3.0 Methodology

Some of the methodologies that have been employed to evaluate the benefits of AVL include technical, empirical, model-based evaluations, or cost/benefit analysis (Hill, 1994). A technical approach is used to assess the functionality of the system being tested. Empirical evaluation uses data collected on selected measurements of effectiveness during the operational test. Models are used to simulate the potential benefits and impacts of AVL. Benefit-cost analysis assesses the benefits of the system and are compared with the cost.

Model-based evaluations simulate the potential benefits and impacts of APTS. Models are used primarily in prospective evaluations to assess the future benefits of an APTS, considering trends in trip demand and market penetration of the system. Those kinds of models provide flexibility in evaluating various APTS strategies without added cost and risk associated with full deployment of a system. On the other hand, there are some drawbacks in this evaluation technique (Hill, 1994) such as;

- Using models to evaluate the effects of an APTS system requires travel demand (i.e., origin-destination) data that needs a massive data collection effort.
- Simulation of APTS applications needs to include mechanisms for representing various types of systems and their capabilities. For example, a geographic update mechanism where a vehicle provided information to passengers on the next scheduled stop when passed a specific point in the simulated network would represent an AVL system.
- Models cannot account for changes in travel demands resulting from other impacts on public transportation (i.e., land-use policies).
- Most of all, public transportation is not a closed loop control system. Decisions by users of the system can neither be simulated, nor can the decisions by non-users of the system be expected to remain in static equilibrium.

Modeling a real system in a computer facilitates and allows us to understand predict its behavior before actual implementation. For successful model building, it is necessary to understand the logical relationships between variables of the entire system and set up a valid mathematical abstraction that behaves in a similar fashion as the system being modeled. Traditionally, transportation planners have focused and tried to solve the urban transportation problem using the conventional four-step urban transportation planning process (UTPP). This problem involves forecasting (i.e., trip generation), trip distribution, modal split, and traffic assignment routines and it is based on the use of some socio-economic data to start. The traditional UTPP problem is solved sequentially and iteratively until a convergence criteria with regard to flows and travel times is reached throughout the network. Considering the drawbacks of model-based evaluation techniques and those of the conventional UTPP procedure the modeling approach has been enhanced using a time dependent simulation approach using Systems Dynamics. This variation of the modeling approach allows us to involve variables of economic, social and technological order into the model facilitating our understanding of the dynamic behavior of the system over time space. Since mass transportation systems are planned as an integral part of the UTPP process we can use the same technique to study the effects of APTS technology deployment in the system.

3.1 Modeling Concept

The modeling scheme to evaluate the impact of AVL technology on the present transportation system is composed of a large number of variables derived from many disciplines. The outputs generated from the implementation of AVL are causally related to the other sub-systems, interacting among themselves and others of transportation and socio-economic character. This result impacts more or less on every other variable of the system with different impacts.

The primary modeling concept in this study is to take quantitative outputs from an AVL operation simulation model and incorporate those results in planning strategies as decision factors in the mass transit planning process. To capture the time-dependent qualities of the real system, the modeling process comprises multitude of variables arranged in blocks representing factors of socio-economic, technological and transportation order.

This concept is illustrated in Figure 3.1. First, the transit environment is defined as a closed system which covers all possible factors to be traced in the model. Second, all variables are connected by pairs of causal links denoting influences between them. Based on this concept, the overall model framework is constructed according to the causal and logical relationships among factors. Controllable variables are adopted and the relationships among them verified. Sub-systems are then identified and categorized according to the analysis technique used to model them. This process is helpful to simplify the analysis of the entire system. In this step, the entire system is divided into three sub-models: demographic, UTPP, and bus operations. Once the causal relationships between model variables are established for each sub-model common variables among them are identified. These variables provide important links between each sub-model and are likely candidates to form feedback loops. Once the causal diagram is completed the next step is to convert it into a suitable mathematical model. This model in turn requires validation prior to formal model use. The most important quality of this modeling framework is the varying nature of the model variables. Outputs of each sub-model are used as the inputs to others and state variables are integrated forward in time. Conducting this iterative procedure, the impact of AVL is traced continuously from system development until the horizon year of the study is reached. In short developing the Integrated Transit Planning Model (hereafter ITPM) is the process of verbally articulating factors, tracing causal relationships between variables in the system modeling a mathematical model based on the causal diagram and finally correlating the model with the real system.

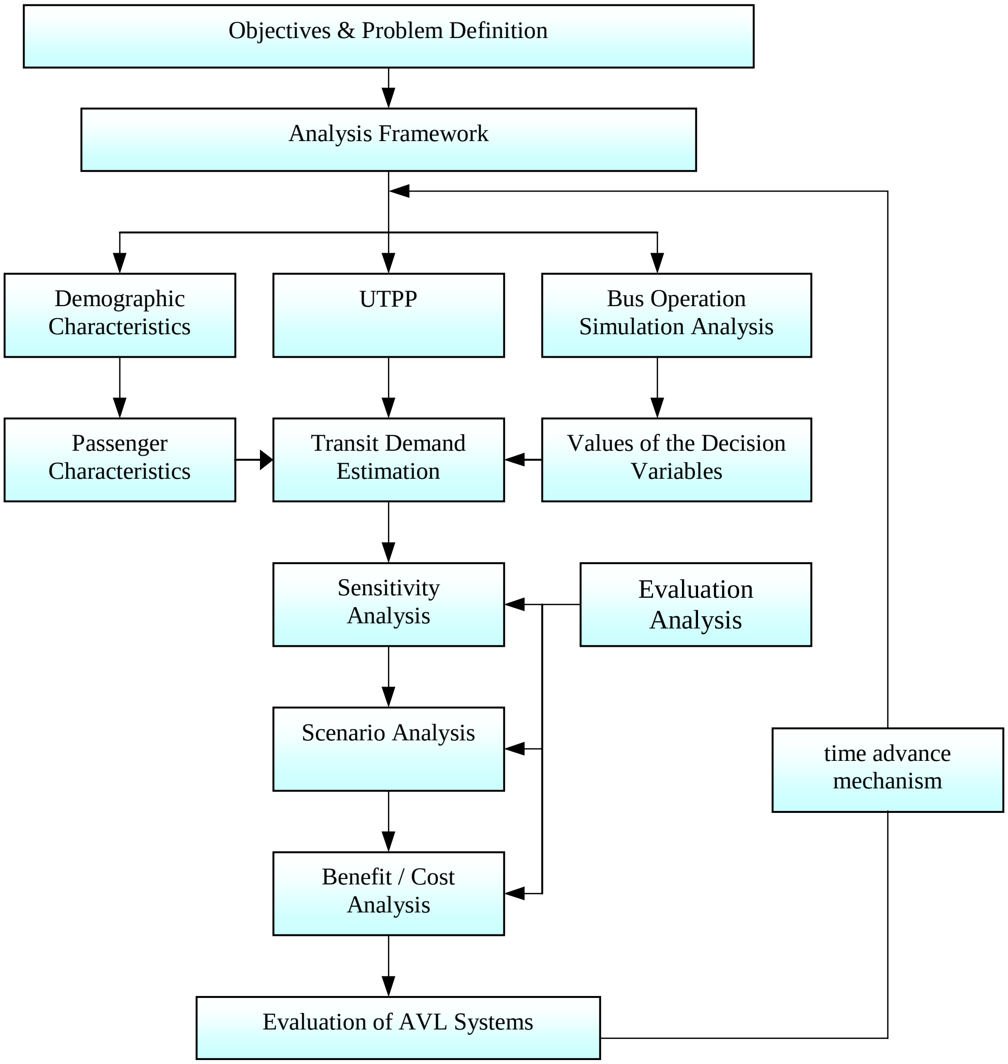


Figure 3.1 Basic Modeling Concept of the ITPM.

3.2 Systems Approach

Over the years it has become evident that analyzing complex problems requires a systems approach to understand the cause and effect relationships when a multitude of variables modeled over time. ITS problems represent complex problems requiring feedback structures to capture time dependent effects of technology implementations and demand driven reactions from users. To illustrate this point consider the value of a simple traveler information system such as a kiosk and its effect in transit ridership. Lets hypothesize that people have better up-to-date information on bus schedules using information kiosks installed through a mass transit network. Users might be more inclined to use the mass transit system over time. This has important implications to competing modes by effectively reducing the volumes on the highway network. This effect in turn will reduce travel times for automobile drivers and mass transit users thus producing gains for both types of users. Since travel time reductions on the highway network could affect the perception of the cost for service for both auto and bus riders a “new equilibrium” solution might take place after some time once users have in fact observed the new system behavior. The closed loop dependency of variables in a complex system cannot be underestimated as feedback structures arise naturally among variables. This closed loop behavior necessitates analytic and modeling techniques capable of handling time dependencies between variables.

In this section we review the systematic approach used to solve problems in a macroscopic approach to draw out clues of system behavior using cause and effect relationships. Generally it is believed that the systems approach developed naturally over time with the advent of the systems age (Ackoff, 1974). With the development of computers scientists widened their perspective and synthesized relationships between phenomenon and cause. The application of this method has been transitioned from the purely physical to the abstract world to include economic, political and management oriented variables. In past five decades scientists have developed sets of tools to solve pieces of these complex problems. For example, mathematical programming techniques have been used to solve parts of complex systems dealing with allocation of resources; queueing models have been used to understand the operational features of complex waiting line systems, etc. At the same time various techniques have been developed to integrate these tools into complex models detailing the connections of otherwise seemingly independent models (i.e., Systems Dynamics, Loop Theory, Feedback Control Theory, H-Infinity Control, etc.).

The systems approach contrasts dramatically from previous problem solving methods such as the mechanical approach. The systems approach by nature is logical, consistent, objective, and quantitative (Drew, 1995). According to Drew (1995), the starting point of systematic analysis occurs during the years of World War II with the launching of some megaprojects such as: the battle of Britain in 1940's, the Manhattan Project, and the publication of "Cybernetics" in 1948. The substitution of the systems age for the machine age in social trend has an important meaning. It means the change from reduction to expansionism, from analytical to synthetic, and from mechanism to humanism.

Developed by Prof. Jay Forrester in the early sixties, the Systems Dynamics methodology has been used to analyze the behavior of complex socio-economic and technological problems (Drew, 1995). Systems Dynamics deals with deterministic, dynamic, non-linear, and closed boundary systems (Sohn, 1996). The word 'Dynamic' means change or variation, and a dynamic system is one whose behavior changes over time (Cochin, 1980). Mahalanabis (1982) pointed out that if the input-output equations describing system behavior are given in the form of differential equations (either in continuous or discrete form) the system is dynamic. Cochin (1980) stressed this model as a state approach described by a set of linear or non-linear first-order differential equations. Today, many computer tools exist to deal with such systems simplifying their analysis (DYNAMO, STELLA, etc.).

3.2.1 Modeling of System Dynamics

According to Drew (1995) the System Dynamics modeling presents relationship among variables over time. Brogan (1985) noted that the process of modeling is the bridge between the real world and the mathematical theory. Schweppe (1973) insists that actual modeling of a system must be done by specialists who thoroughly understand the native behavior of the actual system. So, the modeling process in System Dynamics is the core process to understand the problem and provide mathematical solutions. The process of Systems Dynamics modeling is executed using three complementary approaches: a) verbal (narrative description); b) visual (causal diagram); and c) mathematical (set of equations derived from the causal diagram) modeling (Drew, 1990). Figure 3.2 shows an example of the three complementary modeling forms used in Systems Dynamics to model a water reservoir problem.

3.2.2 Model Structure

As the AVL provides real-time bus location information, it is assumed that the AVL enhances transit service and efficiency in general. Consequently these would induce an increased ridership and bring more profit to transit operators.

Informed passengers know about bus arrival and transfer times and do not need to wait long before the bus comes to their stops resulting in reduced waiting and, travel times, increased level of service (LOS), comfort, reliability, etc. From an operator's perspective, increased overall dispatching reliability and operating efficiency of the system results in possible changes to the operation schedule. This change combined with changes in energy consumption and vehicle speed would eventually impact both the operating economics of the system and the behavioral characteristics of passengers selecting transportation modes.

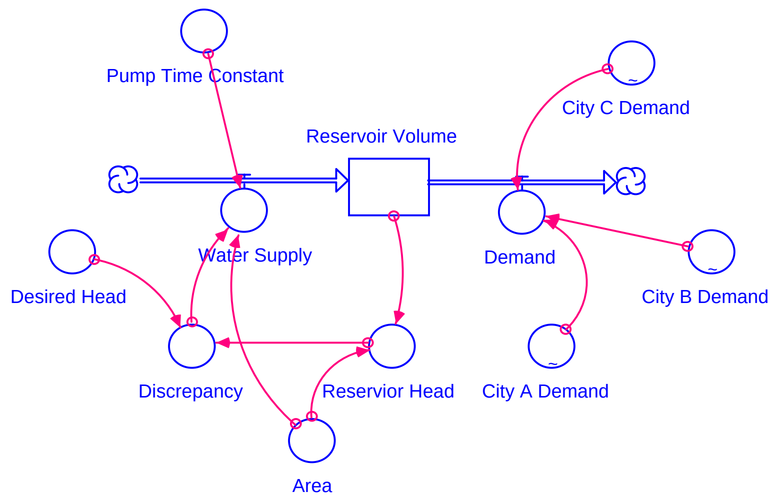
To set up, evaluate and verify these assumed impacts of AVL on the complete mass transportation system, the AVL system was modeled into the bus operations model of ITPM (sub-model C in Figure 3.3). Figure 3.3 shows key output variables of sub-model C such as operating hour, waiting time, travel time, and highway traffic condition impacts on the traffic assignment and mode choice steps in sub-model B; the UTPP. In this step, selecting and quantifying those variables is one of the important procedures in ITPM. Key variables reflect the nature of the transit environment and reflect the impact of AVL in passengers'mode choice behavior, simulaneously. It must be realized that understanding and quantifying causal relationships is a laborious process that necessitates of existing models and data or in some cases requires new relationships.

Verbal Description

Water Reservoir Problem

There is a reservoir which supplies water to three near cities. The demands of each city vary along time. A sensor checks the present head of reservoir and compares it with desired head. If there is discrepancy, the pump works to supply water to the reservoir. The pump have maximum operation time to prevent overheat.

Visual Modeling



Mathematical Modeling

Reservoir_Volume(t) = Reservoir_Volume(t - dt) + (Water_Supply - Demand) * dt
INIT Reservoir_Volume = 10000
Water_Supply = MIN(Area*Discrepancy/Pump_Time_Constant,1000)
Demand = City_A_Demand+City_B_Demand+City_C_Demand
Area = 2500
Desired_Head = 10
Discrepancy = ABS(Desired_Head-Reservior_Head)
Pump_Time_Constant = 20
Reservior_Head = Reservoir_Volume/Area
City_A_Demand = GRAPH(TIME)
(0.00, 10.0), (60.0, 13.0), (120, 24.0), (180, 70.5), (240, 78.5), (300, 10.0)
City_B_Demand = GRAPH(TIME)
(0.00, 90.0),(60.0, 58.0),(120, 41.0),(180, 32.0), (240, 26.0), (300, 20.5)
City_C_Demand = GRAPH(TIME)
(0.00, 15.0), (60.0, 45.8), (120, 106), (180, 135), (240, 119), (300, 54.0)

Figure 3.2 Example of the Three Complementary Modeling Used in Systems Dynamics.

In this study a user survey was conducted to estimate the present values of decision variables of the transit model. Further details of this procedure are discussed in Chapter 5. The output of this study determined two decision variables; relative travel time (in-vehicel travel time divided by total travel time) and LOS of each mode to be important to transit users. On the supply side, changes to transit speed and fuel consumption impact the cost of transit operations. In the evaluation analysis sub-model (Sub-model D in Figure 3.3), those changed costs and benefits yield changes to the cost/benefit of the transit system.

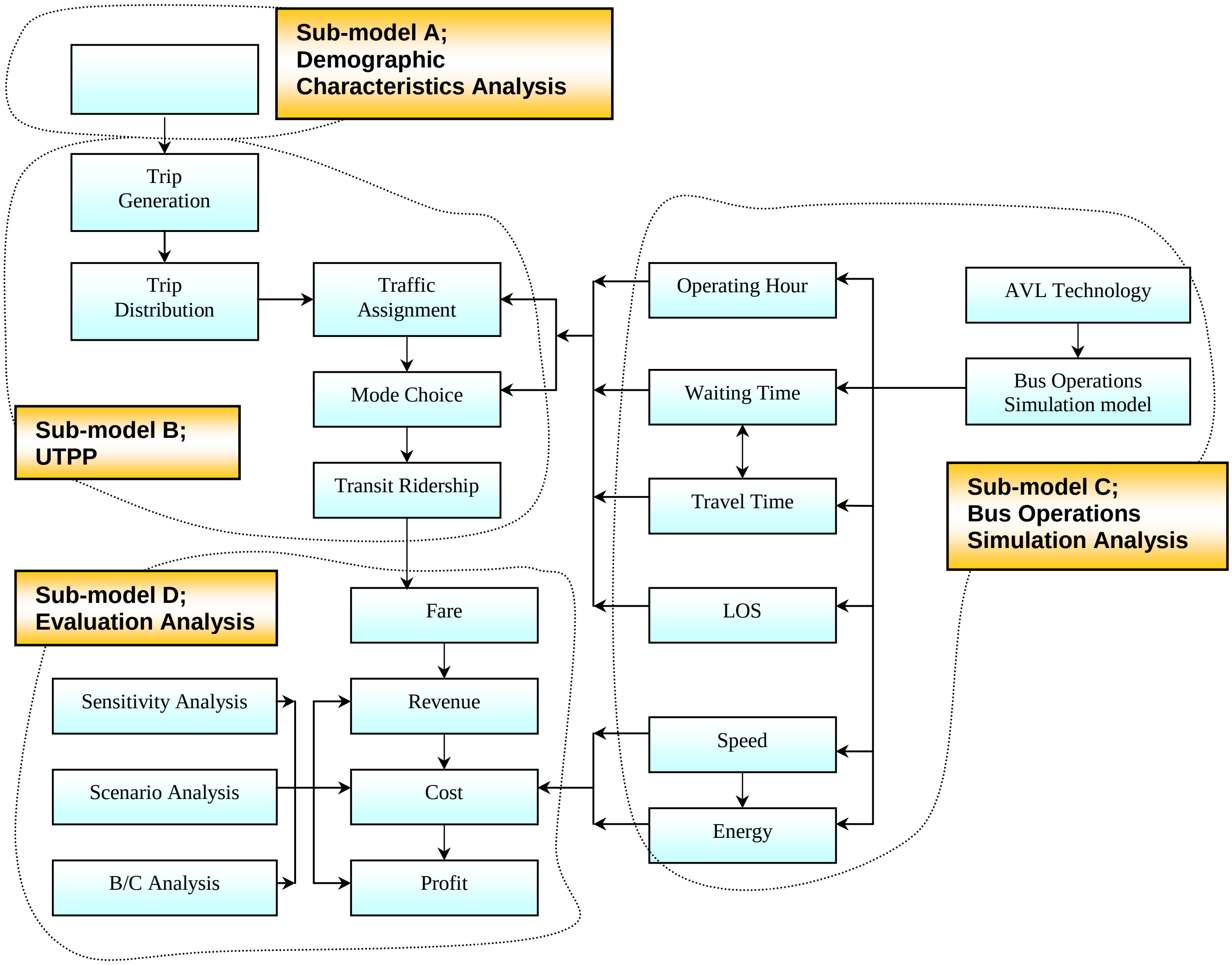


Figure 3.3 Modeling Procedure to Evaluate the Impact of AVL Technology in the ITPM.

3.2.2.1 Sub-Model A; Population Allocation Analysis

Conventional UTPP conducts a static (i.e., time independent) analysis of the transportation network (Mackett, 1977). The process assumes that predicted patterns of all the variables show monotonous, static, time-independent, and stable relationships (Hobeika, 1996). For example, population growth rate, one of the most important variables in the process, is unchanged for the horizon year. Dickey (1983) also points out to another drawback in that demand for travel in the process is assumed independent of the network supply characteristics. In the Systems Dynamics approach time-dependencies between variables are always inherent to the model and from this point of view changes to demographic parameters and network supply characteristics are considered as an input to all other transportation variables.

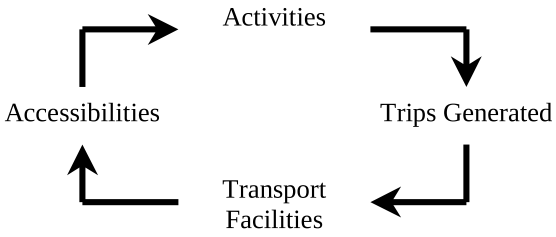


Figure 3.4 Relationship Between Activities and Transportation Facilities.

One of the most important variables in transportation modeling is accessibility or ease of reach, which is commonly represented by travel time (Hansen, 1959; Lee, 1973; Mackett, 1977; Anas, 1982). Increased supply of transportation facilities induces higher accessibilities. This increased accessibility then yields more traffic activities. To serve those increased trips more transportation facilities are needed completing a cycle of transportation facility supply. Accessibility is one of the major outputs and measures of effectiveness (MOEs) of the UTPP method. The demographic characteristics of population are analyzed and estimated by an urban allocation model such as the Lowry model. This analysis is incorporated into the ITPM and yields zonal distribution of population. The result is then used as the input for the trip generation step in UTPP.

3.2.2.2 Sub-Model B; Urban Transportation Planning Process (UTPP)

The ITPM is mainly adopted from a traditional UTPP. Following the process, this model generates changes in transit ridership and highway traffic conditions following four UTPP steps. This procedure can be executed with and without APTS technology to study the impacts of the technology. AVL technology impacts the UTPP sub-model through changes to variables such as travel time, waiting time, LOS, etc.

3.2.2.3 Sub-Model C; Bus Operations Analysis

To understand the impacts of AVL technology (or any other type of ITS technology for that matter) is necessary to ascertain in great detail how mass transit vehicles perform at the microscopic level. For example, if a bus driver is able to utilize this technology to improve the level of service for users it is necessary to understand how the vehicle performs on the highway network to offer such improved service. This microscopic modeling procedure is also necessary to capture the effects of ridership shifts that could occur as a result of deploying new technology that lures users from one mode to another one. In this regard, the analysis of the transportation system requires a deep understanding on how these changes affect the user decision function to select a mode. For this reason, a bus operations model using a continuous simulation technique is developed and implemented in ITPM.

Some of the outputs from this simulation model are susceptible to AVL implementation and are used as inputs to the mode choice component of UTPP. For example, the microscopic bus simulation model yields profiles of speed, travel time, and fuel consumption as outputs. On the other hand, it is widely accepted that passengers pattern in mode choice is a function of travel cost, travel time, and comport/convenience such as fare, total travel time, and LOS (Hobeika, 1996; Papacostas, 1987; Koppelman, 1986). Assuming that those decision factors in the choice model can be estimated with the three outputs, the simulation model can then be used not only to derive MOEs of bus operation performance but also as the tool to estimate changes to passengers mode choice. As result, the simulation model outputs have an important role of connecting the bus operation model and the mode choice step in UTPP. This integration process permits an assessment of microscopic impacts of technology to be transferred to a macroscopic level model such as the UTPP. Ultimately, the mass transit ridership parameter is affected and becomes an important MOE of the complete system.

3.2.2.4 Integration of UTPP and Bus Operation Model

Figure 3.5 shows the detailed framework of mode choice and traffic assignment procedures in the UTPP sub-model combining decision factors from the bus operation analysis sub-model. Given initial values of state variables such as highway LOS, demands of auto, bus, and other modes, the bus operation simulation model updates bus passenger in-vehicle travel times (<1> in Figure 3.5).The total travel time for bus riders (<2>) reflects bus waiting times at bus stops impacted by AVL technology. The relative travel time of bus passengers is estimated from in-vehicle travel time and total travel time (<1/2>). Passenger car travel times (<3>) are estimated from known traffic conditions (highway LOS conditions). This time is used as an input, along with the auto passenger total travel time (<4>), to obtain the auto passenger relative travel time (<3/4>). For other modes such as walking and bicycle, the relative travel time (<5/6>) is estimated using the similar procedure. Assuming that travel times of walk and bicycle modes (<5>) are not impacted by the highway traffic condition, they will not have an influence in the highway LOS variable. With estimates of LOS for each mode relative travel times are used as inputs to execute the mode choice analysis (<7>) along with LOS of each mode. This in turn affects the demand for each mode. Changes to auto demand yield new values of highway LOS (<8>) which ultimately affect the network assignment estimations.

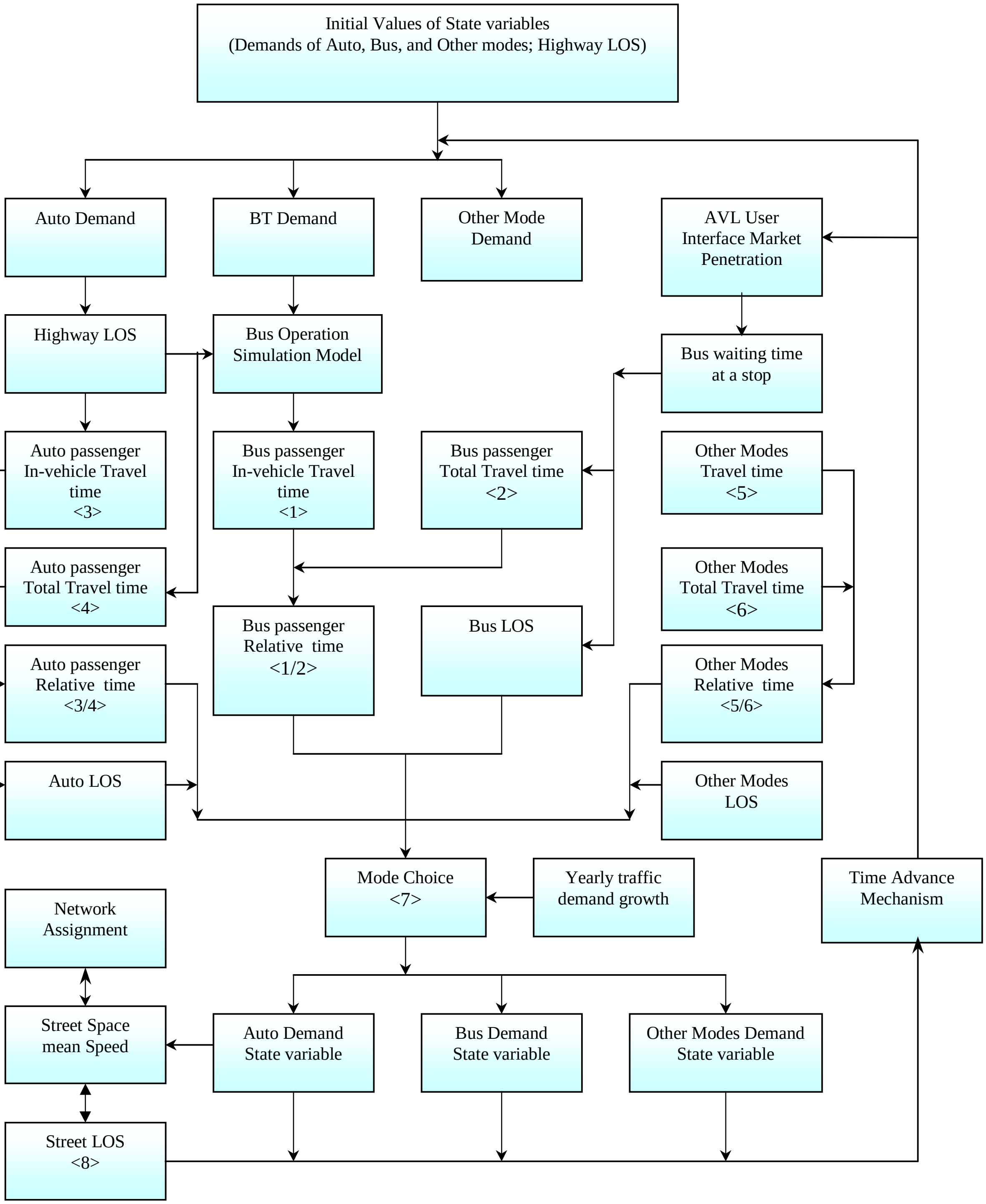


Figure 3.5 Integration of UTPP and Bus Operation Simulation Model in ITPM.

A continuous time step mechanism is embedded into the model to dynamically estimate all model state variables. This cyclic process is repeated at every step in the simulation until the horizon year is reached.

3.2.2.5 Evaluation Analysis

Identifying the various benefits and costs resulting from the implementation of APTS technology is the first task in the economic evaluation of a project. Assigning monetary values to various benefits and costs components is another important issue. Since the value of ITS technology is judged against benefits and cost of current technology an economic analysis technique such as benefit/cost is appropriate for this study. Before discussing the economic model several assumptions are worth discussing:

The change of fare box revenue is considered as a benefit in this analysis. The cost changes to implement APTS technology in mass transit systems come from several sources. Examples of these are: a) changes to the fuel consumption due to improved service; b) schedule speed; and c) dwell time, etc.. In order to simplify the analysis all monetary variables such as subsidy, maintenance cost, rolling stock, etc., are considered to be the same before and after AVL implementation. In a real system this will seldom be the case because additions of technology always results in changes to the maintenance actions performed on a system to keep it running. However, due to the limited experience of BT using AVL technology no real statistics exist to assume otherwise. In the case of AVL technology the systems installed in most modern bus fleets are mature technologies with high reliability and thus perhaps this assumptions is valid. The cost effectiveness of the system is analyzed using a matrix comparison of alternatives. The matrix has both direct and indirect impacts resulting from the integration of technology into the transit planning model and includes productivity performance ratios, such as efficiency.

3.3 Selection of the Measures of Effectiveness (MOEs)

To examine the performance of the bus transit system AVL implementation, a set of Measures of Effectiveness (MOEs) was selected (Galindez, A. A., 1997). In this dissertation, MOEs have to provide quantitative measures of the benefits/costs derived from the APTS technologies. In most economic evaluation analysis, benefits are identified in terms of counts, measurements, dollars, or other physical units. In addition, quantitative MOEs show how an AVL system influences a transit system's work force requirements, use of capital equipment, and ridership. However, in non-user impact analysis, only some values can be quantified in few measurable terms, such as time savings to non-system users. Other parameters such as quality of life are more difficult to estimate. Several methods such as cost-effectiveness, rank-ordering techniques, scoring techniques, and group consensus (Papacostas, 1993) have been developed to measure these types of impacts. In the past few years, a large body of literature has emerged dealing with measures of transit performance and productivity as reported in Highway Capacity Manual (TRB, 1985). However, in many instances these methods fail to include the combined effect of several factors (Ahn, 1996). A sample of the quantitative MOEs that are use to assess the performance of APTS is summarized in Table 3.1 (Hill; 1994). In public transit planning, the following variables are considered as evaluation criteria: transit performance, user travel speed, transfers & waiting times, available seats, and travel times (TRB, 1985; See Table 3.2).

The Highway Capacity Manual (TRB, 1985) also shows various factors in transit planning which are likely to have an influence on the transit capacity. These are shown in Table 3.3. Factors such as maximum speed, vehicle acceleration, deceleration, etc. can be used as variables in the bus operation simulation model and these are marked in the 'SIM' column in Table 3.3. Among those factors selected, some are susceptible to the AVL implementation also. The implementation of AVL technology will provide real-time data transfers from a vehicle to the control center and vice versa.

Table 3.1 Example of Quantitative MOEs.

Benefits	MOEs	Example
Travel benefits	Travel time Safety Comfort and convenience Security Cost	Reduced vehicle trips Accident prevention Customer interface Emergency response Integrated fare payment
Economic Benefits	Productivity Product innovation On-time delivery	Decreased cost and increased revenue Real-time rideshare trip matching Automated dispatching
Environmental Benefits	Air pollution Fuel usage	Reduced emissions Reduced congestion, vehicle trips, and travel times
Information Benefits	Trip efficiency Traffic enforcement	Improved pre-trip planning Traffic signal preferential treatment Improvements to satisfy ADA and Clean Air Act

Table 3.2 Evaluation Criteria in Transit Operations.

Evaluation criteria	
Transit Performance	The perception of quality among customers and potential customers is an important determinant of transit use, often more important than fare levels.
User Travel Speed	One of the most important dimensions of transit performance is speed of service, as perceived by the user. Overall speeds have improved since 1984 for both rail and bus service. Average rail speed improved from 24.8 miles per hour in 1984 to 26.3 miles per hour in 1993. Bus speed, on average, was 12.9 miles per hour in 1984 and 13.7 miles per hour in 1993.
Transfers and Waiting Times	The latest data (1990) indicates that the majority of transit users do not spend much time waiting for service. Well over half of all riders (59 percent) reported wait times of 5 minutes or less. About 80 percent of riders wait no longer than 10 minutes. The need to transfer between transit vehicles en route to one's travel destination also influences transit patronage. Fifty-one percent of transit trips involve one or more transfers. In addition, approximately 17 percent of transit trips involve a private vehicle, e.g., park-and-ride situations.
Available Seats (Seat Capacity)	This term means the number of passenger seats on a transit vehicle. The presence of standees, even one or two, tends to convey a sense of crowding. This is especially true from the perspective of those who must stand. Passengers often consider a vehicle to be crowded when it is operating with a load factor above seated capacity but still significantly below full capacity.
Travel Times	According to data collected in 1990, about 25 percent of all transit users reported trip times of 10 minutes or less, and nearly 76 percent of transit trips were reported to take less than half an hour.

Source : HCM, 1985

The availability of real time data is important in mode choice analysis and thus variables such as travel time, fuel consumption and arrival times to stops affect transit level of service and are modeled explicitly.

Table 3.3 Factors that Influence Transit Capacity.

	Factors	SIM	AVL
1	***Vehicle Characteristics***		
	• Allowable number of vehicles per transit unit (i.e., Single unit)		
	• Vehicle dimensions		
	• Seating configuration and capacity		
	• Number, location, width of doors		
	• Number and height of steps		
	• Maximum speed	*	*
	• Acceleration and deceleration rates	*	*
	• Type of door actuation control		
2	***Right-of-way Characteristics***		
	• Cross-section design (i.e., number of lanes or tracks)		
	• Degree of separation from other traffic		
	• Intersection Design (at grade or grade separated, type of traffic controls)		
	• Horizontal and vertical alignment		
3	***Stop Characteristics***		
	• Spacing (frequency) and duration	*	*
	• Design (on-line or off-line)		
	• Platform height (high level or low level loading)		
	• Number and length of loading positions		
	• Method of fare (prepayments, pay when entering vehicle; pay when leaving vehicle)	* *	
	• Type of fare (single-coin, penny, exact)		
	• Common or separate areas for passenger boarding and alighting)	*	*
	• Passenger accessibility to stops		
4	***Operating Characteristics***		
	• Intercity versus suburban operations at terminals		
	• Layover and schedule adjustment practices		
	• Time losses to obtain clock headways or provide driver relief	*	*
	• Regularity of arrivals at a given stop	*	*
5	***Passenger Traffic Characteristics***		
	• Passenger concentration and distribution at major stops		
	• Peaking of ridership (i.e., peak-hour factor)		
6	***Highway Traffic Characteristic***		
	• Volume and nature of other traffic (on shared right-of-way)	*	
	• Cross traffic at intersections if at grade		
7	***Method of Headway Control***		
	• Automatic or by driver/trainman	*	*
	• Policy spacing between vehicles	*	*

SIM : factors which can be controlled by this bus simulation model
AVL : factors impacted after AVL implementation
Source ; Modified form Highway Capacity Manual (1985)