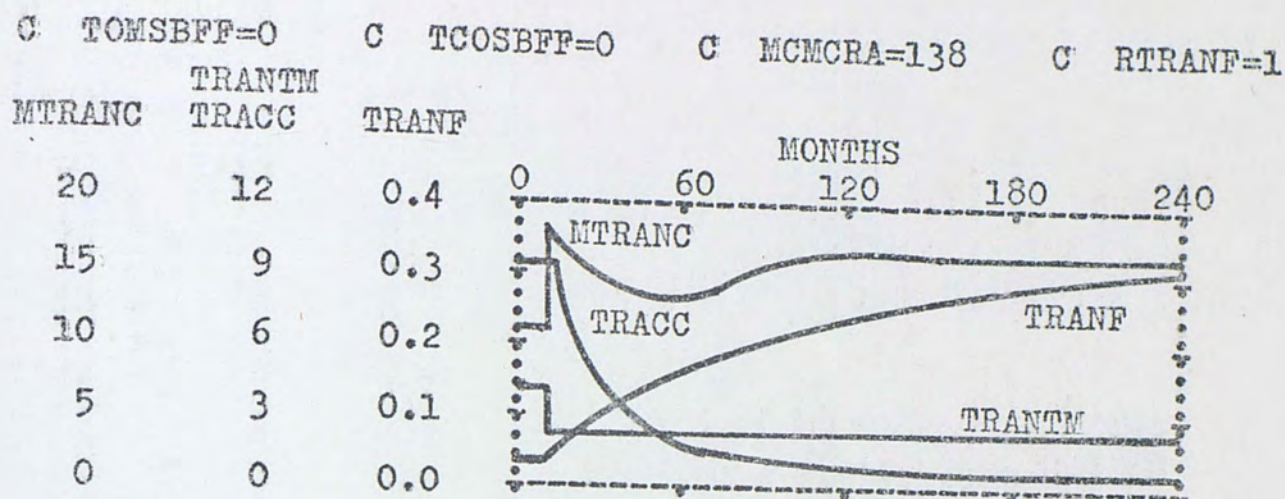


Fig. 23.--Population Increasing,
No Transit Subsidies, Express Bus Lanes

Increasing Population, Continuing Transit Subsidies. - In this experiment the combination of circumstances investigated included (1) population increasing so that 138 new peak hour commuters enter the system each month and (2) the present level of subsidizing transit capital outlay and transit operation and maintenance is continued. Under these conditions, transit fare decreases slightly from 29.326 cents to a low of 27.230 cents and a final 28.439 cents. More significant is the increased level of transit service brought on by the increasing transit demand caused by the growing population. The percent of peak hour commuters selecting the transit system increases

from 3.2388 percent to 12.174 percent in twenty years. See Figure 24.

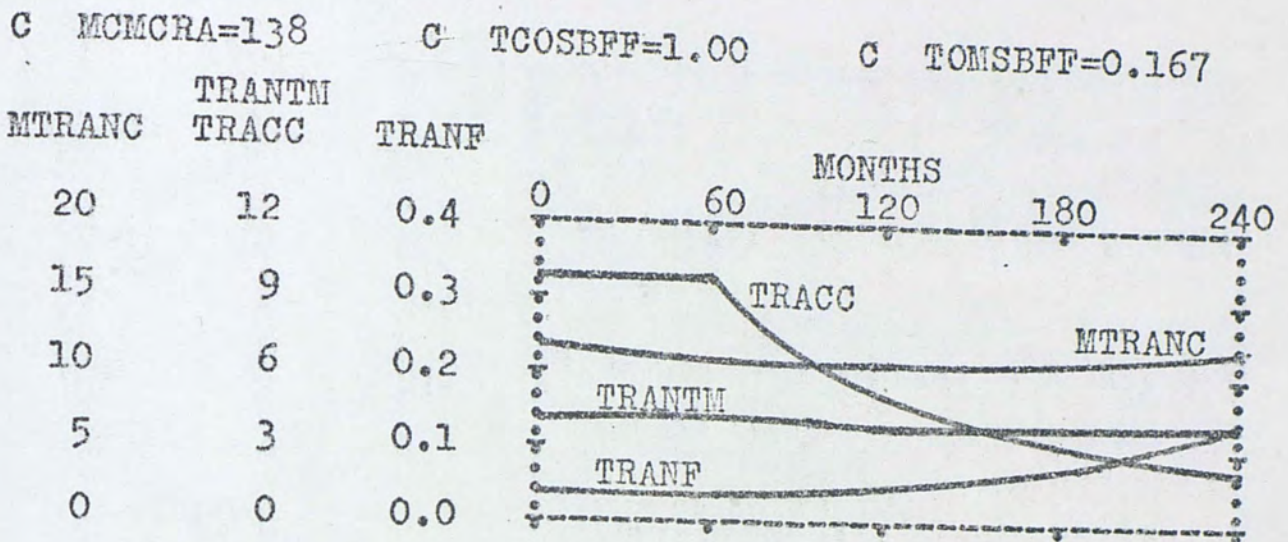


Fig. 24.--Population Increasing, Current Subsidy Levels

Increasing Population, Continuing Transit Subsidies, Express Bus Lanes. - In the final experiment, the interactions of the following conditions were examined: (1) increasing population, (2) continuing transit subsidy levels, and (3) introduction of express bus lanes. Under these conditions, the transit fare held about steady (initially 29.326, finally 28.923 cents). The percent of peak hour commuters using the transit system increased to 34.794 percent. See Figure 25.

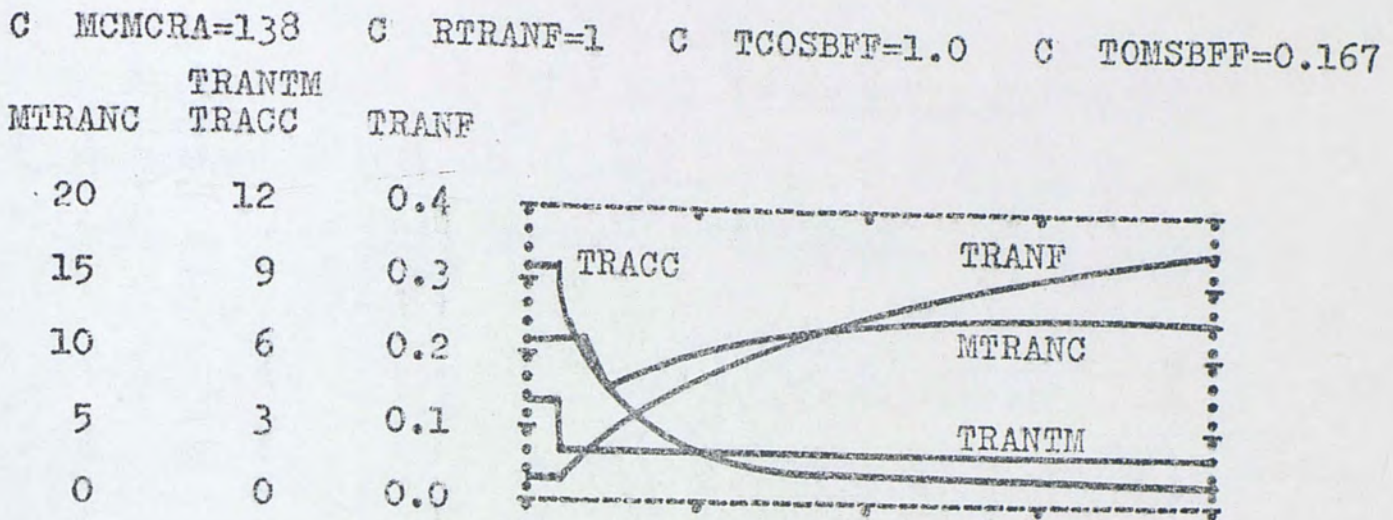


Fig. 25.--Population Increasing,
Current Transit Subsidies, Express Bus Lanes

Analysis of Policies

Experiments investigate various combinations of varying transit subsidy policies, increasing gasoline cost, and introduction of express bus lanes under steady-state and increasing population conditions.

It was found that continuing current policies under a steady state population condition would result in a decrease in transit use from 3.2388 percent to 3.0829 percent. However if current gasoline price increases are included in the model then transit ridership increases from 3.2388 percent to about 3.49 percent. Discontinuing present subsidy levels under steady state population conditions resulted

in transit ridership declining to 2.88 percent, or, if gas price increases are considered, to 3.1482 percent. An increase in the transit subsidy rate under steady-state population conditions resulted in transit demand increasing to 3.626 percent. It was concluded that the level of transit subsidy was not highly significant in determining the split between auto and transit demand, a finding supporting the findings of Domencich and Kraft.⁴²

The effects of a continuing increase in the price of gasoline was examined under steady-state population conditions. If current transit subsidy policies are continued and gasoline prices increase to a dollar per gallon (including taxes), the percent of commuters selecting the transit system increases to about 4.65 percent. If current transit subsidies are discontinued while gasoline goes to a dollar a gallon, the percent of commuters who will select transit will be 3.7340 percent. Clearly, a continuation of the increasing price for gasoline is not, in itself, an important method of significantly increasing transit demand.

Decoupling transit movement from auto traffic by introducing express bus lanes did significantly effect the demand split. Under steady-state population conditions, the transit demand percentage increased to about 11.5 percent if current subsidy policies were continued or 9.576 percent if subsidies were discontinued.

Of particular interest among the simulation results was the effect of continuing the rapid population increase of Orange County. With no change from current transit policies the percent demand for transit commuting began to increase ten years into the simulation rising

to 12.174 percent after twenty years. This increase is attributed in part to the increasing cost of new roadway as the population density increases but more to the increased capacity for transit systems to serve more densely populated areas. Even if current transit subsidies are discontinued, the percent of commuters choosing the transit system is 10.123 after twenty years of continuing population increases.

Finally, the policy of providing express bus lanes was examined under conditions of increasing population. The dramatic results were that, with existing subsidy policies, the percent of peak hour commuters using the transit system rose to 34.794 percent after twenty years. If subsidies were discontinued, the percentage after twenty years was 27.738.

CHAPTER V

CONCLUSIONS AND IMPLICATIONS

Conclusions

The results of this study indicate that the application of System Dynamics techniques can provide a valuable new tool to urban planners seeking to understand the organization of the urban transportation system and to evaluate proposals for improving urban transportation. While the results may not be precise quantitatively, in general the effects of various policies may be clearly evaluated. Application of the techniques provides a more systematic, scientific approach to the urban transportation policies problem than has hitherto been available.

Implications for Orange County Urban Planners

The experiments conducted indicate that increasing the subsidy for the Orange County transit system, or even continuing the present subsidy policies, is of marginal value. Nor will increasing the cost of the auto commuter, either through an increasing gasoline price or other means such as increasing gasoline taxes, have a significant effect on the auto/transit commuter split. Orange County urban planners might expect far greater success if the emphasis is placed on introducing express bus lanes into the Orange County transit system. Beyond that innovation, of the conditions tested, the most significant

is the continuing growth of the area which, in itself, can be expected to assure the success of any competently operated transit system in the area.

Implications for Further Research

The data base included in this model was drawn primarily from published data, not always current, and not always appropriate to the area modeled. An important next step to the development of the model is to investigate the sensitivity of each constant. Those constants found to be significantly sensitive will merit further investigation to provide values appropriate to the time and place of the simulation.

The capacity of the model for expansion is virtually limitless. Detailed improvements demanding further study include: (1) developing the necessary elasticity constants so that changes in transit comfort can be modeled; (2) developing a variable car pool equation to replace the auto commuters per auto constant; (3) developing an auto usage equation to replace the average monthly miles per auto constant; (4) modifying the model to include the effect of increasing gasoline costs on transit operating costs; (5) accounting for the cost of express bus lanes to either transit users or auto users; and (6) developing an integer mathematics for Dynamo so that transit vehicles can be modeled in integers rather than in fractions as they are in this simulation.

On a grander scale, the possibility exists of interfacing this model with Forrester's Urban Dynamics model⁴³ to represent: (1) the relationship of the community's urban transportation system to the

overall desirability of the community; (2) the effect of urban transportation on population, housing and industry; and (3) the competition of urban transportation with others demanding use of available land.

APPENDIX I

TABLE OF DEFINITIONS

ACOPM	AUTO CAPITAL OUTLAY PER MILE
ACPA	AUTO COMMUTERS PER AUTO
ADCHNG1	CHANGE IN AUTO DEMAND DUE TO AUTO COST CHANGE
ADCHNG2	CHANGE IN AUTO DEMAND DUE TO AUTO COMMUTING TIME CHANGE
ADCHNG3	CHANGE IN AUTO DEMAND DUE TO TRANSIT COST CHANGE
ADCHNG4	CHANGE IN AUTO DEMAND DUE TO TRANSIT COMMUTING TIME CHANGE
ADCHNG5	CHANGE IN AUTO DEMAND DUE TO CHANGE IN TRANSIT ACCESSIBILITY
AGSINC	INCREASE IN COST OF GASOLINE AND OIL
AGSOILF	FINAL COST OF GASOLINE AND OIL
AGSOILG	COST OF GASOLINE AND OIL PER GALLON OF GASOLINE (EXCLUSIVE OF TAXES)
AGSOILI	INITIAL COST OF GASOLINE AND OIL
AINSURM	AUTO INSURANCE COST PER MILE
AMMPA	AVERAGE MONTHLY MILES PER AUTO (ALL USES)
AMDPTV	AVERAGE MILES PER DAY PER TRANSIT VEHICLE
AMPG	AVERAGE MILES PER GALLON OF GASOLINE
AMTM	AVERAGE AUTO MAINTENANCE COST PER MILE
APKTL5M	AUTO PARKING AND TOLLS COST PER MILE DRIVEN
AREA	LAND AREA MODELED
ASPEED	AVERAGE PEAK HOUR AUTO SPEED
AUTOF	FRACTION OF PEAK HOUR COMMUTERS USING AUTOS

AUTOTM	AVERAGE AUTO TIME PER MILE DURING PEAK HOUR
AUTOTMC	CHANGE IN AUTO TIME PER MILE DURING PEAK HOUR
CE1	CROSS ELASTICITY BETWEEN PEAK HOUR AUTO DEMAND AND MONTHLY TRANSIT COST
CE2	CROSS ELASTICITY BETWEEN PEAK HOUR AUTO DEMAND AND TRANSIT TIME PER MILE DURING PEAK HOUR
CE3	CROSS ELASTICITY BETWEEN PEAK HOUR TRANSIT DEMAND AND MONTHLY TRANSIT COST
CE4	CROSS ELASTICITY BETWEEN PEAK HOUR TRANSIT DEMAND AND AUTO TIME PER MILE DURING PEAK HOUR
CE5	CROSS ELASTICITY BETWEEN PEAK HOUR AUTO DEMAND AND TRANSIT ACCESSIBILITY
COMDIS	AVERAGE ONE-WAY COMMUTING DISTANCE
COMTPM	ONE-WAY COMMUTER TRIPS PER MONTH
CPAC	PEAK HOUR AUTO COMMUTERS, CORRECTED FOR POPULATION CHANGE
CPAD	PEAK HOUR AUTO DEMAND, CORRECTED FOR POPULATION CHANGE
CPTD	PEAK HOUR TRANSIT DEMAND, CORRECTED FOR POPULATION CHANGE
CPTV	COST PER TRANSIT VEHICLE
CRFR	CAPITAL RECOVERY FACTOR FOR ROADS
CRFTF	CAPITAL RECOVERY FACTOR FOR TRANSIT FACILITIES
CRFTV	CAPITAL RECOVERY FACTOR FOR TRANSIT VEHICLES
CRPLM	COST OF ROADWAY PER LANE MILE
CRPLMRI	COST OF ROADWAY PER LANE MILE RATE OF INCREASE WITH INCREASING POPULATION DENSITY
DE1	DIRECT ELASTICITY BETWEEN PEAK HOUR AUTO DEMAND AND MONTHLY AUTO COST
DE2	DIRECT ELASTICITY BETWEEN PEAK HOUR AUTO DEMAND AND AUTO TIME PER MILE DURING PEAK HOUR
DE3	DIRECT ELASTICITY BETWEEN PEAK HOUR TRANSIT DEMAND AND MONTHLY TRANSIT COST

DE4	DIRECT ELASTICITY BETWEEN PEAK HOUR TRANSIT DEMAND AND TRANSIT TIME PER MILE DURING PEAK HOUR
DE5	DIRECT ELASTICITY BETWEEN PEAK HOUR TRANSIT DEMAND AND TRANSIT ACCESSIBILITY
DPHPPV	DESIRED PEAK HOUR PASSENGERS PER TRANSIT VEHICLE
DRCONG	DESIRED ROAD CONGESTION FACTOR, AUTOS PER LANE MILE
EMRDCO	ESTIMATED MONTHLY ROAD CAPITAL OUTLAY
EMRDOM	ESTIMATED MONTHLY ROAD OPERATION AND MAINTENANCE COST
EMTCO	ESTIMATED MONTHLY TRANSIT CAPITAL OUTLAY
EMTOM	ESTIMATED MONTHLY TRANSIT OPERATION AND MAINTENANCE COST
FARE	REQUIRED ONE-WAY TRANSIT FARE
FAUTOTM	FORMER AUTO TIME PER MILE DURING PEAK HOUR
FCPAD	FORMER CORRECTED PEAK HOUR AUTO DEMAND
FCPTD	FORMER CORRECTED PEAK HOUR TRANSIT DEMAND
FCPV	FACILITY COST PER TRANSIT VEHICLE
FMAUOC	FORMER MONTHLY AUTO COST
MAUTOCC	CHANGE IN MONTHLY AUTO COST PER COMMUTING
MCMCRA	AVERAGE MONTHLY CHANGE RATE IN NUMBERS OF PEAK HOUR COMMUTERS
MCOMCR	MONTHLY CHANGE RATE IN NUMBERS OF PEAK HOUR COMMUTERS
MDFAD	FRACTION OF AUTO DEMAND TRAVELING IN MAJOR DIRECTION
MDFRD	FRACTION OF ROADWAY AVAILABLE FOR TRAFFIC TRAVELING IN MAJOR DIRECTION
MNCRPIM	MINIMUM COST OF ROADWAY PER LANE MILE
MNRURPT	MONTHLY NON-ROAD-USER RECEIPTS INTO ROAD RUNDS
MINTV	NUMBER OF TRANSIT VEHICLES REQUIRED TO SUSTAIN MINIMUM DESIRED SERVICE

MRDREVN	MONTHLY ROAD REVENUE NEEDED
MRREVFU	MONTHLY ROAD REVENUE TO BE PROVIDED BY USERS
MRURPT	MONTHLY ROAD USER TAX RECEIPTS
MTRANC	MONTHLY TRANSIT COST OF COMMUTING
MTRANCC	CHANGE IN MONTHLY COST OF COMMUTING BY TRANSIT
MTREVFU	MONTHLY TRANSIT REVENUE TO BE PROVIDED BY USERS
MTREVN	MONTHLY TRANSIT REVENUE NEEDED
MTSBRPT	MONTHLY TRANSIT SUBSIDY RECEIPTS
MTURPT	MONTHLY TRANSIT RECEIPTS FROM USERS
PAC	PEAK HOUR AUTO COMMUTERS
PAD	PEAK HOUR AUTO DEMAND
PADC	CHANGE IN PEAK HOUR AUTO DEMAND
PADCS	SMOOTHED CHANGE IN PEAK HOUR AUTO DEMAND
PADF	PEAK HOUR AUTO DEMAND FRACTION OF TOTAL AUTOS
PHCPOPR	RATIO OF PEAK HOUR COMMUTERS TO TOTAL POPULATION
PKHRAF	FRACTION OF PEAK HOUR COMMUTERS USING AUTOS
PKHRCOM	TOTAL PEAK HOUR COMMUTERS
PKHRTF	FRACTION OF PEAK HOUR COMMUTERS USING TRANSIT
POP	POPULATION OF THE MODELED AREA
POPDENS	POPULATION DENSITY OF THE MODELED AREA
PRPAD	PROJECTED PEAK HOUR AUTO DEMAND
PRPTD	PROJECTED PEAK HOUR TRANSIT DEMAND
PRTA	PROJECTED TOTAL AUTOS IN MODELED AREA
PRMTD	PROJECTED TOTAL MONTHLY TRANSIT DEMAND
PTD	PEAK HOUR TRANSIT DEMAND

PTDC	CHANGE IN PEAK HOUR TRANSIT DEMAND
PTDCS	SMOOTHED CHANGE IN PEAK HOUR TRANSIT DEMAND
PTDF	PEAK HOUR TRANSIT DEMAND FRACTION OF MONTHLY DEMAND
RCONG	ROAD CONGESTION FACTOR
RDAVBP	BUDGETARY PREDICTION OF TOTAL ROADWAY AVAILABILITY
RDAV1BP	BUDGETARY PREDICTION OF AVAILABLE ROADWAY, FIRST THIRD OF EXPECTED LIFE
RDAV2BP	BUDGETARY PREDICTION OF AVAILABLE ROADWAY, SECOND THIRD OF EXPECTED LIFE
RDAV3BP	BUDGETARY PREDICTION OF AVAILABLE ROADWAY, FINAL THIRD OF EXPECTED LIFE
RDAVLL	LANE MILES OF ROADWAY AVAILABLE, TOTAL
RDAVLL1	LANE MILES OF ROADWAY AVAILABLE, FIRST THIRD OF EXPECTED LIFE
RDAVLL2	LANE MILES OF ROADWAY AVAILABLE, SECOND THIRD OF EXPECTED LIFE
RDAVLL3	LANE MILES OF ROADWAY AVAILABLE, FINAL THIRD OF EXPECTED LIFE
RDBGGR	RATE AT WHICH ROAD CONSTRUCTION IS BEGUN
RDCMGR	RATE AT WHICH ROAD CONSTRUCTION IS COMPLETED
RDCNBP	BUDGETARY PREDICTION OF ROADWAY TO BE UNDER CONSTRUCTION
RDCSND	ROAD CONSTRUCTION DELAY
RDCSNL	LANE MILES OF ROADWAY UNDER CONSTRUCTION
RDDAVA	DESIRED ROADWAY AVAILABILITY IN LANE MILES
RDLIFE	EXPECTED ROAD LIFE IN MONTHS
RDLVGR	ROAD ATTRITION RATE, COMPLETING FINAL THIRD OF EXPECTED LIFE
RDLVGR1	ROAD ATTRITION RATE, COMPLETING FIRST THIRD OF EXPECTED LIFE
RDLVGR2	ROAD ATTRITION RATE, COMPLETING SECOND THIRD OF EXPECTED LIFE
RDPAVA	PROJECTED LANE MILES OF ROADWAY AVAILABLE

RDPLDL	LANE MILES OF NEW ROADWAY PLANNED
RDPLGD	ROAD PLANNING DELAY
RDPLGR	RATE AT WHICH NEW ROADS ARE BEING PLANNED
RDSUBF	FRACTION OF ROADWAY REVENUE NEEDS SATISFIED BY OTHER THAN USER TAXES
RDIMCO	TOTAL MONTHLY CAPITAL OUTLAY FOR ROADS
RDTMOM	TOTAL MONTHLY OPERATION AND MAINTENANCE COSTS FOR ROADS
RDTXRG	TOTAL ROAD USER TAX RATE PER GALLON OF GASOLINE (ALL GOVERNMENT LEVELS)
RD1UMOM	UNIT OPERATING AND MAINTENANCE COSTS PER LANE MILE FOR ROADS IN FIRST THIRD OF EXPECTED LIFE
RD2UMOM	UNIT OPERATING AND MAINTENANCE COSTS PER LANE MILE FOR ROADS IN SECOND THIRD OF EXPECTED LIFE
RD3UMOM	UNIT OPERATING AND MAINTENANCE COSTS PER LANE MILE FOR ROADS IN FINAL THIRD OF EXPECTED LIFE
RFDCMDL	LEVEL OF ROAD FUNDS COMMITTED
RFDCOLD	ROAD FUND COLLECTION DELAY
RFDCOLR	ROAD FUND COLLECTION RATE
RFDCOMR	RATE AT WHICH ROAD FUNDS ARE BEING COMMITTED
RFDDIVF	FRACTION OF ROAD FUNDS DIVERTED FROM ROAD USES
RFDDUEL	LEVEL OF ROAD FUNDS WHICH HAVE BEEN COLLECTED FROM USERS BUT HAVE NOT BEEN CENTRALLY RECEIVED
RFDEXPD	DELAY BETWEEN COMMITMENT OF ROAD FUNDS AND EXPENDITURE OF THOSE FUNDS
RFDEXPR	RATE AT WHICH FUNDS ARE EXPENDED
RFDL	LEVEL OF ROAD FUNDS RECEIVED BUT NOT COMMITTED
RFDRPTR	ROAD FUND RECEIPT RATE
RQDTV	TRANSIT VEHICLES REQUIRED

RTRAN	RAPID TRANSIT DESIGNATOR
RTRANF	FINAL RAPID TRANSIT DESIGNATOR
RTRANI	INITIAL RAPID TRANSIT DESIGNATOR
RTSPEED	RAPID TRANSIT SPEED
SMCON	SMOOTHING CONSTANT
TA	TOTAL AUTOS IN MODELED AREA
TACS	SMOOTHED MONTHLY CHANGE IN TOTAL AUTOS
TCOSBF	TRANSIT CAPITAL OUTLAY SUBSIDY FRACTION
TCOSBFC	CHANGE IN CAPITAL OUTLAY SUBSIDY FRACTION
TCOSBFF	FINAL TRANSIT CAPITAL OUTLAY SUBSIDY FRACTION
TCOSBFI	INITIAL TRANSIT CAPITAL OUTLAY SUBSIDY FRACTION
TDCHNG1	CHANGE IN TRANSIT DEMAND DUE TO TRANSIT COST CHANGE
TDCHNG2	CHANGE IN TRANSIT DEMAND DUE TO TRANSIT PEAK HOUR COMMUTING TIME CHANGE
TDCHNG3	CHANGE IN TRANSIT DEMAND DUE TO AUTO COST CHANGE
TDCHNG4	CHANGE IN TRANSIT DEMAND DUE TO PEAK HOUR AUTO COMMUTING TIME CHANGE
TDCHNG5	CHANGE IN TRANSIT DEMAND DUE TO CHANGE IN TRANSIT ACCESSIBILITY
TFDCMDL	LEVEL OF TRANSIT FUNDS COMMITTED
TFDCOLD	TRANSIT FUND COLLECTION DELAY
TFDCOLR	TRANSIT FUND COLLECTION RATE
TFDCOMR	RATE AT WHICH TRANSIT FUNDS ARE COMMITTED
TFDDUEL	LEVEL OF TRANSIT FUNDS WHICH HAVE BEEN COLLECTED BUT HAVE NOT BEEN RECEIVED CENTRALLY INTO THE TRANSIT FUND ACCOUNT
TFDEXPD	DELAY BETWEEN COMMITMENT OF TRANSIT FUNDS AND EXPENDITURE OF THOSE FUNDS
TFDEXPR	RATE AT WHICH TRANSIT FUNDS ARE EXPENDED

TFDL	LEVEL OF TRANSIT FUNDS RECEIVED BUT NOT COMMITTED
TFDRPTR	TRANSIT FUND RECEIPT RATE
TMTD	TOTAL MONTHLY TRANSIT DEMAND
TMTDCS	SMOOTHED CHANGE IN TOTAL MONTHLY TRANSIT DEMAND
TOMSBF	TRANSIT OPERATING AND MAINTENANCE SUBSIDY FRACTION
TOMSBFC	CHANGE IN TRANSIT OPERATING AND MAINTENANCE SUBSIDY FRACTION
TOMSBFF	FINAL TRANSIT OPERATING AND MAINTENANCE SUBSIDY FRACTION
TOMSBFI	INITIAL TRANSIT OPERATING AND MAINTENANCE SUBSIDY FRACTION
TOTPHD	TOTAL PEAK HOUR COMMUTER DEMAND
TRACC	TRANSIT ACCESSIBILITY
TRACCC	CHANGE IN TRANSIT ACCESSIBILITY
TRANF	FRACTION OF PEAK HOUR COMMUTERS CHOOSING TRANSIT
TRANS	TRANSIT SERVICE IN LINE MILES
TRANIM	TRANSIT TIME PER MILE DURING PEAK HOUR
TRANIMC	CHANGE IN TRANSIT TIME PER MILE DURING PEAK HOUR
TSPEED	AVERAGE PEAK HOUR TRANSIT SPEED
TTMCO	TRANSIT TOTAL MONTHLY CAPITAL OUTLAY
TTMOM	TRANSIT TOTAL MONTHLY OPERATING AND MAINTENANCE COSTS
T1UMOM	TRANSIT UNIT MONTHLY OPERATING AND MAINTENANCE COSTS FOR VEHICLES IN FIRST THIRD OF EXPECTED LIFE
T2UMOM	TRANSIT UNIT MONTHLY OPERATING AND MAINTENANCE COSTS FOR VEHICLES IN SECOND THIRD OF EXPECTED LIFE
T3UMOM	TRANSIT UNIT MONTHLY OPERATING AND MAINTENANCE COSTS FOR VEHICLES IN FINAL THIRD OF EXPECTED LIFE
TVAVBP	BUDGETARY PREDICTION OF TOTAL TRANSIT VEHICLE AVAILABILITY
TVAV1BP	BUDGETARY PREDICTION OF TRANSIT VEHICLE AVAILABILITY, FIRST THIRD OF EXPECTED LIFE

TVAV2BP	BUDGETARY PREDICTION OF TRANSIT VEHICLE AVAILABILITY, SECOND THIRD OF EXPECTED LIFE
TVAVLL	TOTAL TRANSIT VEHICLE AVAILABILITY
TVAVLL1	TRANSIT VEHICLE AVAILABILITY, FIRST THIRD OF EXPECTED LIFE
TVAVLL2	TRANSIT VEHICLE AVAILABILITY, SECOND THIRD OF EXPECTED LIFE
TVAVLL3	TRANSIT VEHICLE AVAILABILITY, FINAL THIRD OF EXPECTED LIFE
TVCNBP	BUDGETARY PREDICTION OF TRANSIT VEHICLES UNDER CONSTRUCTION
TVCSND	TRANSIT VEHICLE CONSTRUCTION DELAY
TVCSNL	TRANSIT VEHICLE CONSTRUCTION LEVEL
TVDAVA	DESIRED AVAILABILITY OF TRANSIT VEHICLES
TVDLGR	RATE AT WHICH NEW TRANSIT VEHICLES ARE BEING DELIVERED
TVLVGR	TRANSIT VEHICLE LEAVING RATE, FINAL THIRD OF EXPECTED LIFE
TVLGR1	TRANSIT VEHICLE LEAVING RATE, FIRST THIRD OF EXPECTED LIFE
TVLGR2	TRANSIT VEHICLE LEAVING RATE, SECOND THIRD OF EXPECTED LIFE
TVLIFE	TRANSIT VEHICLE EXPECTED LIFE IN MONTHS
TVORDER	RATE OF ORDERING NEW TRANSIT VEHICLES
TVPAVA	PROJECTED AVAILABILITY OF TRANSIT VEHICLES
TVPLDL	LEVEL OF NEW TRANSIT VEHICLES PLANNED
TVPLGD	TRANSIT VEHICLE PLANNING DELAY
TVPLGR	TRANSIT VEHICLE PLANNING RATE
VTACP	VALUE OF TRANSIT ACCESS CONSTANT OF PROPORTIONALITY

APPENDIX II

URBAN TRANSPORTATION MODEL LISTING

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* URBAN TRANSPORTATION MODEL
NOTE
NOTE BLOCK 1 AUTO AND TRANSIT DEMAND
NOTE
R MAUTOC, KL=MAUTOC, K-FMAUTOC, K
L FMAUTOC, K=FMAUTOC, J+DT*MAUTOC, JK
R AUTOTMC, KL=AUTOTM, K-FAUTOTM, K
L FAUTOTM, K=FAUTOTM, J+DT*AUTOTM, JK
R MTRANCC, KL=MTRANCC, K-FMTRANCC, K
L FMTRANCC, K=FMTRANCC, J+DT*FMTRANCC, JK
R TRANTHC, KL=TRANTHC, K-FTRANTHC, K
L FTRANTHC, K=FTRANTHC, J+DT*FTRANTHC, JK
R TRACCC, KL=TRACCC, K-FTRACCC, K
L FTRACCC, K=FTRACCC, J+DT*FTRACCC, JK
A ADCHNG1, K=PAD, K*DE1*MAUTOC, JK/FMAUTOC, K
A ADCHNG2, K=PAD, K*DE2*AUTOTM, JK/FAUTOTM, K
A ADCHNG3, K=PAD, K*CE1*MTRANCC, JK/FMTRANCC, K
A ADCHNG4, K=PAD, K*CE2*TRANTHC, JK/FTRANTHC, K
A ADCHNG5, K=PAD, K*CE5*TRACCC, JK/FTRACCC, K
L PAD, K=PAD, J+DT*(ADCHNG1, J+ADCHNG2, J+ADCHNG3, J+ADCHNG4, J+ADCHNG5, J)
A TDCHNG1, K=PTD, K*DE3*MTRANCC, JK/FMTRANCC, K
A TDCHNG2, K=PTD, K*DE4*TRANTHC, JK/FTRANTHC, K
A TDCHNG3, K=PTD, K*DE5*TRACCC, JK/FTRACCC, K
A TDCHNG4, K=PTD, K*CE3*MAUTOC, JK/FMAUTOC, K
A TDCHNG5, K=PTD, K*CE4*AUTOTM, JK/FAUTOTM, K
L PTD, K=PTD, J+DT*(TDCHNG1, J+TDCHNG2, J+TDCHNG3, J+TDCHNG4, J+TDCHNG5, J)
A PAC, K=PAD, K*ACPA
A TOTPHD, K=PAC, K+PTD, K
A PKHRAF, K=PAC, K/TOTPHD, K
A PKHTRF, K=PTD, K/TOTPHD, K
L PKHRCOM, K=PKHRCOM, J+DT*MCOMCR, JK
R MCOMCR, KL=NCMCRA
A CPAC, K=PKHRAF, K*PKHRCOM, K
A CPAD, K=CPAC, K/ACPA
A TA, K=CPAD, K/PADF

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A CPTD,K=PKHRTF,K*PKHRCOM,K
 A TMTD,K=CPTD,K/PTDF
 A AUTOF,K=CPAC,K/(CPAC,K+CPTD,K)
 A TRANF,K=1-AUTOF,K
 NOTE
 NOTE BLOCK 2 PROJECTED AUTO DEMAND
 NOTE
 R PADC,KL=CPAD,K-FCPAD,K
 L FCPAD,K=FCPAD,J+DT*PADC,JK
 A PADCS,K=SMOOTH(PADC,JK,SMCON)
 A TACS,K=PADCS,K/PADF
 A PRPAD,K=CPAD,K+(RDPLGD+RDCSND)*PADCS,K
 A PRTA,K=TA,K+(RFDCCOLD*TACS,K)

NOTE

NOTE BLOCK 3 ROAD INVENTORY

NOTE

R RDPLGR,KL=CLIP(RDDAVA,K-RDPAVA,K,O,RDDAVA,K,RDPAVA,K)
 L RDPLDL,K=RDPLDL,J+DT*(RDPLGR,JK-RDBGGR,JK)
 R RDBGGR,KL=DELAY3(RDPLGR,JK,RDPLGD)
 L RDCSNL,K=RDCSNL,J+DT*(RDBGGR,JK-RDCMGR,JK)
 R RDCMGR,KL=DELAY3(RDBGGR,JK,RDCSND)
 L RDAVLL1,K=RDAVLL1,J+DT*(RDCMGR,JK-RDLVGR1,JK)
 R RDLVGR1,KL=RDAVLL1,K/(RDLIFE/3)
 L RDAVLL2,K=RDAVLL2,J+DT*(RDLVGR1,JK-RDLVGR2,JK)
 R RDLVGR2,KL=RDAVLL2,K/(RDLIFE/3)
 L RDAVLL3,K=RDAVLL3,J+DT*(RDLVGR2,JK-RDLVGR,JK)
 R RDLVGR,KL=RDAVLL3,K/(RDLIFE/3)
 A RDAVLL,K=RDAVLL1,K+RDAVLL2,K+RDAVLL3,K
 A RDPAVA,K=RDAVLL,K+RDCSNL,K+RDPLDL,K-((RDPLGD+RDCSND)*RDLVGR,JK)
 A RDDAVA,K=(NDFAD*PRPAD,K)/(NDFRD*DRCONG)

NOTE

NOTE BLOCK 4 ROAD BUDGET

NOTE

R RFDCOLR,KL=MRURPT,K*(1-RFDDIVF)+MNRURPT,K
 L RFDDUEL,K=RFDDUEL,J+DT*(RFDCOLR,JK-RFDRPTR,JK)
 R RFDRPTR,KL=RFDDUEL,K/RFDCOLR
 A RDTMOM,K=RD1UMOM*RDVLL1,K+RD2UMOM*RDVLL2,K+RD3UMOM*RDVLL3,K
 A POP,K=PKHRCOM,K/PHCPOP
 A POPDENS,K=POP,K/AREA
 A CRPLM,K=MNCRPLM+CRPLMRI*POPDENS,K
 A RDTMCO,K=(RDVLL,K+RDCSNL,K)*CRPLM,K*(CRFR/12)
 R RFDCOMR,KL=RDTMOM,K+RDTMCO,K
 L RFDL,K=RFDL,J+DT*(RFDRPTR,JK-RFDCOMR,JK)
 L RFDCMDL,K=RFDCMDL,J+DT*(RFDCOMR,JK-RFDEXPR,JK)
 R RFDEXPR,KL=RFDCMDL,K/RFDEXPD
 A RDAV1BP,K=RDVLL1,K+RFDCOLR*(PDCMGR,JK-RDLVGR1,JK)
 A RDAV2BP,K=RDVLL2,K+RFDCOLR*(PDLVGR1,JK-RDLVGR2,JK)
 A RDAV3BP,K=RDVLL3,K+RFDCOLR*(RDLVGR2,JK-RDLVGR,JK)
 A RDAVBP,K=RDV1BP,K+RDV2BP,K+RDV3BP,K
 A RDCNBP,K=RDCSNL,K+RFDCOLR*(RDBGGR,JK-RDCMGR,JK)
 A EMRDOM,K=RD1UMOM*RDV1BP,K+RD2UMOM*RDV2BP,K+RD3UMOM*RDV3BP,K
 A EMRDCO,K=(RDAVBP,K+RDCNBP,K)*CRPLM,K*(CRFR/12)
 A MRDREVN,K=EMRDCO,K+EMRDOM,K-RFDL,K
 A MRREVFU,K=(1-RDSUBF)*MRDREVN,K
 A MNRURPT,K=RDSUBF*MRDREVN,K
 A RDTXRG,K=(MRREVFU,K*AMPG)/((PRTA,K*AMMPA)*(1-RFDDIVF))
 A MRURPT,K=RDTXRG,K*TA,K*(AMMPA/AMPG)

NOTE

NOTE BLOCK 5 AUTO COMMUTING COST

NOTE

A MAUTOC,K=((COMTPM*CONDIS)*(AMTM+(AGSOILG,K/AMPG))+AINSURN+APKTLN+
 X ACOPM+(RDTXRG,K/AMPG))/ACPA
 A AGSOILG,K=AGSOILI+STEP(AGSINC,K,12)
 A AGSINC,K=AGSOILF-AGSOILI

NOTE

NOTE BLOCK 6 AUTO COMMUTING TIME

NOTE

A RCONG,K=(MDFAD*CPAD,K)/(MDFRD*RDVALL,K)

A ASPEED,K=45-0.375*RCONG,K

A AUTOTM,K=60/ASPEED,K

NOTE

NOTE BLOCK 7 PROJECTED TRANSIT DEMAND

NOTE

R PTDC,KL=CPTD,K-FCPTD,K

L FCPTD,K=FCPTD,J+DT*PTDC,JK

A PTDCS,K=SMONTH(PTDC,JK,SMCON)

A TMTDCS,K=PTDCS,K/PTOF

A PRPTD,K=CPTD,K+(TVPLGD+TVCSND)*PTDCS,K

A PRMTD,K=TMTD,K+TFDCOLD*PTDCS,K

NOTE

NOTE BLOCK 8 TRANSIT VEHICLE INVENTORY

NOTE

R TVPLGR,KL=CLIP(TVDAVA,K-TVPAVA,K,O,TVDAVA,K,TVPAVA,K)

R TVORDER,KL=DELAY3(TVPLGR,JK,TVPLGD)

R TVDLGR,KL=DELAY3(TVORDER,JK,TVCSND)

L TVPLDL,K=TVPLDL,J+DT*(TVPLGR,JK-TVORDER,JK)

L TVCSNL,K=TVCSNL,J+DT*(TVORDER,JK-TVDLGR,JK)

L TVAVLL1,K=TVAVLL1,J+DT*(TVDLGR,JK-TVLVGR1,JK)

R TVLVGR1,KL=TVAVLL1,K/(TVLIFE/3)

L TVAVLL2,K=TVAVLL2,J+DT*(TVLVGR1,JK-TVLVGR2,JK)

R TVLVGR2,KL=TVAVLL2,K/(TVLIFE/3)

L TVAVLL3,K=TVAVLL3,J+DT*(TVLVGR2,JK-TVLVGR,JK)

R TVLVGR,KL=TVAVLL3,K/(TVLIFE/3)

A TVAVLL,K=TVAVLL1,K+TVAVLL2,K+TVAVLL3,K

A TVPAVA,K=TVAVLL,K+TVCSNL,K+TVPLDL,K-((TVPLGD+TVCSND)*TVLVGR,JK)

A RQDTV,K=PRPTD,K/DPPPV

A TVDAVA,K=MAX(RQDTV,K,MINTV)

NOTE

NOTE BLOCK 9 TRANSIT BUDGET

NOTE

R TFDCOLR,KL=MTURPT,K+MTSBRPT,K
 L TFDDUEL,K=TFDDUEL,J+DT*(TFDCOLR,JK-TFDRPTR,JK)
 R TFDRPTR,KL=TFDDUEL,K/TFDCOLD
 A TTMMOM,K=TIUMOM*TVAVLL1,K+T2UMOM*TVAVLL2,K+T3UMOM*TVAVLL3,K
 A TTMCQ,K=(TVAVLL,K+TVCSNL,K)*((CPTV*CRFTV)/12)+((FCPV*CRFTF)/12))
 R TFDCOMR,KL=TTMMOM,K+TTMCQ,K
 L TFDL,K=TFDL,J+DT*(TFDRPTR,JK-TFDCOMR,JK)
 L TFDOMDL,K=TFDCMDL,J+DT*(TFDCOMR,JK-TFDEXPR,JK)
 R TFDEXPR,KL=TFDCMDL,K/TFDEXPD
 A TVAV1BP,K=TVAVLL1,K+TFDCOLD*(TVDLGR,JK-TVLVGR1,JK)
 A TVAV2BP,K=TVAVLL2,K+TFDCOLD*(TVLVGR1,JK-TVLVGR2,JK)
 A TVAV3BP,K=TVAVLL3,K+TFDCOLD*(TVLVGR2,JK-TVLVGR,JK)
 A TVAVBP,K=TVAV1BP,K+TVAV2BP,K+TVAV3BP,K
 A TVCNBP,K=TVCSNL,K+TFDCOLD*(TVORDER,JK-TVDLGR,JK)
 A EMTOM,K=TIUMOM*TVAV1BP,K+T2UMOM*TVAV2BP,K+T3UMOM*TVAV3BP,K
 A EMTCO,K=(TVAVBP,K+TVCNBP,K)*((CPTV*CRFTV)/12)+((FCPV*CRFTF)/12))
 A MTREVN,K=EMTCD,K+EMTOM,K-TFDL,K
 A MTSBRPT,K=TCOSBF,K*EMTCD,K+TOMSBF,K*EMTOM,K
 A TCOSBF,K=TCOSBFI+STEP(TCOSBFC,K,12)
 A TCOSBFC,K=TCOSBFF-TCOSBFI
 A TOMSBF,K=TCOSBFI+STEP(TOMS8FC,K,12)
 A TOMSBFC,K=TCOSBFF-TOMS8FI
 A MTREVFU,K=MTREVN,K-MTSBRPT,K
 A FARE,K=MTREVFU,K/PRTMTD,K
 A MTURPT,K=FARE,K*TMTO,K

NOTE

NOTE BLOCK 10 TRANSIT COMMUTING COST

NOTE

A MTRANC,K=COMTPM*FARE,K

NOTE

NOTE BLOCK 11 TRANSIT COMMUTING TIME

NOTE

A RTRAN,K=RTRANI+STEP(RTRANF,12)
 A TSPEED,K=SWITCH(25-0,375*RCONG,K,RTSPEED,RTRAN,K)
 A TRANSM,K=60/TSPEED,K
 A TRANS,K=TVAVLL,K*AMDPTV
 A TRACC,K=(VTACP*AREA)/TRANS,K

NOTE

NOTE MODEL CONSTANTS

NOTE

C DE1=-0,5
 C DE2=-0,8
 C DE3=-0,1
 C DE4=-0,4
 C DE5=-0,7
 C CE1=0,1
 C CE2=0,1
 C CE3=0,1
 C CE4=0,1
 C CE5=0,1
 C ACPA=1,6
 C RADF=0,10
 C PTDF=0,006
 C MDFAD=0,60
 C MDFRD=0,50
 C RDPLGD=12
 C RDGSND=24
 C RDLIFE=360
 C RFDCOLD=3
 C RFDEXPD=3
 C PHCOPR=0,092
 C RFDDIVF=0,5
 C MNCRPLM=145000
 C CRPLMRI=8,33

C	RD1UMDM=130
C	RD2UMDM=160
C	RD3UMDM=200
C	CRFR=0.08059
C	RDSURF=0.05
C	COMDIS=10
C	COMTPM=40
C	ANTM=0.026
C	AGSDILI=0.21
C	AGSDILF=0.21
C	AMPG=10.0
C	AINSURM=0.014
C	APKTLISM=0.018
C	ACOPM=0.044
C	AMMPA=833
C	HINTV=33
C	DPHPPV=43
C	AMDPTV=150
C	TVPLGD=6
C	TVCSND=9
C	TVLIFE=144
C	CRFTV=0.11928
C	FCPV=4500
C	CRFTF=0.06646
C	CPTV=39000
C	TFDCOLD=1
C	TFDEXPD=3
C	T1UMDM=2125
C	T2UMDM=2540
C	T3UMDM=3050
C	TOMS8FI=0.167
C	TOMS8FF=0.167
C	TCOS8FI=1.

TCDSBFF=1.
 RTRANI=0.
 RTRANF=0.
 RTSPEED=30
 VTACP=53.17
 MCMCRA=0
 AREA=900
 SMCON=6

NOTE

NOTE INITIAL CONDITIONS

NOTE

RDVLL1=500
 RDVLL2=300
 RDVLL3=200
 TVAVLL1=33
 TVAVLL2=0
 TVAVLL3=0
 PAD=22407
 PTD=1200
 RFDL=0
 TFDL=0
 PADCS=0
 PTDCS=0

NOTE

NOTE COMPUTED INITIAL CONDITIONS

NOTE

RDPLGR=RDLVGR
 RDBGGR=RDLVGR
 RDCMGR=RDLVGR
 TVPLGR=TVLVGR
 TVORDER=TVLVGR
 TVDLGR=TVLVGR
 PKHRCOM=PTD+PAD*ACPA
 CPAD=PAD
 FCPAD=PAD
 TA=PAD/PADF
 FCPTD=PTD


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N N TMTD=PTD/PTDF
N N RDAVLL=RDAVLL1+RDAVLL2+RDAVLL3
N N RDLVGR=RDAVLL3/(RDLIFE/3)
N N RDPLDL=RDLVGR*RDPLGD
N N RDGSNL=RDLVGR*RDGSND
N N POPDENS=POP/AREA
N N CRPLM=MNCRPLM+CRPLMRI*POPDENS
N N RDTMCO=(RDAVLL+RDGSNL)*CRPLM*(CRFR/12)
N N RDTMDM=RD1UMDM*RDAVLL1+RD2UMDM*RDAVLL2+RD3UMDM*RDAVLL3
N N RFDCOMR=RDTMDM+RDTMCO
N N RFDDUEL=RFDCOMR*RFDCOLD
N N RFDCMDL=RFDCOMR*RFDEXPD
N N MRDREVN=RDTMCO+RDTMDM
N N MRREVFU=(1-RDSUBF)*MRDREVN
N N RDTXRG=(MRREVFU*AMPG)/((TA*AMPA)*(1-RFDDIVF))
N N RCONG=(HDFAD*CPAD)/(MDFRD*RDAVLL)
N N ASPEED=45-0.375*RCONG
N N TVAVLL=TVAVLL1+TVAVLL2+TVAVLL3
N N TVLVGR=TVAVLL3/(TVLIFE/3)
N N TVPLDL=TVLVGR*TVPLGD
N N TVCSNL=TVLVGR*TVCSND
N N TTMCO=(TVAVLL+TVCSNL)*((CPTV*CRFTV)/12)+((FCPV*CRFTF)/12)
N N TTMOM=T1UMDM*TVAVLL1+T2UMDM*TVAVLL2+T3UMDM*TVAVLL3
N N TFDCOMR=TTMOM+TTMCO
N N TFDDUEL=TFDCOMR*TFDCOLD
N N TFDCMDL=TFDCOMR*TFDEXPD
N N MTREVN=TTMCO+TTMOM
N N MTSBRPT=TCOSBF*TTMCO+TOMSBF*TTMOM
N N MTREVFU=MTREVN-MTSBRPT
N N FARE=MTREVFU/TMTD
N N TSPEED=25-0.375*RCONG
N N TRANS=TVAVLL*AMDPTV
N N MAUTOC=(COMTPM*COMDIS)*(AMTM+(AGSOILG/AMPG)+AINSURM+APKTLISM+ACOPM+
X (RDTXRG/AMPG))/ACPA

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N AUTOTM=60/ASPEED
N MTRANC=COMTPM*FARE
N TRANTM=60/TSPEED
N TRACC=(VTACP*AREA)/TRANS
N FMAUTOC=MAUTOC
N FAUTOTM=AUTOTM
N FTRANCM=MTRANC
N FTRANTM=TRANM
N FTRACC=TRACC
N DRCONG=RCONG
SPEC DT=1/LENGTH=240/PRTPER=12/PLTPER=12
PRINT RDTXRG,MAUTOC,ADCHNG1,TDCHNG4,ASPEED,AUTOTMC,ADCHNG2,TDCHNG5,
X FARE,MTRANC,ADCHNG3,TDCHNG1,CPAD,CPTD,TSPEED,TRANM,ADCHNG4,TDCHNG2,
X TRANS,TRACC,TRACC,ADCHNG5,TDCHNG3,RDAVLL,TVAVLL,RCONG,AUTOF,TRANF
PLOT MAUTOC=A,MTRANC=T
PLOT AUTOTM=A,TRANM=T,TRACC=C
PLOT AUTOF=A,TRANF=T
RUN SSPOP/XCOSUB/XONSUB
C TOMSBFF=0.5
RUN SSPOP/XCOSUB/XONSUB
C RTRANF=1.
RUN SSPOP/XSUB/XBUS
C AGSDILF=0.40
RUN SSPOP/XSUB/40GAS
C AGSDILF=0.90
RUN SSPOP/XSUB/90GAS

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CP TMSBFF=0,
CP TCOSBFF=0,
RUN SSPOP/NDSUB
C AGSDILF=0.40
RUN SSPOP/NDSUB/40GAS
C AGSDILF=0.90
RUN SSPOP/NDSUB/90GAS
C RTRANF=1,
RUN SSPOP/XBUS/NDSUB
CP MCMCRA=138
RUN POPINC/NDSUB
C RTRANF=1,
RUN POPINC/NDSUB/XBUS
CP TMSBFF=0.167
CP TCOSBFF=1,
RUN POPINC/XSUB
C RTRANF=1,
RUN POPINC/XSUB/XBUS

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