

4.0 Modeling the System

In this chapter the development and integration issues of the proposed ITPM are described in detail. While the application of this model will be made to a bus transit system in Chapter 5, the framework is judged to be general enough to be applicable to other types of mass transit systems. This chapter tries to describe each one of the four sub-models discussed in Chapter 3 in more detail and presents model building procedures including some of the algorithms used. In later part of this chapter, the integration procedure of these sub-models is also presented step by step describing source codes of a simulation programming language.

4.1 Population Allocation Sub-Model

Urban simulation modeling of demographic activities emerged as an area of urban planning research in the sixties. There have been two notable accomplishments in representing several aspects of the urban system; by Lowry and Forrester (Lee, 1973; Anas, 1982). According to Anas, Lowry's approach was more popular as his model incorporated within its structure both a forecasting and an allocation procedure. This model enables not only the forecasting procedure but the analysis of the spatial dimension of urban areas and the resulting spatial interactions among land uses, transportation, housing, and employment.

In this study, Lowry's urban model is adopted. The model is based on the concept that a two-way interaction between employment and population drives urban development. A given spatial distribution of employment will generate a certain distribution of population and housing as a result of the employee's demands for residences. According to Lee (Lee, 1973). The model considers the three major components of metropolitan areas - a) population, b) employment in terms of numbers of

basic and non-basic employment, and c) the means of communication between them - the transportation network, as represented by journey time. This model attempts to describe urban change. Figure 4.1 shows a flowchart of the Lowry model. Appendix D shows programming sources for the Lowry model.

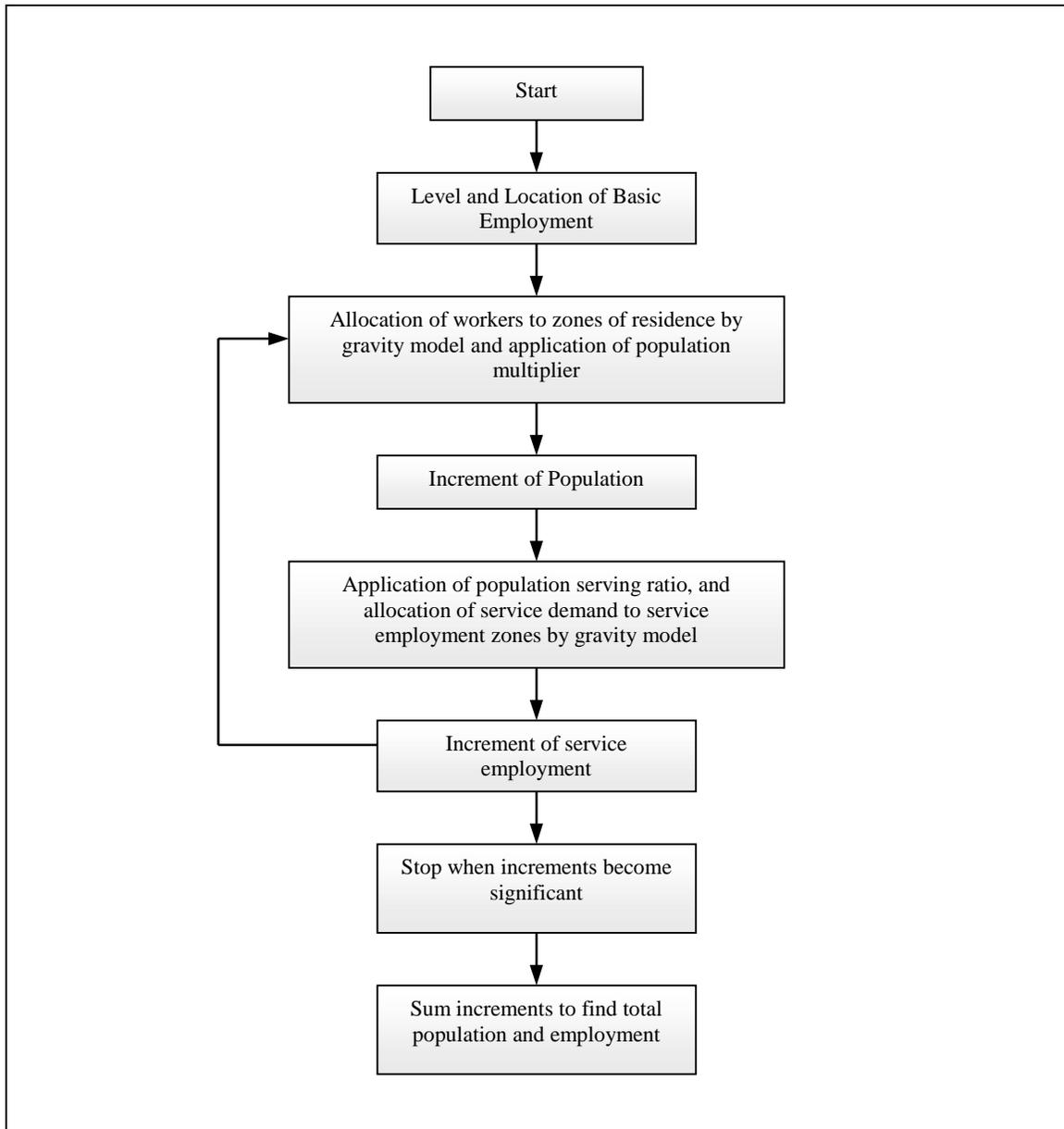


Figure 4.1 Flowchart of Lowry Model.

4.2 Modeling the Urban Transportation Planning Process

Generally it is believed that the Urban Transportation Planning Process (UTPP) originated with the Chicago Area Transportation Study (CATS, 1959), in which traffic demands were forecasted based on the assumption that they were related to human travel behavior, land use, and travel patterns. The UTPP has been the most popular tool for travel demand forecast in urban areas (Dickey, 1983). Papacostas (1993) defines UTPP as “to perform a conditional prediction of travel demand in order to estimate the likely transportation consequences of several transportation alternatives (including the do-nothing alternatives) that are being considered for implementation”. This process is an iterative, sequential procedure for evaluation and selection of transportation projects to serve present and future land uses. It is also recognized as a long-term planning process to forecast the future demand by mode and evaluate alternative networks based on certain scenarios. Throughout the years this sequential process has been refined with various techniques and methodologies. The following description provides a simple explanation of the four steps encompassed in the UTPP method.

1) Trip Generation: The main function of the trip generation is to process and estimate the total number of trips generated and attracted by each area unit (zone) in conjunction with the land use and the socio-economic characteristics of each zone. There are three approaches commonly used in the trip generation analysis: regression analysis, trip rate analysis, and cross-classification analysis. It is interesting to note that perhaps other novel approaches to approximate data with more complex mathematical models such as the use of neural networks and genetic algorithms might prove to be successful in the future.

2) Trip Distribution: In trip distribution each zone is taken one at a time and a determination is made of the zones to which its produced trips will be attracted. The trip

pattern within a study area is usually represented by means of a trip table. The distribution of trips is assumed to be dependent upon factors such as the availability of jobs, transportation facilities and travel times. Many mathematical models have been tried in trip distribution analysis: linear programming formulations, regression models, growth factor model, intervening opportunity model and gravity-type models.

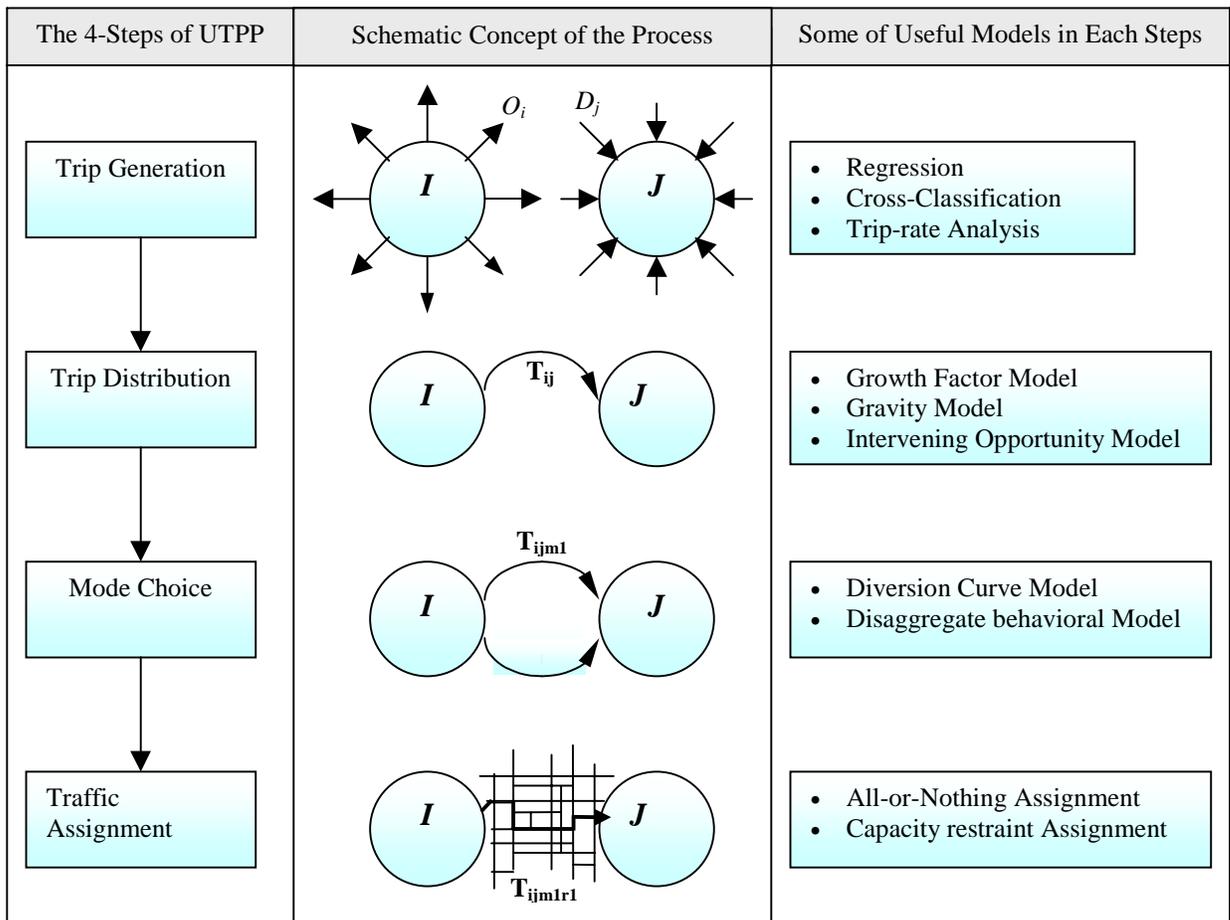


Figure 4.2 Schematic Illustration of the Four-Steps in UTPP.

3) Modal Split (Modal Choice): The modal split attempts the assignment of person-trips to the various alternative modes available in the study area. Three types of modal split models are usually used: trip-end model, trip interchange model, and

individual mode choice model. Significant factors in the determination of the mode used are grouped into three characteristics: trip, trip makers, and transportation system.

4) Traffic Assignment: This step involves the assignment of the distributed volumes of trips, by mode, to individual network links. Some types of assignment techniques used are: all-or-nothing, iterative, incremental, user-equilibrium, and system optimal traffic assignments.

4.2.1 Modeling the Trip Generation Process

The goal of trip generation (TG) process is to forecast the number of person-trips that will begin from or end at each travel analysis zone contained in the area of study. This forecast procedure is usually done for a typical day of the horizon year. This process usually considers some socio-economic data as input producing trip production/attraction values as the output.

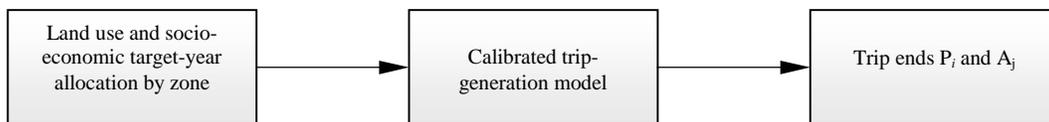


Figure 4.3 Trip Generation Inputs and Outputs.

The number of trips entering or leaving a zone is considered dependent on the socio-economic characteristics of people and land use in that zone (Dickey, 1983). Based on this idea person-trip productions (trips by all modes of travel) are influenced mainly by factors that speculate how people travel within an urban area. Factors such as car ownership, income, employment on the demand side serve to explain travel behaviors (Kanafani, 1989). On the supply side factors such as network performance are also considered for some types of trips (non-work trips).

Various aggregate models are used to estimate trip-productions and trip-attractions. Two general forms of these models are regression models and cross-

classification models (or category analysis models). For the proposed ITPM the regression model is selected.

1) Regression models:

If trip generation patterns and some socio-economic activity show considerable correlation, ordinary least-squares regression is often used to estimate the relationship between the number of trip productions and/or attractions. The general form of the multiple regression is shown in Equation 4.1.

$$Y = a_0 + a_1X_1 + a_2X_2 + \dots + a_rX_r \quad (4.1)$$

Where Y is the dependent variable (i.e., the number of trips produced or attracted), the X 's are the relevant independent or explanatory variables, and the a 's are the parameters of the model. While trip production is expressed as function of socio-economic data and/or population, trip attraction is expressed as function of land use, employment, and/or other economic activities (See Equations 4.2 and 4.3; Hobeika, 1996). Regression models are relatively straight forward to implement, thus cost effective and the data needs are moderate in size (Meyer et al, 1984).

$$\text{Trips Produced} = f(\text{Socio-economic var., Population}) \quad (4.2)$$

$$\text{Trips Attracted} = f(\text{Land use, Employment \& other Economic Activities}) \quad (4.3)$$

2) Cross-classification models:

Individual households are classified according to common socio-economic characteristics such as auto-ownership, income, or household size. Average trip production rates are then computed for each group from observed data. Multiplying the number of households in each category by the corresponding trip rate for the category in question one can then estimate the total; number of trips (per type of trip) generated in an urban area (see Figure 4.4). This model does not need many of the assumptions made for regression models (i.e., linear, additive relationship) and is preferred by many planners (Papacostas, 1993).

a) Number of households and total trips made, categorized by household size and auto-ownership level							b) Household trip rate			
	Auto ownership						Auto ownership			
	No. of Households			No. of trips						
Family Size	0	1	2~	0	1	2~	0	1	2~	
1	925	1872	121	1098	4821	206	1.19	2.57	1.70	
2	1471	1934	692	2105	6129	1501	1.43	3.16	2.17	
3	1268	3071	4178	1850	13989	19782	1.45	4.55	4.74	
4 ~	745	4181	4967	1509	18411	25106	2.02	4.40	5.05	
c) Forecasted number of households in one zone, categorized by household size and auto-ownership level							d) Forecasted number of trips from this zone			
Family Size	Auto ownership			Auto ownership						
	0	1	2~	0	1	2~	Total			
1	24	42	8	29	106	14	151			
2	10	51	107	14	161	232	407			
3	11	31	158	16	141	749	906			
4 ~	3	17	309	6	75	1564	1645			
Total				65	485	2559	3109			

Source : Meyer et al, 1984

Figure 4.4 An Example of Cross-Classification Trip Analysis.

4.2.2 Modeling the Trip Distribution Process

The task of trip distribution (TD) modeling is to distribute or link up the zonal trip ends (either productions or attractions) generated in TG step in order to predict the flow of trips T_{ij} from each production zone i to each attraction zone j .

The most common mathematical formulations of TD include various growth factor models, the gravity model, and a number of opportunity models. In general TD models can be classified into three categories according to the basic modeling approach; 1) Origin-destination or unconstrained gravity models (utility model of TD, and the generation-distribution models), 2) Choice models (intervening opportunity model, and gravity model), and 3) Physical models of spatial interaction (most of the original formulations of TD models derived from concepts of statistical likelihood and entropy).

Among them, gravity model, in one form or another, has been the most popular and commonly used method to model this step. In this study, a doubly-constrained gravity model shown in Equations 4.4 through 4.6 is used. This model calibrates both predicted productions (O'_i) and attractions (D'_j) one by one until O'_i and D'_j computed and those observed achieve some degree of convergence.

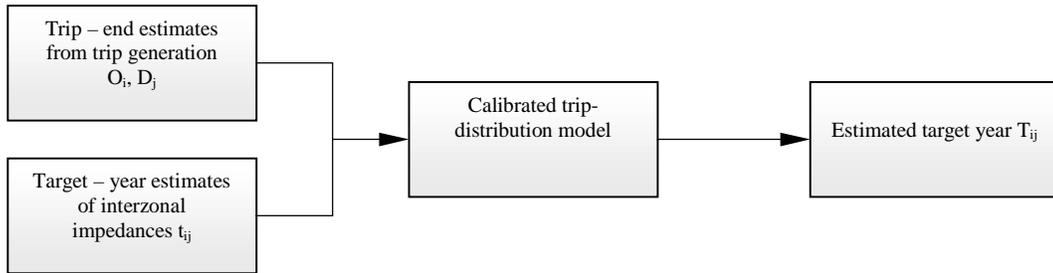


Figure 4.5 Trip Distribution Inputs and Outputs.

$$V_{ij} = \frac{A_i B_j O_i D_j}{t_{ij}^x} \quad (4.4)$$

$$A_i = \frac{1}{\sum_j (B_j \cdot D_j / T_{ij}^x)}, (i = 1, \dots, m) \quad (4.5)$$

$$B_j = \frac{1}{\sum_i (A_i \cdot O_i / T_{ij}^x)}, (j = 1, \dots, n) \quad (4.6)$$

where, V_{ij} = Interzonal trips produced in zone i and attracted to zone j
 A_i = number of trips produced by zone i
 x = gravity constant
 B_j = number of trips attracted by zone j
 T_{ij} = travel time between zone i and zone j
 m = number of zones producing trips
 n = number of zones attracting trips

4.2.3 Modeling the Mode Choice Process

The mode choice is used to estimate future travel volumes by mode. This step is based on the concept that the mode-choice behavior of trip makers can be explained generally by three categories of factors: the characteristics of available modes; the socioeconomic status of the trip maker; and the characteristics of the trip (Papacostas, 1993).

Usually mode choice models are classified into two groups according to the type of mathematical abstraction used; 1) aggregate models, and 2) disaggregate behavioral models. Statistical data are mainly considered in aggregate models, and for the latter the individual utility measures are considered. The aggregate models are differentiated according to the sequential procedure in which each model is applied. 'Trip-end mode choice model', is processed just after the trip generation step. 'Trip interchange mode choice model' is executed after the trip distribution model.

In disaggregate behavioral models the term 'disaggregate' means that the models are based on individual observations and the term 'behavioral' means that they reflect the actual choice process level on which the choice is made.

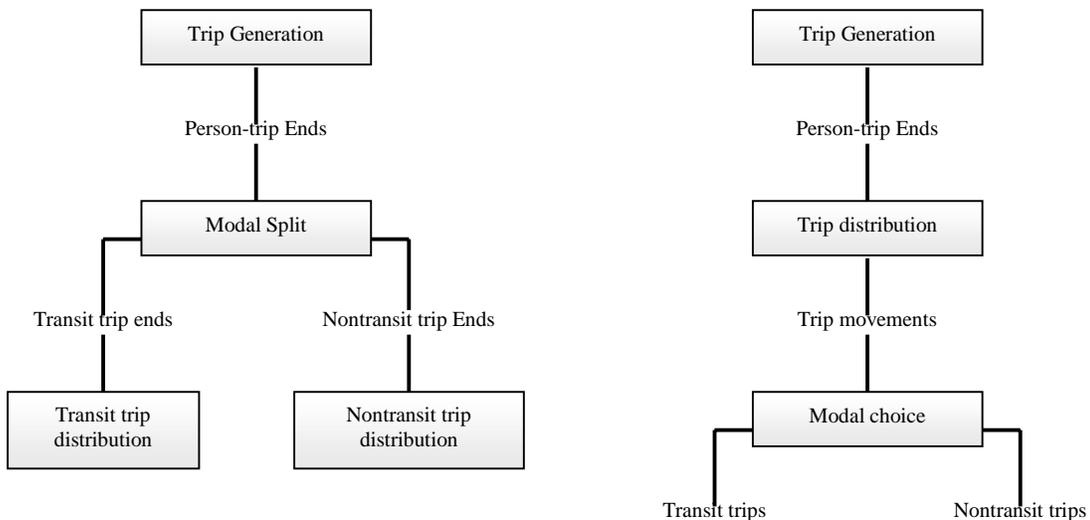


Figure 4.6 Modal Choice Alternatives in the UTPP.

The disaggregate behavioral model applied in this study is often called ‘individual mode choice model’. This name is based on the theories of the individual choice behavior first proposed by economists (Horowitz, 1986). Practically all of these models are based on the following relationship: the probability that an individual will choose a particular alternative is a function of the characteristics of the individual and of the overall desirability of the chosen alternative relative to all other alternatives. The desirability of an alternative is usually represented through a linear utility expression.

In order to predict whether or not a particular alternative will be chosen, the value of its linear utility expression must be transformed into a probability value, ranging between zero and one. These probabilities are usually characterized by G-shaped behavior curves as seen in Figure 4.7.

Because the dependent variable of an individual choice model is a probability, which cannot be observed, this model cannot be estimated using simple curve fitting techniques like linear regression analysis. To overcome this problem, the technique known as the 'Maximum Likelihood Estimation' is used. The two functions, which can be used to make this transformation, most commonly used in individual choice modeling are the probit and logit functions.

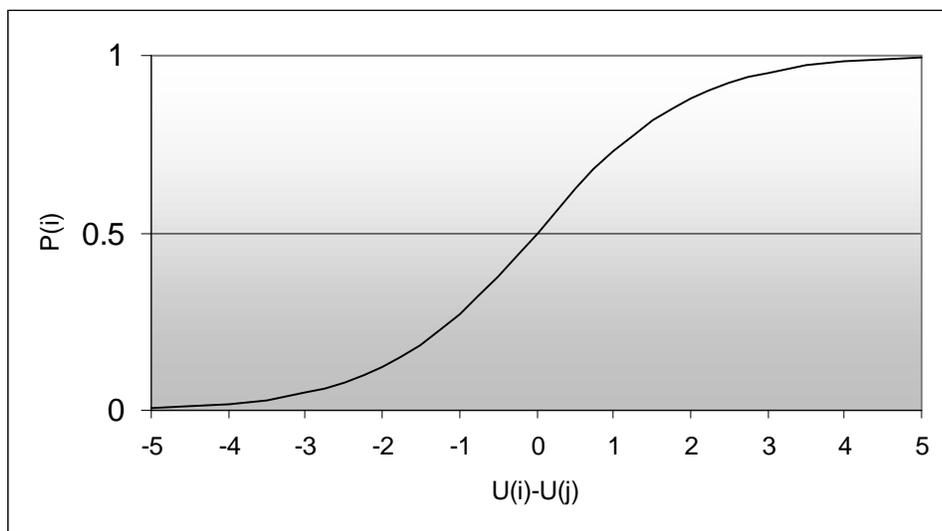


Figure 4.7 The Binomial Logit Model.

The probit and logit models are shown in Equations 4.7 and 4.8 respectively. The logit model has more advantages than its probit model counterpart. Logit models have been successfully applied to estimate mode choice behavior and transportation market share when supply variables of the model change (e.g., change of fare, service or introduction of new mode, etc.). The sample size needed for this model is relatively modest and the model itself can be adapted across time and space.

$$P_i = \frac{1}{\sigma \sqrt{2\pi}} \int_{-\infty}^{u_i} \exp \left\{ -\frac{1}{2} \left(\frac{x - \mu}{\sigma} \right)^2 \right\} dx \quad (4.7)$$

$$P_i = \frac{\exp(U_i)}{\sum_{j=1}^n \exp(U_j)} \quad (4.8)$$

where, P_i = the probability of choosing alternative i

U_i = the value of the utility function associated with alternative i

σ, μ = the mean and variance, respectively, of the associated normal distribution

Kanafani (1989) presented some common decision variables to explain mode choice behavior: i) in-vehicle travel time; ii) access, waiting, and transfer times; iii) travel cost; and iv) qualitative and attribute variables such as comfort, reliability, and safety. Typical forms of these variables must be either in difference, ratio, or logarithm form.

Conventional statistics based on transportation planning models are generally calibrated using data which has been aggregated in some manner. On the other hand the individual choice models are calibrated using observations of individual choice behavior as input data. Due to this individual characteristics of data, choice models are more data efficient than conventional transportation model. Some of the other desirable characteristics of these models have following characteristics:

- Can be calibrated with a small database.
- May be transferable to other urban area.
- Policy sensitive.
- Compare several alternatives in a single model.

To estimate the change of behavioral characteristics of passengers in choosing modes before and after the implementation of AVL system, the multinomial logit model is used in the proposed integration model. For this model a user questionnaire (survey) was developed and a model was calibrated using standard and its statistical techniques. The procedure is introduced in Chapter 5, the case study of Blacksburg Transit.

4.2.4 Modeling the Traffic Assignment Process

Traffic Assignment is the last phase of the urban transportation planning process. Traffic assignment step assigns zonal destination flows to transportation routes, based on some factors that affect route choice (i.e., travel times, travel costs, comfort, and levels of service; Hobeika, 1995; Dickey at al, 1983). This process adopts several techniques according to the ways of network traffic distribution methods; All or nothing, Single path with Capacity Restraint Assignment and Multipath Assignment.

4.3 Simulation Model for the Bus Operation

To trace the impacts of AVL technology on several decision variables in the UTPP (i.e., travel time, LOS, waiting time), a bus operations model using a continuous simulation technique was developed. Important transit supply characteristics such as LOS, waiting time, fuel consumption etc., are used as the MOEs in this study to understand their effects on ridership. For our purpose a continuous simulation technique was adopted to understand the microscopic behavior of the transit system throughout the

network. Some of the outputs of this microscopic simulation serve as inputs to the more macroscopic mode choice step in UTPP to link important behavior of one sub-model with another one.

Figure 4.8 shows a simplified flowchart of the transit simulation model developed. The first step in executing this simulation is the initialization step of the state variables of the model. A discrete step size is used as the time advance mechanism of the simulation clock. In this study time unit of second is applied. This would create good time history of all state variables. The bus starts its operation and travels along designated links on an urban network. Acceleration, speed, distance traveled and travel time are tracked as part of the state and rate variable definitions in the model. Fuel consumption, another state variable is also computed to assess one of the important cost components in the bus operation. The acceleration model developed uses realistic engine power-speed curves to ascertain instantaneous acceleration and acceleration potential considering external factors such as highway grades and number of passengers inside the vehicle. One of the most important outputs of this model is travel time and scheduling conformance. The simulation process integrates the basic equations of motion of the vehicle forward in time until the bus reaches its next stop point along the route. Dwell times consistent with number of boarding/alighting passengers are included in the simulation to add realism. Time conformance checks are also part of the model to understand microscopically the level of service relationships achieved with specific technologies. This continuous simulation behavior process is repeated until the vehicle completes its route. During the simulation of bus operations, buses encounter various types of intersection (signalized, unsignalized) and turns. Surrounding traffic conditions also impacts the bus performance, speed regulations, terrain conditions and so on. In this model traffic network conditions are fed as exogenous variables based on engineering computations consistent with traffic flow theory. Geographic Information Systems (GIS) modeling environment is used to acquire and process network data from topology maps and electric databases. The simulation model has been developed in MODSIM II, an object-oriented simulation programming language developed by CACI (CACI, 1993).

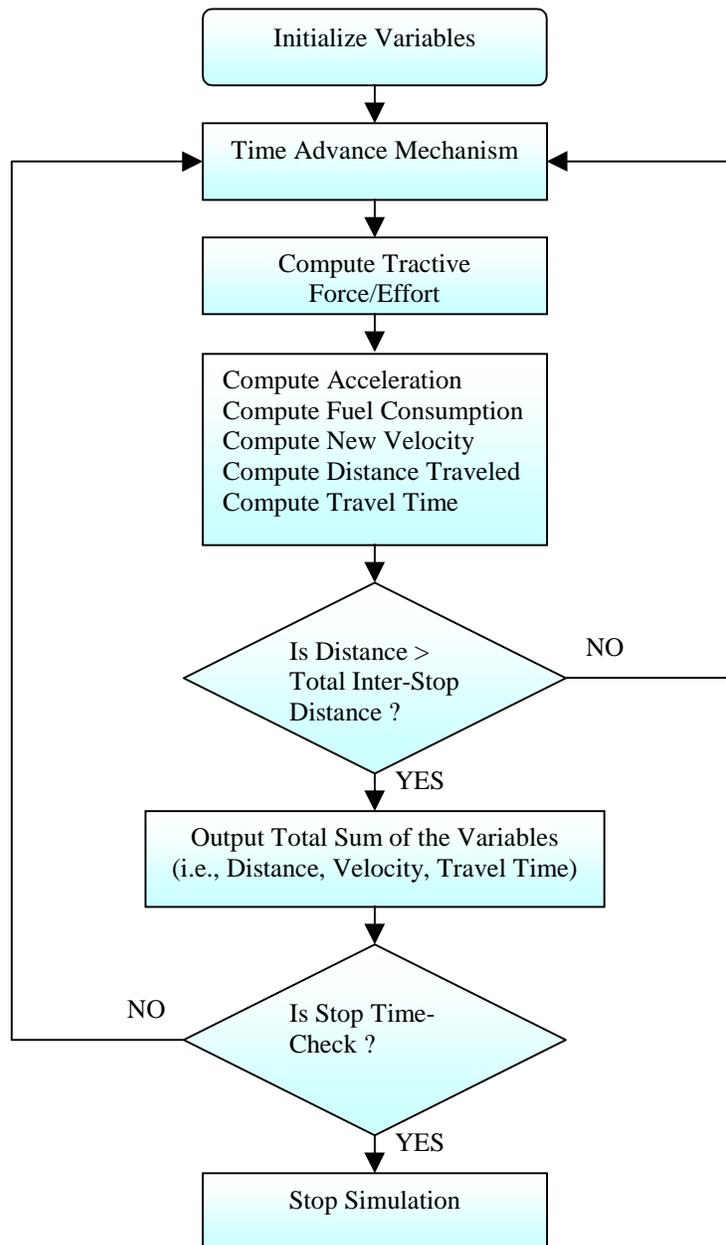


Figure 4.8 Flow Chart to Estimate Some MOEs for Bus Operation.

This analysis is based mainly on bus performance specifications supplied by the vehicle manufacturer. For GIS manipulation purpose, ARC/INFO, a standard GIS management software package developed by ESRI (ESRI, 1996) was used. Several

variables in this model are stochastic in nature to add realism to the transit operation. The model can be extended to make every variable stochastic if needed with very little effort.

The schematic relationship of each factor considered in the bus operation simulation is presented in Figure 4.9. Based on bus manufacturer specification data, bus power output and its tractive effort are estimated in Part A of the causal diagram. During the simulation of bus operations, buses encounter various types of intersections (signalized, unsignalized) and turns. Surrounding traffic conditions also impact the bus performance; speed regulations, terrain conditions, dwell times from number of passengers' alight/boarding and so on. In this model those traffic network conditions and passengers characteristics are fed in Part B as exogenous variables based on engineering computations consistent with traffic flow theory. In Part C of Figure 4.9, the outputs of bus performance (Part A) and bus travel characteristics (Part B) are applied to estimate bus speed profiles, travel distance, travel time, and fuel consumption. One of the most important outputs of this model is travel time along any route on the network. The simulation process integrates the basic equations of motion of the vehicle forward in time until the bus reaches its next stop point along the route. The integration of this simulation model requires relationships adopted from transportation planning and traffic engineering. Finally the cyclic behavior process is repeated until the vehicle completes its route.

4.3.1 Development of ITPM

The development process of the ITPM framework consists of 6 iterative loops representing various levels of analyses as shown in Figures 4.10 and 4.11. These loops are labeled : 1) the bus performance characteristics analysis (Loop A); 2) highway traffic condition and bus demand analysis (Loop B); 3) bus route operation (Loop C); 4) inter stop bus operation (Loop D); 5) microscopic bus performance simulation (Loop E); and 6) evaluation analysis (Loop F).

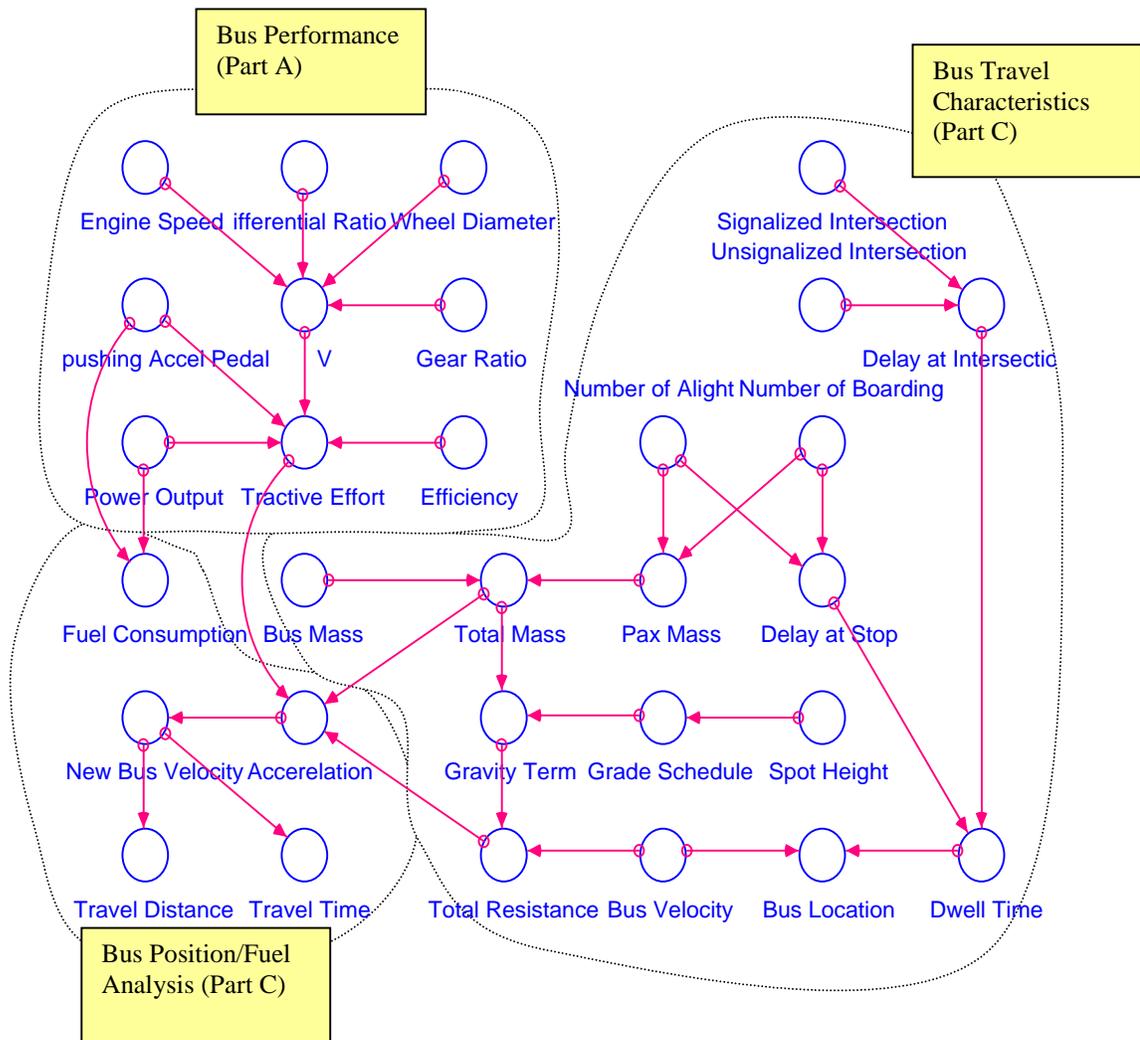


Figure 4.9 Causal Relationships in the Microscopic Bus Simulation Model.

Figure 4.10 shows a simplified diagram of this computational framework. Figure 4.11 shows the framework in more detail. The function and role of each loop is described in the following paragraphs.

In loop A, the basic bus performance characteristics such as vehicle engine speed and tractive effort curves are estimated from the data of specifications of the bus model. The output of this process is saved and used as the input data in the form of table functions in the microscopic bus performance simulation in Loop E. In loop B several

measures of the traffic condition are estimated. Loop D estimates physical road traffic conditions such as street grade, passenger demands at each bus stop (boarding, alighting number of passengers at each bus stop), and delay/dwell times at each stop and intersections/turns. With the bus performance and traffic demand data at each bus stop and knowing the interval between stops from loops A and B, a microscopic bus operation analysis is conducted in loop E, from which several MOEs are obtained. Finally, in Loop F, by modifying conditions according to the given several scenarios analyses are executed. These include; sensitivity analysis, B/C analysis, and scenario analysis. This process forms a closed system and is repeated iteratively until then horizon is reached.

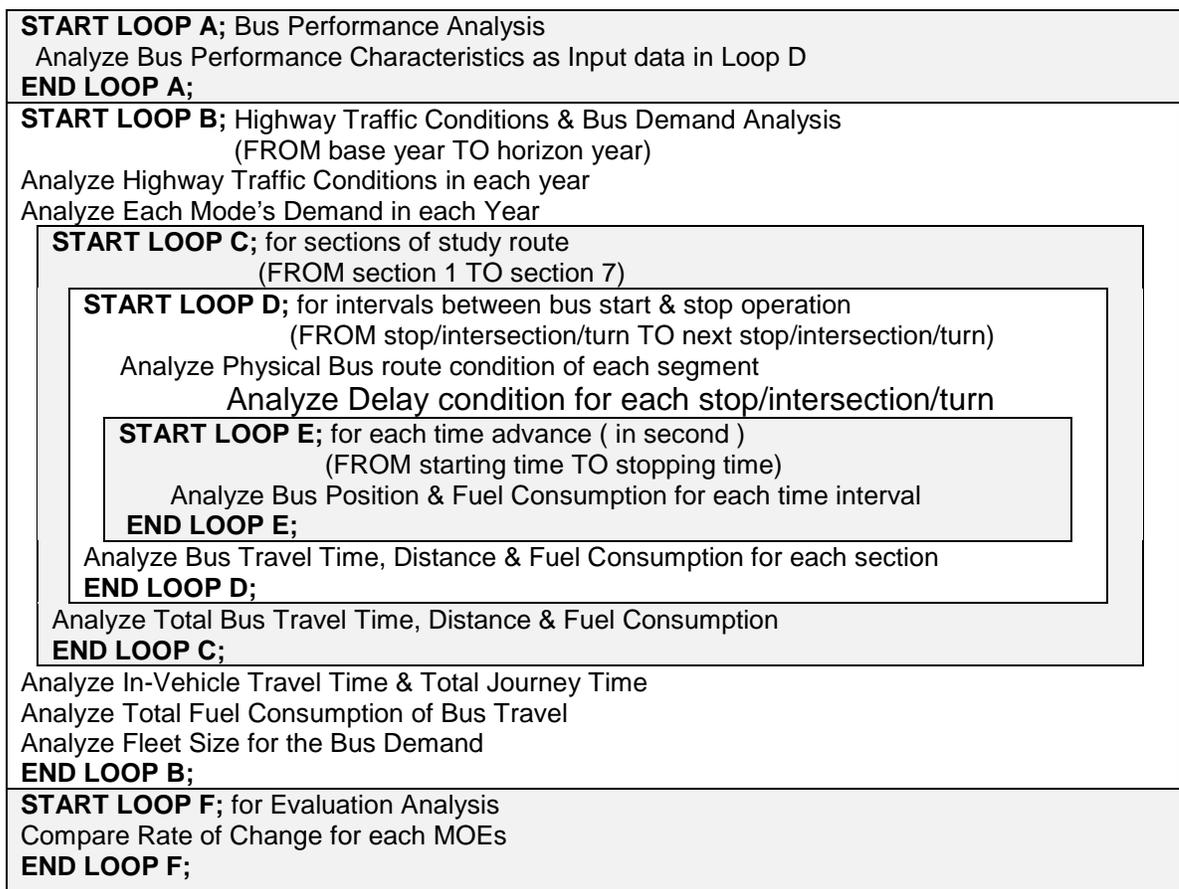


Figure 4.10 Conceptual Framework of Bus operation Simulation (Stage I).

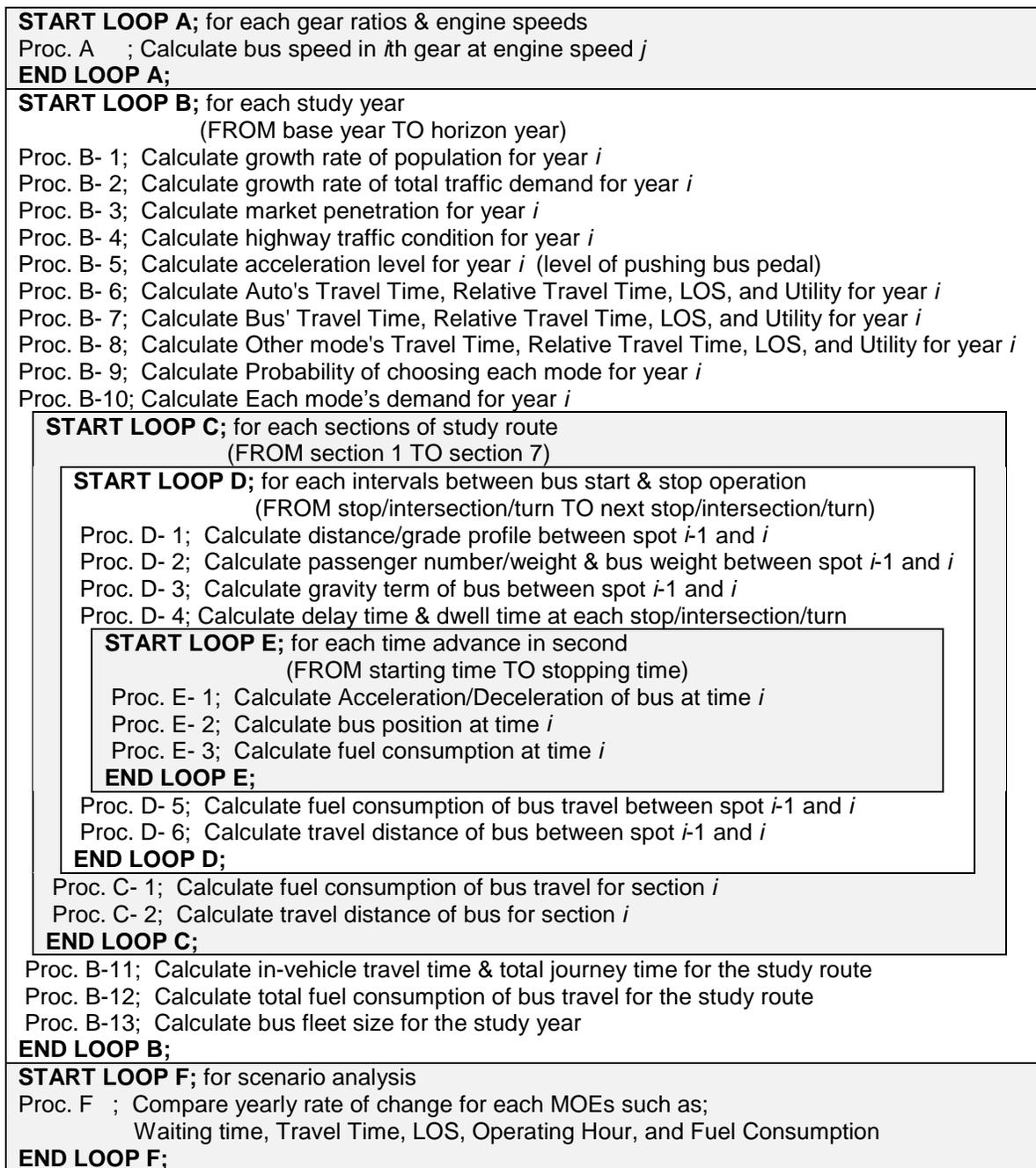


Figure 4.11 Framework of Bus operation Simulation (Stage II)

With this conceptual framework, next a description of the mathematical algorithms needed to estimate all model variables are presented whenever possible. Those

detailed and tangible programming codes are generated using MODSIM simulation programming language.

4.3.1.1 Loop A: Bus Performance Analysis

- Procedure A : Calculate bus speed in i th gear at engine speed j

Highway vehicles obtain their power from internal combustion engines. The speed of vehicle (V) is proportional to the power plant engine speed (N) and the diameter of the tractive wheels and inversely proportional to the transmission gearing ratio. The relationship is presented in Equation 4.9.

$$V = \frac{N \cdot D \cdot \pi}{J \cdot u_i} \quad (4.9)$$

Where, J is the differential gearing ratio, u_i is the transmission gearing ratio for the i th gear, D is the diameter of the tractive wheels, and N is the engine speed.

Using a simple expression to convert power to tractive effort a formula relating power to tractive effort and speed is obtained (See Equation 4.10).

$$TE = \frac{\eta \cdot P}{V} \quad (4.10)$$

Where, TE is engine tractive effort, P is the power output, η is the efficiency of the engine, and V is the vehicle speed. This tractive effort directly effects the acceleration, which impacts its velocity. The acceleration is also affected by the total mass of the bus and the gravity-aided resistance. The total number of passengers in vehicle is used to estimate the total mass of the bus and the corresponding vehicle resistance factor (i.e., proportional to the normal force acting on the vehicle tires). These relationships are represented in loop C which details the procedure to analyze the bus position and perform

fuel consumptions. One assumption about the bus performance model is that the bus simulated has a fully automatic transmission so that gear shifts occur at prescribed speeds. For example, Blacksburg Transit (BT) operates GMC RTS-2 and ROHR Flexible buses with automatic transmissions. Table 4.1 shows some of the bus specifications applicable to a GMC RTS-2 bus. Detailed specifications for the simulation model such as vehicle mass, and engine power curves are adapted from manufacturer performance data (See Appendix D).

Table 4.1 Bus Specifications used in the Bus Performance Analysis Sub-Model.

Variable	Description	Applied Value for The BT Case Study				
		Gear Ratio				
		1st	2nd	3rd	4th	5th
$U[i]$	Transmission gearing ratio for the i th gear	4.5	3.0	2.3	1.5	1.0
$RPM[i]$	Engine Speed for the i th gear	800	1,000	1,600	2,000	2,400
$hp[i]$	Power output of Bus engine in gear i	70	125	180	220	230
J	differential gearing ratio	4.5				
Diameter	diameter of the tractive wheels	0.92				
Efficiency	Efficiency of the Engine system	0.8				
Buston	Bus Weight in Ton	120				

Equations 4.11 and 4.12 show the MODSIM code to calculate the bus speed and its tractive effort. The values '(60./1000.)' in Equation 4.11 and '2650.' in Equation 4.12 are used as conversion factors to change the units from $m/min.$ to $km/hr.$, and $hp/km/hr.$ to $Newton (N)$.

```

...
FOR i :=1 TO 5                                (** i = gear ratio      **)
  FOR j :=1 TO 5                              (** j = Engine Speed  **)
    V[i,j]:=(RPM[i]*diameter*pi/(J*u[j]))*(60./1000.); (4.11)
    TE[i,j]:=2650.*hp[i]*efficiency/V[i,j];          (4.12)
  END FOR;
END FOR;
...
(** V[i,j]   : Bus speed in jth gear at engine speed i      **)
(** RPM[i]   : Engine Speed for the ith gear                **)
(** J        : differential gearing ratio                    **)
(** u[j]     : Transmission gearing ratio for the jth gear   **)
(** TE[i,j]  : Tractive effort of bus engine system for the  **)
(**          : jth gear, engine speed i                     **)
(** hp[i]    : Power output of Bus engine in ith gear       **)

```

4.3.1.2 Loop B: Highway Traffic Conditions and Bus Demand Analysis

- Procedure B – 1, 2 : Estimation of Population growth and the total traffic demand for year i

Modeling population growth rate step has important meaning in the ITPM simulation model. Conceptually, the population growth rate of a given year is planned to be controlled by accessibility that impacted by travel time change due to APTS technology in previous study year. This causal relation can be modeled using population allocation analysis. However, in the BT case study, the model is modified considering actual conditions of the study area. Due to the data limitation and size of study area, the population growth rate is set to be exogenous and it controls the total amount of traffic demand for all transportation modes every year. While this reduces the precision of the ITPM model as the impact of travel time change will not reflect the total population change and thereon the change of total traffic demand of study year, the model can be adapted to include a feedback loop to reflect this behavior. In spite of this shortcoming, considering both sizes of two systems of the study area (AVL implementation on a public transit route and total population of the society), it can be shown that the modifications would not impact significantly the results of the model. With this assumption, the modeling steps are continued.

Table 5.11 shows the population projection for the BT case study. Equation 4.13 through 4.18 shows the programming code in MODSIM II.

```

...
FOR year:= 1 TO numyear;
...
IF (1<year) AND (year<4)                                (** 1999 - 2000 **)
    growthrate:=growthrate*1.0098;                      (4.13)
    traffiddemand:=iniddemand*growthrate;               (4.14)
ELSIF (4<=year) AND (year<14)                          (** 2001 - 2010 **)
    growthrate:=growthrate*1.0077;                      (4.15)
    traffiddemand:=iniddemand*growthrate;               (4.16)
ELSIF (14<=year)                                        (** 2011 - 2020 **)
    growthrate:=growthrate*1.0058;                      (4.17)
    traffiddemand:=iniddemand*growthrate;               (4.18)
END IF;

```

```

...
END FOR;
(** numyear      : Number of study year from 1998, the starting year**)
(** growthrate   : Yearly growth rate of traffic demand          **)
(** trafficdemand: Total traffic demand using all the modes      **)
(** inidemand    : Total traffic demand of the first study year  **)

```

- Procedure B- 3; Estimation of market penetration for year i

Market Penetration or the rate of information diffusion is a critical variable in APTS. This parameter shows the accessibility to advanced traveler information systems (ATIS). Typically these ATIS are located at strategic points on the network and provide useful information to users about the location of the buses on the network. Examples of ATIS technology used in conjunction of AVL systems are: bus stop displays, cable TV, information systems, kiosks, and the internet. This indicator shows the rate of informed customers who are able to take advantage of the ITS technology. Passenger accessibility to bus operation information including present bus location and estimated arrival times at stop affects waiting times as well as the LOS of the system.

Previous research efforts report that the benefits of ITS should increase with an increase in market penetration (Hamerslag, R. et al, 1991; Boyce, D. E.1991; Kanafani et al, 1991). However, the relationship between market penetration and benefits may not always be linear (Underwood, 1992). For example, In the case of dynamic route guidance at certain bottleneck, high market penetration of traveler information systems would even show negative relation with traveler satisfaction. This example tells that it may be difficult to predict what types of impacts APTS technology could have in transit acceptance. Previous research also tried to find the value and impact of market penetration under various ITS conditions. In many existing UTPP models it is assumed that people have full knowledge about the condition of all travel mode and route alternatives (Hobeika, 1995). This yields optimistic predictions where drivers always choose the best modes and routes based on timely and precise information. It is assumed that the market penetration increases over time depending upon the scenario being

investigated. There is a detailed description of this issue in Chapter 5.5. Equations 4.19 through 4.25 show the actual source code for the market penetration of BT.

```

...
(** YEARLY GROWTH RATE OF Mktpnt**)
IF (scenario=1)
    mktpnt:= .0;
ELSIF (scenario=2)
    mktpnt:= 1.;
ELSE
    IF (2=year)
        mktpnt:= .3;
    ELSIF (2<year) AND (year<7)
        mktpnt:= mktpnt*1.1362;
    ELSIF (7<=year) AND (year<12)
        mktpnt:= mktpnt*1.0845;
    ELSIF (12<=year) AND (year<17)
        mktpnt:= mktpnt*1.0371;
    ELSIF (17<=year)
        mktpnt:= mktpnt*1.0078;
    END IF;
END IF;
...
(** mktpnt: Market Penetration of AVL user-interface in each study **)
(** year

```

Proc. B- 4; Estimation of Highway Traffic Conditions for year *i*

In this process, the model tries to represent highway traffic conditions such as vehicle travel speed and travel time as functions of traffic volume and capacity of the route. This procedure is important as travel time is one of the major factors considered in mode choice analysis. Microscopic bus operations are also impacted by the highway traffic conditions (i.e., bus operation speed, fuel consumption). The traffic condition is mainly dictated by annual traffic volume increments due to population growth and mobility. Mode choice preferences impact the highway traffic condition as more people could use transit modes and free congestion on highways and streets. In the ITPM, the highway travel time is expressed as a function of population (growth rate), probability of choosing each node, and highway physical characteristics conditions such as link

capacity and volume. With these variables, the analysis follows three steps to represent the highway condition.

Equations 4.26 through 4.28 show the MODSIM code to calculate changes to annual traffic volume. Note that traffic volume is a state variable estimated using the growth rate factor on the network and the average car occupancy. The average car occupancy is assumed to be 1.2 in this study.

```

...
FOR year:= 1 TO numyear;
...
FOR i :=1 TO NumOfRt                                (**Number of Sections**)
FOR j :=1 TO NumOfAltn                              (**Number of alternative routes**)
IF year<=2
Vol[i,j]:= (Vol[i,j]+Vol[i,j]*(growthrate-1.)/AvgPaxPerAuto);      (4.26)
ELSE
Vol[i,j]:= (Vol[i,j]+Vol[i,j]*(growthrate-1.)/AvgPaxPerAuto)*ATP/IniATP;      (4.27)
END IF;
      Qtotal[i]:=Qtotal[i]+Vol[i,j];      (4.28)
...
END FOR;
...
END FOR;
...
END FOR;
(**AvgPaxPerAuto : Average number of passenger in a auto ; 1.2      **)
(**NumOfRt      : Number of sections in study route                  **)
(**NumOfAltn    : Number of alternative routes in each section      **)
(**Vol[i,j]     : Traffic volume of alternative route j, section i  **)
(**ATP          : probability to select auto                        **)
(**IniATP       : probability to select auto in 1998                **)
(**Qtotal[i]    : Total traffic volume on section i via all        **)
(**alternative routes                                             **)

```

A travel time, capacity restrained traffic assignment is used in the model to set up a relationship between traffic volume and capacity of bus route. The basic equation for this model is shown in Equation 4.29. This equation implies that traffic volume is inverse proportional to the link impedance.

$$q(r_{ij}^k) = Q_{ij} \cdot \frac{1/w(r_{ij}^k)}{\sum_k \left(\frac{1}{w(r_{ij}^k)} \right)} \quad (4.29)$$

where, $q(r_{ij}^k)$ is traffic volume from i to j through path k , Q_{ij} is total traffic volume from i to j , and $w(r_{ij}^k)$ is link impedance from i to j through path k .

Initial traffic flows are assigned to the minimum paths computed on the basis of free-flow link impedances (i.e., travel time, travel distance or travel cost). However, as traffic flows are assigned to the minimum paths, the travel speed of each path decreases as traffic volume increases. In other words, as traffic flow increases toward capacity, the average stream speed decreases from the free speed to the speed at maximum flow. Here, link speed has to be checked and updated every time the network is loaded. This iterative procedure between traffic assignment and travel time check is necessary until a network equilibrium is reached. Figure 4.12 shows the relationship between traffic assignment and travel time changes.

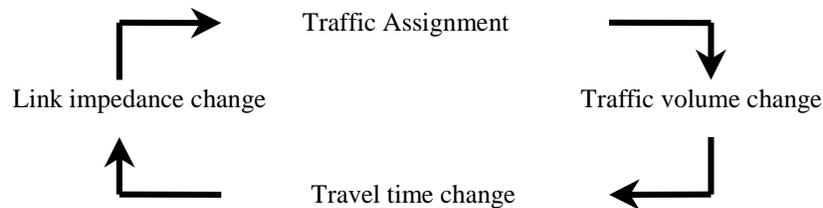


Figure 4.12 Iterative Procedure Between Travel Time and Traffic Assignment Processes.

There are several methods to estimate highway travel times based on volume and capacity. For illustrative purposes two forms of the travel time estimation equations are shown in Equations 4.30 (BPR) and 4.31 (Davidson).

$$T_n = T_o \left[1 + 0.15 \left(\frac{v}{c} \right)^4 \right] \quad (4.30)$$

$$T_n = T_o \left[1 + J \left(\frac{v}{c - v} \right) \right] \quad (4.31)$$

where, T_n is new travel time, T_o is free flow travel time, V is link volume, C is link capacity, and J is a parameter. J can be used as an adjust factor of the equation to represent the travel time. This parameter can be traced by experimental method. Equations 4.32 through 4.40 show the MODSIM II code to estimate traffic volumes and speeds to reach network equilibrium.

```

...
FOR k :=1 TO NumOfIterate      (** Start BPR & Traffic Assignment **)
  totalTn:=0.;
  FOR i :=1 TO NumOfRt
    FOR j :=1 TO NumOfAltn
      LOS:=Vol[i,j]/Cap[i,j];      (4.32)
      Tn[i,j]:=To[i,j]*(1.+0.15*(LOS*LOS*LOS*LOS));      (4.33)
    END FOR;
    totalTn:=totalTn+Tn[i,1];      (4.34)
  END FOR;
  IF year=1;
    Tnini:=totalTn;      (4.35)
  END IF;
  FOR i :=1 TO NumOfRt
    FOR j :=1 TO NumOfAltn
      Sigmainvtt[i]:=Sigmainvtt[i]+(1./Tn[i,j]);      (4.36)
    END FOR;
  END FOR;
  FOR i :=1 TO NumOfRt
    FOR j :=1 TO NumOfAltn
      Vol[i,j]:=Qtotal[i]*(1./Tn[i,j])/Sigmainvtt[i];      (4.37)
    END FOR;
    Sigmainvtt[i]:=0.;      (4.38)
  END FOR;
END FOR;
END FOR;      (** End BPR & Traffic Assignment **)
CongestionRate:=totalTn/Tnini;      (4.39)
AutoTT:=9.11*CongestionRate;      (4.40)
...
(**totalTn : Sum of revised travel times for each alternative route **)
(**      at every iteration **)
(**NumOfRt : Number of sections in study route **)
(**NumOfAltn : Number of alternative routes in each section **)
(**LOS : Level of traffic condition for each alternative route **)
(**Vol[i,j] : Traffic volume of alternative route j, section i **)
(**Cap[i,j] : Estimated capacity on section i, alternative route j **)
(**      for traffic assignment **)
(**Tn[i,j] : Revised Travel time of section i, alternative route j **)
(**      at each iteration **)
(**To[i,j] : Free flow travel time using alternative route j, **)
(**      section i **)
(**Tnini : First revised value of travel time for each section and **)
(**      alternative route **)

```

```

(**Sigmaintvt[i] : Sum of times travelling all alternative routes **)
(**              in section i **)
(**Qtotal[i] : Total traffic volume on section i via all **)
(**              alternative routes **)
(**CongestionRate : Relative level of traffic congestion comparing **)
(**              that of year 1998 **)
(**AutoTT : travel time of auto **)

```

Table 4.2 and Figure 4.13 shows sample output of the previous procedure for the BT network study. For each of 7 sections, 3 alternative links including bus route are shown in the first column of the table. This iterative procedure requires initial travel times and volumes to be entered. After 4 iterations, each link reached equilibrium as shown in Figure 4.13.

Table 4.2 Output of Traffic Equilibrium Assignment for BT Network.

		Observed Traffic Condition		Assigned Traffic Volume							
				Iteration 1		Iteration 2		Iteration 3		Iteration 4	
		Travel T. (min.)	Volume (veh.)	Travel T. (min.)	Volume (veh.)	Travel T. (min.)	Volume (veh.)	Travel T. (min.)	Volume (veh.)	Travel T. (min.)	Volume (veh.)
Sct.1*	Alt.1	13.50	1260.0	13.82	986.0	13.62	1011.3	13.63	1008.9	13.63	1009.1
	Alt.2	14.00	865.0	14.57	935.4	14.78	932.2	14.76	931.5	14.76	931.8
	Alt.3	14.10	742.0	14.41	945.6	14.92	923.5	14.84	926.7	14.85	926.1
Sct.2*	Alt.1	12.50	1313.0	12.85	1109.8	12.68	1128.9	12.69	1126.9	12.69	1127.1
	Alt.2	12.50	916.0	12.76	1117.4	13.08	1094.4	13.03	1097.4	13.04	1097.0
	Alt.3	12.70	1098.0	12.96	1099.9	12.97	1103.8	12.97	1102.7	12.97	1102.9
Sct.3*	Alt.1	8.70	502.0	8.90	544.6	8.98	539.3	8.97	539.9	8.97	539.8
	Alt.2	11.50	461.0	12.10	400.6	11.84	408.9	11.87	407.9	11.87	408.0
	Alt.3	10.80	416.0	11.17	433.8	11.24	430.8	11.23	431.2	11.23	431.1
Sct.4*	Alt.1	13.00	1387.0	13.31	1297.9	13.24	1305.1	13.24	1304.5	13.24	1304.6
	Alt.2	15.60	1089.0	15.81	1092.8	15.81	1092.8	15.81	1092.7	15.81	1092.7
	Alt.3	14.80	1061.0	15.07	1146.3	15.17	1139.1	15.16	1139.7	15.16	1139.7
Sct.5*	Alt.1	6.70	1317.0	6.83	882.2	6.73	899.8	6.73	899.0	6.73	899.1
	Alt.2	6.70	562.0	6.73	895.8	6.87	881.1	6.86	882.1	6.86	882.0
	Alt.3	6.50	814.0	6.58	915.0	6.64	912.1	6.63	911.9	6.63	911.9
Sct.6*	Alt.1	6.20	1219.0	6.29	990.4	6.24	1003.1	6.24	1001.7	6.24	1001.8
	Alt.2	6.20	573.0	6.23	1000.2	6.44	971.3	6.42	974.3	6.42	974.0
	Alt.3	7.80	976.0	8.01	777.5	7.88	793.6	7.89	792.0	7.89	792.2
Sct.7*	Alt.1	13.50	1425.0	13.86	1314.4	13.76	1324.6	13.77	1323.7	13.77	1323.7
	Alt.2	15.60	1182.0	15.89	1146.5	15.85	1149.6	15.86	1149.2	15.86	1149.3
	Alt.3	14.90	1055.0	15.16	1201.1	15.34	1187.8	15.32	1189.1	15.33	1189.0

Sct*.; Seven sub-routes (sections) which consist of the BT study route.

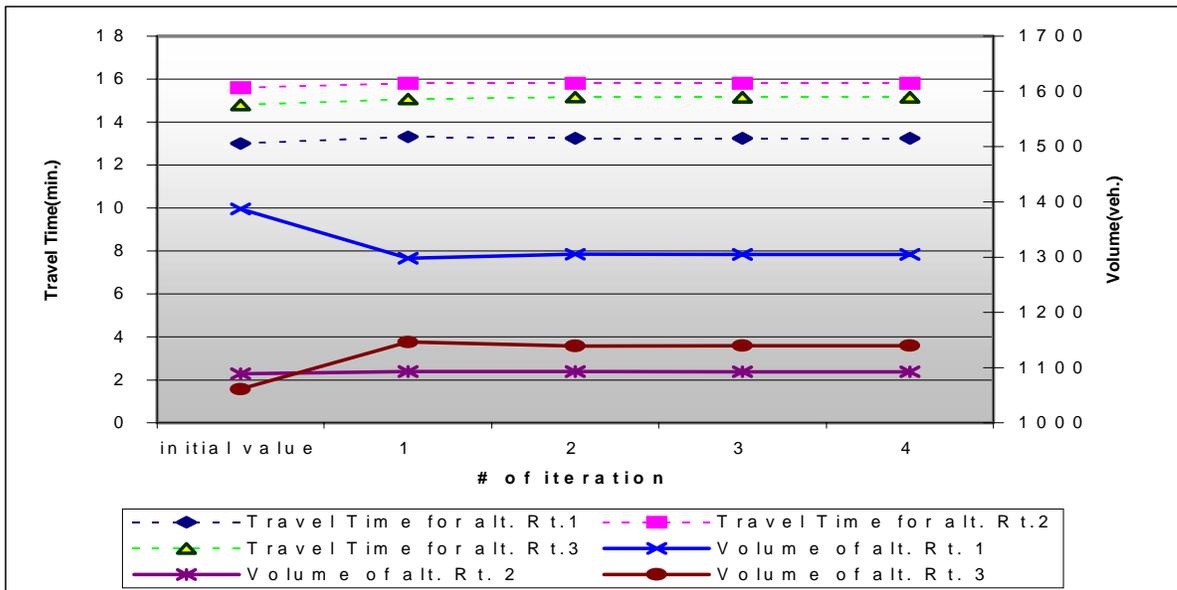


Figure 4.13 Output of Travel-time-restrained Network Assignment.

- Procedure B-5; Estimation of Bus Acceleration

Bus speed is controlled by individual driving behavior. If driver wants to modulate speed this is usually done with changes to the accelerator pedal. This driving behavior is governed by a combination of individual and also by street traffic. In congested highway traffic, the level of acceleration pedal modulation requires more changes. In LOS A condition, the modulation would be less. To reflect this, the 'PushPedal' variable is set to be a function of 'CongestionRate' which is generated in 'Procedure B-4 (estimation of highway traffic conditions)'. The following MODSIM II code controls the acceleration pedal during the simulation. Speed limit controls are also imposed in the model to reflect low speed driving conditions around campus. In Equations 4.41 through 4.43, the parameters are set to adjust model output to roadside field data. These were estimated using a least-square regression analysis using empirical data collected in Blacksburg.

```

...
IF route = 1
    PushPedal:=1.-(.3*CongestionRate); (4.41)
ELSIF route = 3
    PushPedal:=1.-(.65*CongestionRate); (4.42)
ELSIF route = 4
    PushPedal:=1.-(.3*CongestionRate); (4.43)
END IF;
...
TractiveEffort:=TGear[1]*PushPedal; (4.44)
...
(**PushPedal: Intensity of drivers' pushing acceleration pedal **)
(**CongestionRate: Relative level of highway traffic congestion **)
(** compared to that of year 1998 **)

```

- Procedures B-6, 7, and 8; Estimation of travel time, relative travel time, LOS, and utility for each mode

Using the results of the previous UTPP step, the utility function of each mode is calibrated as function of each mode relative time and LOS. The coefficients of each variables in Equations 4.49 through 4.51 were the result of a Logit model calibration using Blacksburg Data. (See Equations 5.5 through 5.7).

```

...
FOR year:= 1 TO numyear;
...
ATRELT:= totalTn/(totalTn*.5+231.*.55); (4.45)
BTRELT:=totinvehtime[year-1]/((5.79-.52*mktpnt)*432.+totinvehtime[year-1]+4350.); (4.46)
OTRELT:=.9;
ATLOS:=.8*2.7+.2*2.7*(Tnini/totalTn);
BTLOS:=5.19+.54*(mktpnt+(1.-mktpnt)*FLOAT(fleetsize-inifleetsize)/10.); (4.47)
OTLOS:=2.85; (4.48)
ATU:= 1.758*ATRELT+.667*ATLOS+2.205; (4.49)
BTU:= 1.758*BTRELT+.667*BTLOS-1.129; (4.50)
OTU:= 1.758*OTRELT+.667*OTLOS; (4.51)
IF year=1
    IniATP:=ATP; (4.52)
END IF;
...
END FOR;
...
(**ATU : Utility of Auto **)

```

```

(**ATRELT : relative time of auto **)
(**ATLOS : level of service of Auto **)
(**BTU : Utility of BT **)
(**BTRELT : relative time of BT **)
(**BTLOS : level of service of BT **)
(**OTU : Utility of Other modes (walk, bicycle) **)
(**OTRELT : relative time of other modes **)
(**OTLOS : level of service of Other modes **)

```

- Procedure B- 9; Estimation of Mode Choice Probabilities

The probability of each mode's demand is represented by logit model (See Equation 4.8). The source code used to estimate mode choice probabilities in MODSIM II are shown in Equations 4.53 through 4.55.

```

...
FOR year:= 1 TO numyear;
...
ATP:= EXP(ATU)/(EXP(ATU)+EXP(BTU)+EXP(OTU)); (4.53)
BTP:= EXP(BTU)/(EXP(ATU)+EXP(BTU)+EXP(OTU)); (4.54)
OTP:= EXP(OTU)/(EXP(ATU)+EXP(BTU)+EXP(OTU)); (4.55)
...
END FOR;
...
(**numyear : Number of study year from 1998, the starting year **)
(**ATU : Utility of Auto **)
(**BTU : Utility of BT **)
(**OTU : Utility of Other modes (walk, bicycle) **)
(**ATP : probability to select auto **)
(**BTP : probability to select BT **)
(**OTP : probability to select other modes **)

```

- Procedure B-10; Estimation of BT ridership

With the mode choice probability to select BT (BTP) the total number of BT riders (BTdemand) is estimated multiplying the BTP by total traffic demand (trafficdemand; See Equation 4.56). Using the total BT demand Equations 4.57 through 4.61 estimate the number of passengers alight and boarding at each bus stop.

```

...
FOR year:= 1 TO numyear;
...
FOR i :=1 TO NumOfRt                                (**Number of Sections**)
...
BTdemand:=trafficdemand*BTP;                        (4.56)
FOR i :=1 TO stopnumb (** # of stops**)
  ASK Strm TO ReadInt(IntLine);
  stopid[i]:=IntLine;
  ASK Strm TO ReadReal(RealLine);
  boarding:=RealLine;
  ASK Strm TO ReadReal(RealLine);
  alight:=RealLine;
  IF year>1
    boarding:=BTdemand*boarding/iniBTdemand;        (4.57)
    alight:=BTdemand*alight/iniBTdemand;            (4.58)
  END IF;
  totalpax:=totalpax+alight;                          (4.59)
  pax[i]:=previouspax+previousboarding-previousalight; (4.60)
...
IF year=1
iniBTdemand:=totalpax;
inidemand:=totalpax/.1154;                            (4.61)
(**Initially BT had 11.54% of total demand**)
trafficdemand:=inidemand;
END IF;
END FOR;

```

4.3.1.3 Loop D: Bus Operation Simulation

- Procedure D- 1; Computation of Individual Road Profiles

Bus operation simulation is heavily governed not only by the bus performance and traffic engineering related characteristics but also by the topological terrain conditions along the study route. The bus simulation model estimates grade schedule, distance among stops, intersections or turns from GIS data. For a successful model building, the accuracy and availability of GIS data is essential. To enhance the reliability of the data, precise terrain condition information was adopted and incorporated into the ITPM from the digital map of the study area using ARC/INFO. A simple three dimension

geometry method is used to estimate grade profiles, distances and average grades between link nodes, etc. (See equations 4.62 through 4.65).

```

IF i=0
grade:=0.;
avggrade[m]:=0.;
  ELSE
grade:=(SpotHght[i]-SpotHght[i-1])*100./(totaldist[i]-totaldist[i-1]);
(4.62)
avggrade[m]:=(gradesum + grade) / ( spots + 1.);
(4.63)
  END IF;
spots:=0.;
gradesum:=0.;
  ELSIF (class[i]<>0)
stopdistnt[i]:=0.;
grade:=(SpotHght[i]-SpotHght[i-1])*100./(totaldist[i]-totaldist[i-1]);
(4.64)
gradesum:=gradesum+grade;
(4.65)
spots:=spots+1.;
  ELSE
dummy:=dummy;
  END IF;
END FOR;

```

- Procedure D- 4; Estimation of Dwell and Delay Times at Stops

Bus performance is also affected by various network controls of the route such as speed regulations, stop spacing, number of stops, type of turns and intersections, etc. The delay time at each turn and intersection is directly impacted by traffic conditions and the types of turns and intersections. To model stopped delays in signalized intersections, Equations 4.66 through 4.68 are recommended by the Highway Capacity Manual (TRB, 1994) and used in the model.

$$TD_i = PF_i(d_{1i} + d_{2i}) \quad (4.66)$$

$$d_1 = 0.38 \cdot C \cdot \frac{\left(1 - \frac{g}{C}\right)^2}{1 - \left(\frac{g}{C}\right)} \quad (4.67)$$

$$d_2 = 173 \cdot X^2 \left\{ X - 1 + \sqrt{\left((x-1)^2 + 16 \cdot \frac{X}{c}\right)} \right\} \quad (4.68)$$

Where, TD_i is total delay for lane group i , PF_i is progression factor for lane group i , d_1 is the uniform delay, d_2 is the overflow delay, C is cycle length, c is capacity of subject lane group, g is green time allotted to subject lane group, X is v/c ratio for the subject lane group. Green time and cycle lengths of each intersection, network link volumes, and link capacities are input parameters to the model. The corresponding expressions in the bus operations model are shown in Equations 4.69 through 4.72.

```

FOR i :=1 TO stopdelay
...
numsec[i]:=IntLine;
...
Intsectype:=IntLine;
IF (Intsectype=1001) OR (Intsectype=1002) OR (Intsectype=1003)
...
IF year>=2
volume:=(volume+volume*(growthrate-1.)/1.2)*ATP/IniATP;
(** 1.2 : PCE conversion factor;1.2 person per vehicle      **)
END IF;
...
X[i]:=volume/capacity;                                     (4.69)
d1:=.38*cycle*((1.-green/cycle)*(1.-green/cycle)/(1.-
((green/cycle)*X[i]));                                     (4.70)
d2:=173.*X[i]*X[i]*((X[i]-1.)+SQRT((X[i]-1.)*(X[i]-
1.)+(16.*X[i]/capacity)));                               (4.71)
Delay[i]:=PF*(d1+d2);                                     (4.72)
ELSIF ...

```

To estimate the delays of unsignalized intersections Equation 4.73 is used (TRB, 1985). In this expression, the critical gap for each case is shown in Table 4.3 (TRB, 1985).

$$TD = \frac{3600}{V} \times e^{\left(\left(\frac{V}{3600}\right) \times G\right)} - 1 - \frac{V}{3600} \times G \quad (4.73)$$

Where: V is volume of the incumbent lane group, and G is critical gap for buses. The computations in MODSIM II are shown in Equations 4.74 through 4.80.

Table 4.3 Critical Gap Acceptance for Buses at Unsignalized Intersections.

Intersection Type	Critical Gap (sec.)	Equations in MODSIM code
RT from Minor to 2 or 4 lane Major road	6.00 × PCE	Eq. 4.75
LT from 2 lane Major road to Minor road	5.25 × PCE	Eq. 4.76
LT from 4 lane Major road to Minor road	5.75 × PCE	Eq. 4.77
LT from Minor road to 2 lane Major road	7.25 × PCE	Eq. 4.78
LT from Minor road to 4 lane Major road	7.75 × PCE	Eq. 4.79

Source : Modified from Highway Capacity Manual, 1985.

```

FOR i :=1 TO stopdelay
...
numsec[i]:=IntLine;
...
ELSIF Intsectype=20021      (**RT from Major**)
Delay[i]:=3.;              (4.74)
ELSE
IF Intsectype=20022        (**RT from Minor to Major**)
...
CriticalGap:=6.*pcu*CongestionRate;      (4.75)
ELSIF Intsectype=20031      (**LT from 2 lane Major**)
...
CriticalGap:=5.25*pcu*CongestionRate;    (4.76)
ELSIF Intsectype=20032      (**LT from 4 lane Major**)
...
CriticalGap:=5.75*pcu*CongestionRate;    (4.77)
ELSIF Intsectype=20033      (**LT from Minor to 2 lane Major**)
...
CriticalGap:=7.25*pcu*CongestionRate;    (4.78)
ELSIF Intsectype=20034      (**LT from Minor to 4 lane Major**)
...
CriticalGap:=7.75*pcu*CongestionRate;    (4.79)
...
END IF;
Delay[i]:=(3600./volume)*(EXP((volume/3600.)*CriticalGap)-1.
-(volume/3600.)*CriticalGap);          (4.80)
END IF;
END FOR;

```

The delays associated with four-way stop controlled intersections are estimated using Equation 4.81 (TRB, 1985). Its MODSIM II equivalent is shown in Equation 4.82.

$$TD = e^{3.8\left(\frac{v}{c}\right)} \quad (4.81)$$

```
FOR i :=1 TO stopdelay
...
ELSIF Intsectype=2004
...
capacity:=RealLine;
Delay[i]:=EXP(3.8*(volume/capacity));
...

```

(4.82)

For an unsignalized right turn from a two or four lane major road to minor road, a fixed delay time of 5 seconds is applied. It can be said that since the simulation language being used it is relatively easy to convert these deterministic variables into stochastic values if specific distributions are known.

The dwell time at each bus stops is necessary for estimating bus capacities, operation times, and travel times for each passenger (TRB, 1985). The following definitions are applied to our model;

- Dwell time : The time, in seconds, that a transit vehicle is stopped for the purpose of serving passengers. It includes the total passenger service time plus the time needed to open and close doors.
- passenger service time : The time, in seconds, that is required for a passenger to board or alight from a transit vehicle.

Dwell times may be governed by boarding demand, alighting demand, or total interchanging passenger demand. There have been several studies to estimate simple relationships between dwell times and passenger demands. Table 4.4 shows a summary of the empirical equations obtained. In all cases, dwell times are proportional to boarding

and / or alighting volumes. According to the HCM (TRB, 1985), The alighting time per passenger varies from 1.5 to 6.0 seconds according to baggage carrying conditions. For the loading time, the time per passenger varies from 1.5 to 8.0 seconds according to the fare collection method used. Under operating conditions of single door loading, pay on bus, and exact fare, typical bus passenger boarding service times is 3.0 seconds and the alighting service time is 1.7 to 2.0 seconds (TRB, 1985). These conditions are the same as those found in the BT system. Nevertheless the author conducted an on-board survey using BT buses and Equations 4.83 through 4.87 to represent those parameters.

Table 4.4 Bus Dwell Times at Bus Stops in Selected Urban Areas (TRB, 1985).

Location	Bus Type	Boarding and Alighting Method	Fare Type	Fare Collection	Dwell time, in sec. ^a
Louisville, Ky.	One-man	Alighting only	Flat fare	Driver	$1.8 + 1.1 F$
	One-man	Boarding only	Flat fare	Driver	$- 0.1 + 2.6 N$
	One-man	Simultaneous	Flat fare	Driver	$1.8 + 1.0 F + 2 - 0.02 F N$
London	Two-man	Simultaneous	Graduated	Conductor	$1.3 + 1.5 (N + F)$
	One-man	Simultaneous	Graduated	Driver	$8 + 6.9 N + 1.4 F$
	One-man	Simultaneous	Single coin	Mechanical	$7 + 2.0 N$
			Two coin	Mechanical	$5.7 + 3.3 N$ (in peak time) $5.7 + 5.0 N$ (in off-peak time)
Toronto	One-man	Simultaneous	Zonal	Fare Box	$1.7 N, 1.25 F, 1.4 (N + F)$
Copenhagen	One-man	Simultaneous	Flat fare	Split Entry ^b	$2.2 N$
Dublin	Two-man	Consecutive	Graduated	Conductor	$1.4 (N + F)$
	One-man	Simultaneous	Graduated	Driver	$6.5 N + 3.0 F$
France;					
Bordeaux	One-man	Simultaneous	Flat fare	Driver	$15 + 3 N$
Toulouse	One-man	Simultaneous	Flat fare	Driver	$11 + 4.6 N$
Paris	One-man	Simultaneous	Graduated	Driver	$4 + 5 N$
	Two-man	Simultaneous	Graduated	Conductor	$2.3 N$

^a N = number of passengers boarding; F = number of passengers alighting.

^b Driver and machine.

SOURCE : adapted from Highway Capacity Manual, 1985.

```

...
FOR year:= 1 TO numyear;
...
FOR i :=1 TO NumOfRt
...
FOR i :=1 TO stopnumb
...
IF (boarding=0.) AND (alight=0.)
    boardingtime:=0.; (4.83)
    alighttime:= 0.; (4.84)
ELSE
    boardingtime:=4.1+boarding*3.; (4.85)
    alighttime:= 4.1+alight *3.; (4.86)
END IF;
StopTime[i]:=MAXOF(MinStopTime, boardingtime, alighttime); (4.87)
previouspax:=pax[i];
previousboarding:=boarding;
previousalight:=alight;
END FOR;

```

4.3.1.4 Microscopic Bus Performance Simulation

- Procedures E-1, 2, and 3; Estimation of Acceleration/Deceleration, Bus Position and Fuel Consumption

The bus simulation model uses basic equations of motion to predict travel times between stops along a route. Tractive effort curves are generated in the program using power vs. engine speed curves. This relationship is expressed in Equation 4.94. The ‘TractiveEffort’ of bus is adjusted according to the accelerator pedal modulation parameter (‘PushPedal’) and according to engine gear shifts (‘TGear[i]’) as shown in Equations 4.96, 4.98, 4.100, 4.102, and 4.104. A quadratic resistance expression (‘TotalResistance’) is used to appropriate low and high speed performance adequately. The total weight of bus in Newtons (‘TotalMassNewton’) includes bus and passenger weight components (See Equation 4.88).

```

...
TotalMassNewton[i]:=paxMassNewton[i]+busnewton; (4.88)
...

```

```

GravityTerm[i]:=TotalMassNewton[j]*ATAN(avgrade[k]/100.);           (4.89)
...
time:=time+1;
  IF (dwelltime<=stpndly)
    BusVelocity:=0.;
    dwelltime:=dwelltime+1.;
  ELSE
    IF BusPosition>(distance-StopDistance)
      Accel:=-1.*BusDeceleration;                                   (4.90)
    ELSE
      Accel:=Acceleration;                                         (4.91)
    END IF;
    BasicResistance:=960.+8.4*BusVelocity+.1403*BusVelocity*BusVelocity;
                                                                    (4.92)

    IF BusVelocity<.0
      BusDeceleration:=.0;
    ELSE
      BusDeceleration:=1.;
    END IF;
    TotalResistance:=BasicResistance+GravityTerm[k];               (4.93)
    IF (TractiveEffort-TotalResistance)>0.
      Acceleration:=(TractiveEffort-TotalResistance)/(TotalMassNewton[i]);
                                                                    (4.94)
    ELSE
      Acceleration:=0.;
    END IF;
    IF BusVelocity>.0
      StopDistance:=BusVelocity*BusVelocity/(2.*BusDeceleration);
    ELSE
      StopDistance:=.0;
    END IF;
  IF (dwelltime<=stpndly)
    BusVelocity:=0.;
  ELSE
    BusVelocity:=MAXOF(0.,BusVelocity+Accel);                       (4.95)
  END IF;
  END IF;
  IF BusVelocity<15./3.6
    TractiveEffort:=TGear[1]*PushPedal;                             (4.96)
    Energy:=160.*hp[1]*.59/3600.;                                   (4.97)
  ELSIF BusVelocity<30./3.6
    TractiveEffort:=TGear[2]*PushPedal;                             (4.98)
    Energy:=145.*hp[2]*.59/3600.;                                   (4.99)
  ELSIF BusVelocity<45./3.6
    TractiveEffort:=TGear[3]*PushPedal;                             (4.100)
    Energy:=130.*hp[3]*.59/3600.;                                   (4.101)
  ELSIF BusVelocity<60./3.6
    TractiveEffort:=TGear[4]*PushPedal;                             (4.102)
    Energy:=150.*hp[4]*.59/3600.;                                   (4.103)
  ELSE
    TractiveEffort:=TGear[5]*PushPedal;                             (4.104)
    Energy:=160.*hp[5]*.59/3600.;                                   (4.105)

```

```

        END IF;
        FOR j:=1 TO 5
            IF BusVelocity<V[j,2]
                TGear[j]:=(TE[j,2]-TE[j,1])*(BusVelocity-V[j,1])/(V[j,2]-
                V[j,1])+TE[j,1]; (4.106)
                ELSIF BusVelocity<V[j,3]
                    TGear[j]:=(TE[j,3]-TE[j,2])*(BusVelocity-V[j,2])/(V[j,3]-
                    V[j,2])+TE[j,2]; (4.107)
                    ELSIF BusVelocity<V[j,4]
                        TGear[j]:=(TE[j,4]-TE[j,3])*(BusVelocity-V[j,3])/(V[j,4]-
                        V[j,3])+TE[j,3]; (4.108)
                        ELSE
                            TGear[j]:=(TE[j,5]-TE[j,4])*(BusVelocity-V[j,4])/(V[j,5]-
                            V[j,4])+TE[j,4]; (4.109)
                            END IF;
                            END FOR;
                            BusPosition:=BusPosition+BusVelocity; (4.110)
                            BusPositionTotal:=BusPositionTotal+BusVelocity; (4.111)
                            EnergyConsumed:=EnergyConsumed+Energy; (4.112)
                            ...
                            BusVelocity:=0.;
                            ...
                            Energy:=100.*hp[1]*.59/3600.; (4.113)
                            EnergyConsumed:=EnergyConsumed+Energy; (4.114)
                            time:=time+1;
                            END WHILE;

```

4.3.2 Estimation of Transit MOEs

- Procedures D- 5, 6 and C- 1, 2; Estimation of total fuel consumption and travel distance for section *i*

Fuel consumption is directly proportional to engine power output. This power output varies according to bus velocity that is governed by tractive effort and network conditions. For the fuel consumption in every second, the engine power output in bus velocity range *i* ('hp[*i*']') provided by vehicle manufacturer is applied (See Equations 4.97, 4.99, 4.101, 4.103, 4.105) and integrated for total fuel consumption (See Equations 4.112, 4.113, and 4.114). As distance is integration of momentary velocity, the total bus travel distance is estimated by integrating the bus velocities in every second as shown in Equations 4.95, 4.110, and 4.111.

- Procedures B-11, 12; Calculate In-Vehicle Travel Time, Total Journey Time, Total Fuel Consumption for the Study Route

Integrating bus in-vehicle travel time (bus travel time except rest time in check-out; 'time'), total journey time (bus travel time plus rest time) and fuel forward in time yields three important MOEs of the model.

- Procedure F ; Estimation of MOE Changes over Time

This part of the evaluation analysis is described in detail in Chapter 5.

At this stage, each of the casual elements for each sub-model have been described to represent the real system. Appendix D lists all source code. All variables in the model are time dependent except all constants. The sub-models are integrated into a time-dependent, demand-supply system. After integration, a case study was conducted to demonstrate the adaptability and feasibility of the ITPM. Sensitivity analysis and scenario analysis are performed as part of the evaluation process and the results of this implementation are shown in the following chapter.