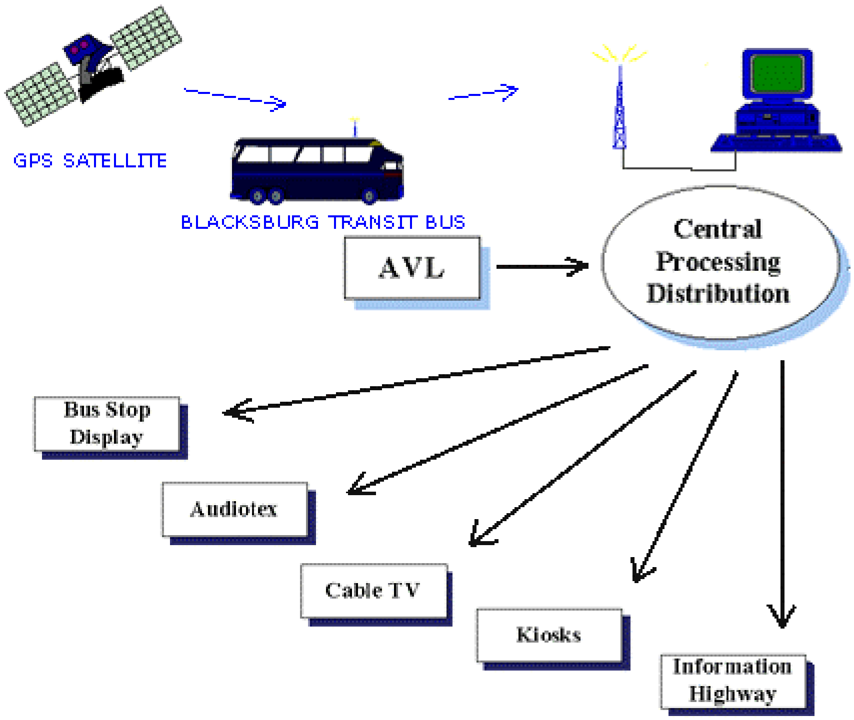
5.0 Case Study : Blacksburg Transit AVL System

To illustrate the application of the ITPM model described in Chapter 4, the Blacksburg Transit (BT) is set as the case study. Blacksburg Transit is in the process of equipping 30 buses of its fleet with a GPS-based AVL (See Figure 5.1). This program is being implemented in coordination with research activities at the Center for Transportation Research (CTR) in Virginia Polytechnic Institute and State University (Virginia Tech). The BT system was selected as case study for the following: 1) familiarity with the system and its demographics; 2) relatively well known traffic network conditions 3) BT is under an AVL implementation process; 4) possibility to get reliable data prior and post-AVL implementation; and 5) good relationship and cooperation with BT authority. The study period before AVL implantation started in February 1997 and ended in March 1998.

5.1 Condition of the Study Area

The town of Blacksburg encompasses of 18.8 square miles and located in Montgomery County, Southwestern Virginia, 40 miles southwest of Roanoke on U.S. 460 West off Interstate Highway 81 (See Figure 5.2). Blacksburg is also a farm center with several manufacturing industries spread around town. The population in 1998 is estimated to be 37,500. Among them more than two-thirds of the total population are students enrolled at Virginia Tech (enrollment: 25,213; Virginia Tech, 1997) and more than 5,100 persons are faculty and staff members directly linked to the university.

BT authority operates seven fixed and flexible routes throughout the town of Blacksburg. For a detailed description of Blacksburg network and route schedule, see Figure A.1 in Appendix A or visit the BT Website (http://www.btbus.org).



Automatic Vehicle Locator (AVL) : The Automatic Vehicle Locator uses the Global Positioning System (GPS) to pinpoint the location of the bus. This is done by signals received from the GPS satellites. The receiver unit installed on the bus than relays the position information (latitude and longitude) of the bus to the Base Station, which handles the Central Processing Distribution. The communication between the bus and the base station is done through a Motorola MaxTrac radio. Location update from satellites is 2-3 times per second. Location accuracy is within 50ft.

Central Processing & Distribution : A central Base Station, referred to as the Central Processing & Distribution unit, manages the system. The location information from the AVL equipment on the buses is received and processed by the base station. The equipment used at the base station consists of a CB radio receiver, modems and 2 PC's.

Bus Stop Displays : The Bus Stop Displays are receiver units that are placed at selected bus stops. The transit user will be able to obtain the arrival time of the next bus simply pressing a button on the bus stop display unit. The time is decreased in steps of one minute to provide a fairly accurate estimation. The base station puts the arrival times of each bus on a FM subcarrier. The relevant information is than plucked from the data stream by each bus stop display unit and presented to the transit user at the press of a button.

Audiotex : The arrival information for each bus at different stops will also be available by simply calling a phone number. The transit user will enter in the bus stop that he will be using and will then hear the arrival times. The structure of the voice response system will be very easy to use, since just the bus stop number is required.

Cable TV : The arrival times of each bus will be displayed on cable TV. The Transit user may switch to the Blacksburg Transit's TV station and observe the time of arrival of a particular bus.

Kiosks : Kiosks will be placed at high traffic areas like the Library Plaza, Squires Student Center, the New River Valley Mall, and other desirable locations. The transit user will be shown a map of Blacksburg and asked to select their location. The user will then be asked to select the desired bus stop. The arrival times of buses coming to that particular stop will then be displayed on the screen. The kiosk displays will look quite similar to the Internet web page.

Internet : The arrival times of different buses will also be made available on the Internet. The transit user may select the option of viewing a map of Blacksburg with moving buses, or get the time of arrival of a bus at their desired stop. The Internet will provide an easy accessible way for transit patrons to obtain this information from their homes or offices.

Source : Blacksburg Transit

Figure 5.1 Overview of the AVL System in Blacksburg Transit.

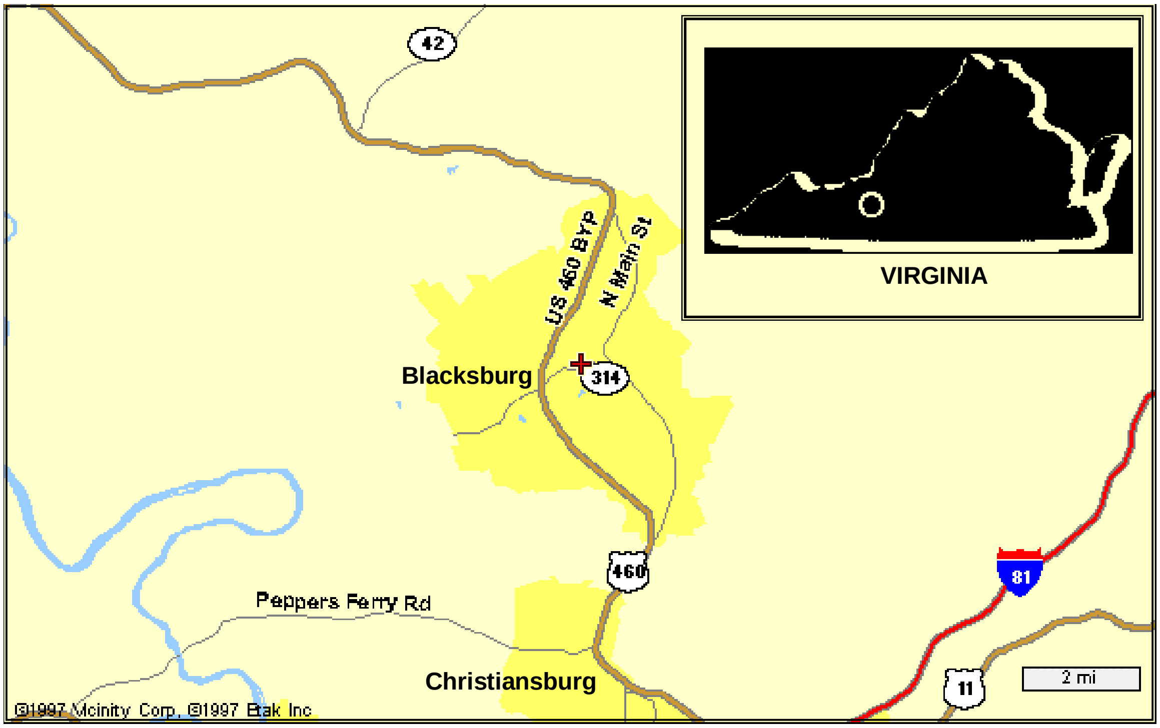


Figure 5.2 Location Map of Blacksburg.

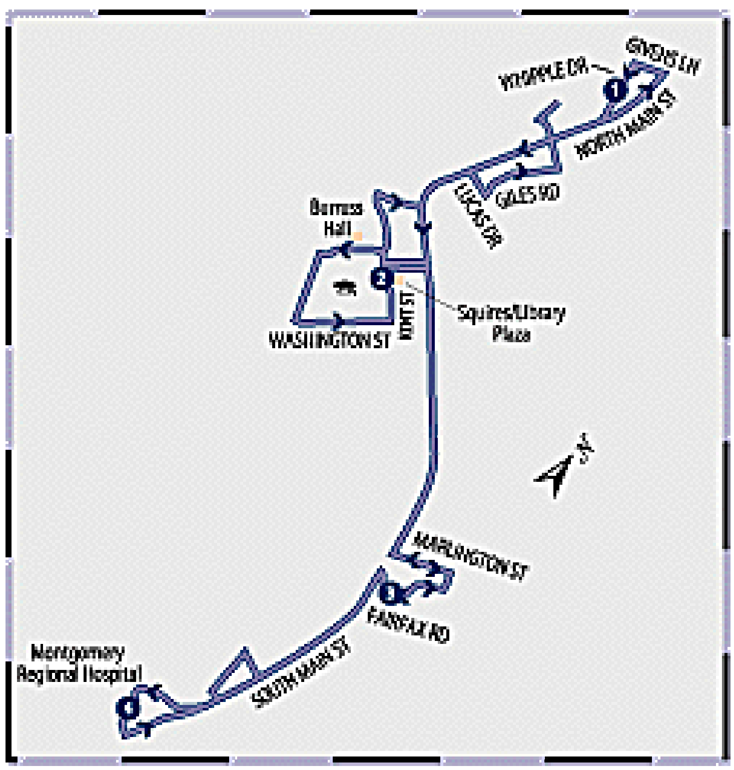


Figure 5.3 Route Map of Main Street (Route 1).

In 1997, the average number of passengers in a weekday, during a regular Virginia Tech semester was around 7,500 and this figure equated to 11% of total town daily traffic demand (See Table 5.1). BT operates 7 routes shown in Table 5.1. The Main Street route (route #1) was selected for detailed analysis in this study. This route is one of the major routes in the system in terms of boardings and route length (See Figure 5.3). This route has good geographical coverage The Main Street route also has varied topographical (uphills and downhills) and traffic conditions all kinds of signalized / unsignalized intersections and turns. The route crosses the downtown and remote areas which show a clear contrast in passenger demand. With those conditions, the Main Street route was selected as study route and evaluated throughout this chapter. A illustrative outlines of this route is shown in Appendix A.

Table 5.1 BT Demand for Each Route (1997; Weekday, Fall/Spring Semesters).

Route / Operation hour		Main Street Route	Tom's Creek Route	Hethwood /Windsor Route	Para-Transit.	Two Town Trolley	Special Purpose Housing	Campus Circulator	Total
6:45- 9:45am		583	623	496	17	13	73	25	1,829
	Row Pct.	0.32	0.34	0.27	0.01	0.01	0.04	0.01	1.00
	Col Pct.	0.33	0.22	0.24	0.37	0.09	0.16	0.17	0.25
9:45-12:45pm		214	621	458	10	0	108	42	1,454
	Row Pct.	0.15	0.43	0.31	0.01	0.00	0.07	0.03	1.00
	Col Pct.	0.12	0.22	0.22	0.22	0.00	0.23	0.29	0.19
12:45-3:45pm		548	610	679	8	43	128	46	2,063
	Row Pct.	0.27	0.30	0.33	0.00	0.02	0.06	0.02	1.00
	Col Pct.	0.31	0.21	0.33	0.17	0.31	0.27	0.32	0.28
3:45-6:45pm		172	528	156	4	82	78	30	1,049
	Row Pct.	0.16	0.50	0.15	0.00	0.08	0.07	0.03	1.00
	Col Pct.	0.10	0.19	0.08	0.09	0.59	0.17	0.21	0.14
6:45-9:45pm		121	263	133	5	0	45	0	567
	Row Pct.	0.21	0.46	0.23	0.01	0.00	0.08	0.00	1.00
	Col Pct.	0.07	0.09	0.06	0.11	0.00	0.10	0.00	0.08
9:45-1:15am		106	199	154	2	0	34	0	495
	Row Pct.	0.21	0.40	0.31	0.00	0.00	0.07	0.00	1.00
	Col Pct.	0.06	0.07	0.07	0.04	0.00	0.07	0.00	0.07
Total		1,744	2,845	2,077	46	138	466	143	7,458
	Row Pct.	0.23	0.38	0.28	0.01	0.02	0.06	0.02	1.00
	Col Pct.	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Source : BT Authority

The study route is divided into seven sub-routes or sections according to the presence of time-checks. Throughout the route there are six time-check points. Each section starts at and ends at time-checks. Table 5.2 summarizes all sections of BT Main Street route.

Table 5.2 Description of the BT Main Street (Route #1) Sections.

Section #	Route Description	Distance
1	Squires West bound→ Lucas St.→ Giles St.→ N. Main Time-check	4711.5 *m*
2	North main Time-check→ Hunters Ridge→ N. Main→ Squires West bound	4054.2 *m*
3	Squires West Bound→ Burrus hall→ Library→ Squires East bound	2886.0 *m*
4	Squires East bound→ S. Main→ Marlington St.→ South Main time-check	4303.7 *m*
5	South main time-check→ S. Main→ High Top Rd.→ Hospital	3560.8 *m*
6	Hospital→ S. Main →South main time-check	3545.1 *m*
7	South main time-check→ Marlington St.→ S. Main→ Squires West bound	4304.7 *m*
Total		27366.0 *m*

Table 5.3 Main Street BT Operation Schedule (Monday-Friday).

Bus I.D. #	Leave Shop	Hospital	South Main	Squires West	North Main	Squires West	Squires East	South Main	Hospital
10	6:25		6:30	6:45	7:00	7:15	7:25	7:40	7:50
11	6:45		7:00	7:15	7:30	7:45	7:55	8:10	8:20
12	7:15	7:20	7:30	7:45	8:00	8:15	8:25	8:40	8:50
10		7:50	8:00	8:15	8:30	8:45	8:55	9:10	9:20
11		8:20	8:30	8:45	9:00	9:15	9:25	9:40	9:50
12		8:50	9:00	9:15	9:30	9:45*	9:55	10:10	10:20
10		9:20	9:30	9:45*	10:00	10:15	10:25	10:40	10:50
11		9:50	10:00	10:15	10:30	10:45	10:55	10:10	10:20
12		10:20	10:30	10:45	11:00	11:15	11:25	11:40	11:50
10		10:50	11:00	11:15	11:30	11:45	11:55	12:10	12:20
11		10:20	11:30	11:45	12:00	12:15	12:25	12:40	12:50
12		11:50	12:00	12:15	12:30	12:45*	12:55	1:10	1:20
10		12:20	12:30	12:45*	1:00	1:15	1:25	1:40	1:50
11		12:50	1:00	1:15	1:30	1:45	1:55	2:10	2:20
12		1:20	1:30	1:45	2:00	2:15	2:25	2:40	2:50
10		1:50	2:00	2:15	2:30	2:45	2:55	3:10	3:20
11		2:20	2:30	2:45	3:00	3:15	3:25	3:40	3:50
12		2:50	3:00	3:15	3:30	3:45*	3:55	4:10	4:20
10		3:20	3:30	3:45*	4:00	4:15	4:25	4:40	4:50
11		3:50	4:00	4:15	4:30	4:45	4:55	5:10	5:20
12		4:20	4:30	4:45	5:00	5:15	5:25	5:40**	
10		4:50	5:00	5:15	5:30	5:45	5:55	6:10	6:20
11		5:20	5:30	5:45	6:00	6:15		6:30	
			6:30	6:45*	7:00	7:15		7:30	
			7:30	7:45	8:00	8:15		8:30	
			8:30	8:45	9:00	9:15		9:30	
			9:30	9:45	10:00	10:15		10:30	
			10:30	10:45	11:00	11:15		11:30	
			11:30	11:45	12:00	12:15		12:30	
			12:30	12:45	1:00	1:15		1:30[#]	
			1:30	1:45	2:00	2:15		2:30[##]	

* Denotes shift change
** Return to Shop M-F
[#] Return to shop M-W (end of service)
[##] Return to shop Th-S (end of service)

The specifications for transit routes are presented in Table 5.2 and Figures A.1 through A.9 in Appendix A. The operation distance of the route is 27.37 *km* from Squires Student Center at Virginia Tech westbound to the same location after one and half hours of operation. Every section of the route has an assigned operation time varying from 900 to 600 seconds according to the length of the sections and demand. Buses wait at the time-check point when they arrive earlier than the next scheduled start time. Table 5.3 shows the current fixed operation schedule for the Main Street. Presently (1998), BT operates two pilot runs with two AVL-equipped test buses (See Figures 5.1).

5.2 Evaluating Current BT Performance

Before the application of the ITPM, the current BT conditions are reviewed from the supply side point of view. For this, general figures related to the present BT operation condition such as passenger demand, performance and geographical characteristics were reviewed and checked. The data sources are on-board/ road-side observations, passenger response surveys, and BT authority statistics.

The average operating speed for the Main Street route is 18.22km/h (11.32mph) as shown in Table 5.4. The total number of stops is 92 with an average stop distance of 297 meters (5.4 stops/ *mi*). The scheduled operation hours and actual average travel times for section 1 are 900 seconds and 838 seconds respectively (See Table 5.5). This means on the average a bus waits for 62 seconds at section 1 time-check before the next run. Along the Main Street routes, three buses are operating along the same route with a 30 minute headway during daytime hours (6:30AM ~ 6:30PM). The headway increases to one hour after 6:30PM until 2:30AM when the daytime service ends. There are about 22 round trips during daytime hours (6:30AM - 6:30PM) and 7 shortened round trips from 6:30PM until 1:30AM in a typical weekday (the route skips the Hospital circuit; routes 5 and 6). The total operation time for these three buses is 41 hours (a utilization of 13.67 hours per bus per day). The total travel distance is around 464 *mi* per day not counting the deadhead distance between the BT shop and the start and end of in-service trips. The perceived Level of Service (LOS) by passengers indicates 5.19 (with 7 being excellent and 1 poor), which shows a high level of satisfaction from users. This LOS is, under

Blacksburg traffic conditions, better than that of auto (2.70), and other modes (walk/bicycle; 2.87).

Table 5.4 Conditions of Blacksburg Transit Operations (Main Street Route).

BT Main Street Conditions	Values	
Average Operating Speed	18.22km/h (11.32mph)	
Number of Stops	92	
Average Stop Distance	297 meters (5.4 stops/ *mi*)	
Operations Hour	6:30AM ~ 6:30PM (13.8hr/bus)	• Bus I.D. # 10 ; 12.0 hr. 6:30AM – 6:30PM • Bus I.D. # 11 ; 19.5 hr. 7:00AM – 2:30AM • Bus I.D. # 12 ; 10.0 hr. 7:30AM – 5:30PM
Number of Round Trips	About 27	• 6:30AM - 6:30PM : 30 min. headway • 6:30PM - 2:30AM : 60 min. headway
Operation hour per shift	1.5hr.	
Total operation distance	About 848.0Km (464.0*mi*)	• 27.366km/shift × 27.3(round trip)
Fuel consumption	400 *l* (106 gal)	
Miles-Per-Gallon (MPG)	2.11Km/*l* (4.4MPG)	• 848 (Km) / 400(*l*)
Level of Service (LOS)*	5.19	• Auto(2.70) ; Other modes (2.87)

* : 1; poor, 7; excellent ; from passenger survey questionnaire

Table 5.5 Scheduled Vs. Actual Average Operation Time for Main Street Route (sec.).

BT Main Street Conditions	Scheduled Operation Time	Actual Average Operation Time
Section 1 (Squires West bound→ N. Main Time-check)	900	838
Section 2 (North main Time-check→ Squires West bound)	900	768
Section 3 (Squires West Bound→ Squires East bound)	600	583
Section 4 (Squires East bound→ South Main time-check)	900	801
Section 5 (South main time-check→ Hospital)	600	413
Section 6 (Hospital→ South main time-check)	600	383
Section 7 (South main time-check→ Squires West bound)	900	825
Total	5,400	4,611

Table 5.6 Comparison Between Suggested Planning Guidelines for Bus Operation and BT Case.

Category	Suggested Guidelines	BT case
Route Length	a. Routes should be as short as possible to serve their markets; excessively long routes should be avoided. Long routes require more liberal travel times because of the difficulty in maintaining reliable schedules b. Route length generally shall not exceed 25*mi* round trip or 2 *hr*.	27.37Km(17*mi* ; round trip:1.5*hr*.)
Service period	a. Regular service : 6 a.m. to 11 p.m./midnight, Mon. – Fri. b. Owl service : selected routes, large cities–24hr. c. Suburban feeder service: weekdays, 6–9a.m., 4–7p.m.	6:30AM - 6:30PM 6:30AM - 2:30AM
Policy Headways	a. Peak : 20 min. –urban 20-30–suburban b. Midday : 20 min. –urban 30–suburban c. Evening : 30 min. –urban 60–suburban	30 min. 30 min. 60 min.
Bus Stop frequency	a. Central areas: 10–12 stops/*mi* b. urban area, major intersections: 6–8 stops/*mi* c. sub urban areas: 2–5 stops/*mi* d. express or sub urban service: 2–4 stops/*mi* in pickup zone	5.4 stops/*mi*
Route Speeds	a. Central area 6–8 mph b. Urban 10–12 mph c. Suburban 14–20 mph	11.32mph

Source : Levinson, 1982

Considering the guidelines for bus planning prepared by TRB (Levinson, 1982), in every category BT Main Street route meets the minimum guidelines (See Tables 5.4 and 5.6). The route length and round trip statistics (17*mi* and 1.5*hr*.) also meet the suggested guidelines (25*mi*, less than 2*hr*.). Other categories such as service period, policy headways, bus stop frequency, and route speeds of BT show quite good values of service considering that Blacksburg is a small rural university town with homogeneous traffic demand patterns.

The fuel economy also shows relatively good figures comparing it with the average fuel economy in United States (See Table 5.7). The fuel consumption and fuel efficiency is estimated to be 400 *l* per day (106 gal/day) and 2.11Km/*l* (4.4mi/gal), respectively. This value is quite reasonable when compared with average fuel economy figures estimated by TRB.

Table 5.7 Projected Average Fuel Economy by Vehicle Type.

Vehicle type	Fuel Economy (MPG)				
	1980	1985	1990	1995	2000
Automobile	14.3	18.2	22.1	NA	28.6
Light Truck	12.7	14.6	16.3	NA	20.4
Transit Bus	3.6	3.3	3.3	NA	3.3
School Bus	7.4	7.6	8.0	NA	8.5

Source : TRB, 1984

5.2.1 BT Operation Regularity Assessment

To check quality of BT service, the current transit operation condition was evaluated. One of the important characteristics in service quality of bus operation is scheduled time-adherence operations. Generally speaking higher on-time performance yields higher reliability and therefore higher service. Irregular arrival times cannot meet passenger needs and this could yield low demands. One of the methods used by many transit operators to estimate transit time-adherence is the so-called regularity index. The regularity index (R) has been adopted from Henderson (Henderson et al, 1991). This index shows regularity of bus headway performance in a normalized scale from 0 to 1. If headways of all the buses servicing a route are equal, the regularity index is just 1 whereas if all buses run together (very short headways), the value indicates 0. The concept of this index is similar to that of Gini's ratio, which has been used by economists and sociologists to measure the degree of income inequality within groups of people. After some modifications, the following shortcut formula presented in Equation 5.1 is used to estimate R:

$$R = 1 - \frac{2\sum_{r=1}^{n}(h_r - H)r}{n^2 H} \qquad (5.1)$$

where
h_r = series of headways;
r = 1, . . . n, the rank of the headways from smallest to largest; and
H = mean headway.

With this R index, the BT regularity of headway performance is evaluated. The results of BT Main Street route regularity indices are shown in Table 5.8 and Figure 5.4. The horizontal axis in Figure 5.4 is the cumulative proportion of buses (headways), ordered from the smallest to the largest headway. The vertical axis represents the cumulative proportion of the total headway minutes of individual buses as they are organized in the x-axis. The diagonal line describes regular services providing evenly distributed headways. The black area represents the difference between actual service and perfectly regular service. The regularity index is the ratio of the shaded area to the area of the entire triangle.

The regularity index for BT operations averaged 0.9217. In other words the shaded area is 92.17 percent of the triangle. In simple terms BT buses maintain regular headways 92.17 percent of accuracy. Considering that in a large metropolitan area such as New York City bus operation regularity is about 0.67 due in part to heavy traffic conditions, BT shows relatively high reliability in its operation. In conclusion, it can be said that BT provides high quality of transit service to the average Blacksburg resident.

5.3 Model Building

The modeling the Blacksburg Transit system was conducted in accordance to the modeling procedure proposed in Chapters 3 and 4. In order to consider particular operating conditions of BT as a case study the following simplifications were made. One important consideration for this case study is the fidelity of data needed to carry out the analysis. In the network structure of BT there are more than 450 bus stops (for example, the Main Street route has 92 bus stops alone as shown in Appendix A). Estimation of the exact demand ridership at each bus stop would need a high quality data set (i.e., al least several dozen zones; socio-economic data, etc.). However, the actual Blacksburg zonal system shows only 11 tracts and socio-economic data based on existing zones. Considering such constraints, both the zonal population data and on-board observation data was used at each UTPP step to reduce possible errors and to help validating the model.

Table 5.8 BT Regularity Index Results.

Case	Headway (Unit : Min.; Scheduled Headway: 30 min.)										R index	Coefficient of Variance
	1st	2nd	3rd	4th	5th	6 th	7 th	8 th	9 th	10 th		
1	25	28	30	31	33	34	34	35	36	40	0.829	0.161
2	25	29	29	30	30	33	33	35	35	36	0.884	0.121
3	22	23	27	27	29	31	32	34	36	40	0.895	0.179
4	25	26	27	28	31	31	31	31	38	38	0.901	0.144
5	24	25	27	28	29	33	33	33	33	38	0.912	0.139
6	23	24	24	28	30	33	33	34	34	35	0.925	0.149
7	18	22	25	26	29	29	30	34	35	37	0.949	0.195
8	20	25	27	29	29	29	29	30	35	36	0.964	0.149
9	26	26	26	26	27	27	31	32	34	36	0.969	0.124
10	24	26	26	26	28	28	29	29	34	36	0.989	0.127
Average											0.922	0.149

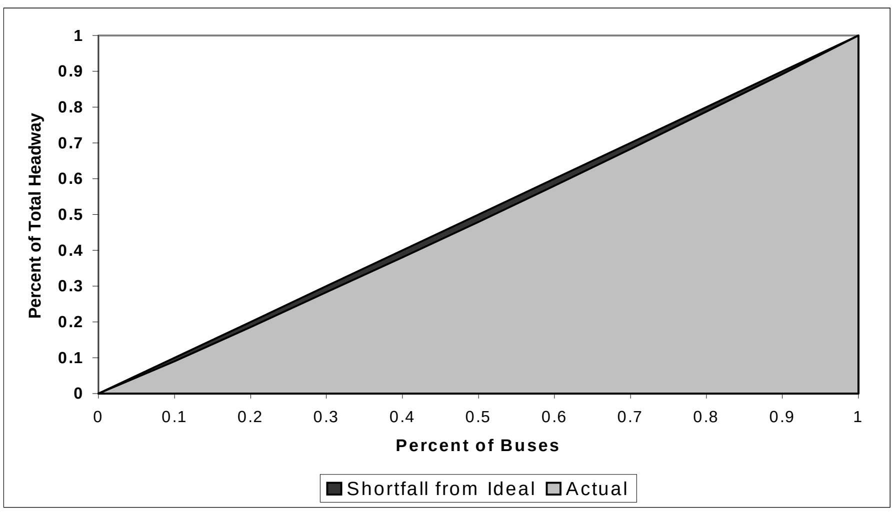


Figure 5.4 Graphical Dedication of BT Regularity Index.

The procedure to analyze the BT case study using actual data sets is shown in Figure 5.5. In the population allocation analysis (A), a Lowry model was used to estimate the size of each zone of population. This output was calibrated with Blacksburg zonal population data. Bus trip generation (B) and trip distribution (C) processes estimated bus demands at each zone. The generation and distribution algorithms were calibrated using empirical data collected during the study in the form of a questionnaire (D, E). The same data was also used in mode choice (F) and bus/auto demand analyses (G, H). With survey data, a multinomial logit mode choice model (E) estimated the relationship between bus demand and other decision variables. Bus demands were observed at each bus stop to calibrate the model. Under various transit operating conditions walking distances between centroids and each bus stop were calculated. Using this information transit demand values were then assigned to each stop (J). The outputs of processes (B), (C), and (D) were checked again using survey data and the observed BT trip demand data. Traffic condition data from roadside observations were used as input data in the traffic assignment procedure (K). The output from procedures (J) and (K) were then used as inputs to estimate travel time (L) using the bus operation simulation model. Finally, with this model, several analyses were conducted according to to proposed transit alternatives. Sensitivity analysis for each transit operating condition (M) was also conducted with and without AVL technology (N). These processes from (A) to (N) were iterated every step in the macroscopic simulation with revised state variables until the horizon year condition was reached. In other word, the proposed APTS analysis framework solves a microscopic simulation inside a UTPP procedure which in turn is solved iteratively over the life cycle of the system.

5.3.1 Population allocation

Table 5.9 is the population projection for Blacksburg from Town of Blacksburg. For the future population growth, those were adopted in the model validation step. Table 5.10 shows the Blacksburg zonal system which is consists of 11 tracts. Among those, route 1 serves 7 zones excluding A, I, J, and K zones. Socio-economic data and population / employment condition of Blacksburg are presented in Tables 5.11 and 5.12.

Table 5.9 Population Projection for Town of Blacksburg.

Year	1995	2000	2010	2020	2030	2040	2046
Town Population (Person)	36,400	38,222	41,280	43,757	46,164	48,471	49,926
Annual growth rate (%)	.	1.05	0.8	0.6	0.55	0.5	0.5

Source : Town of Blacksburg

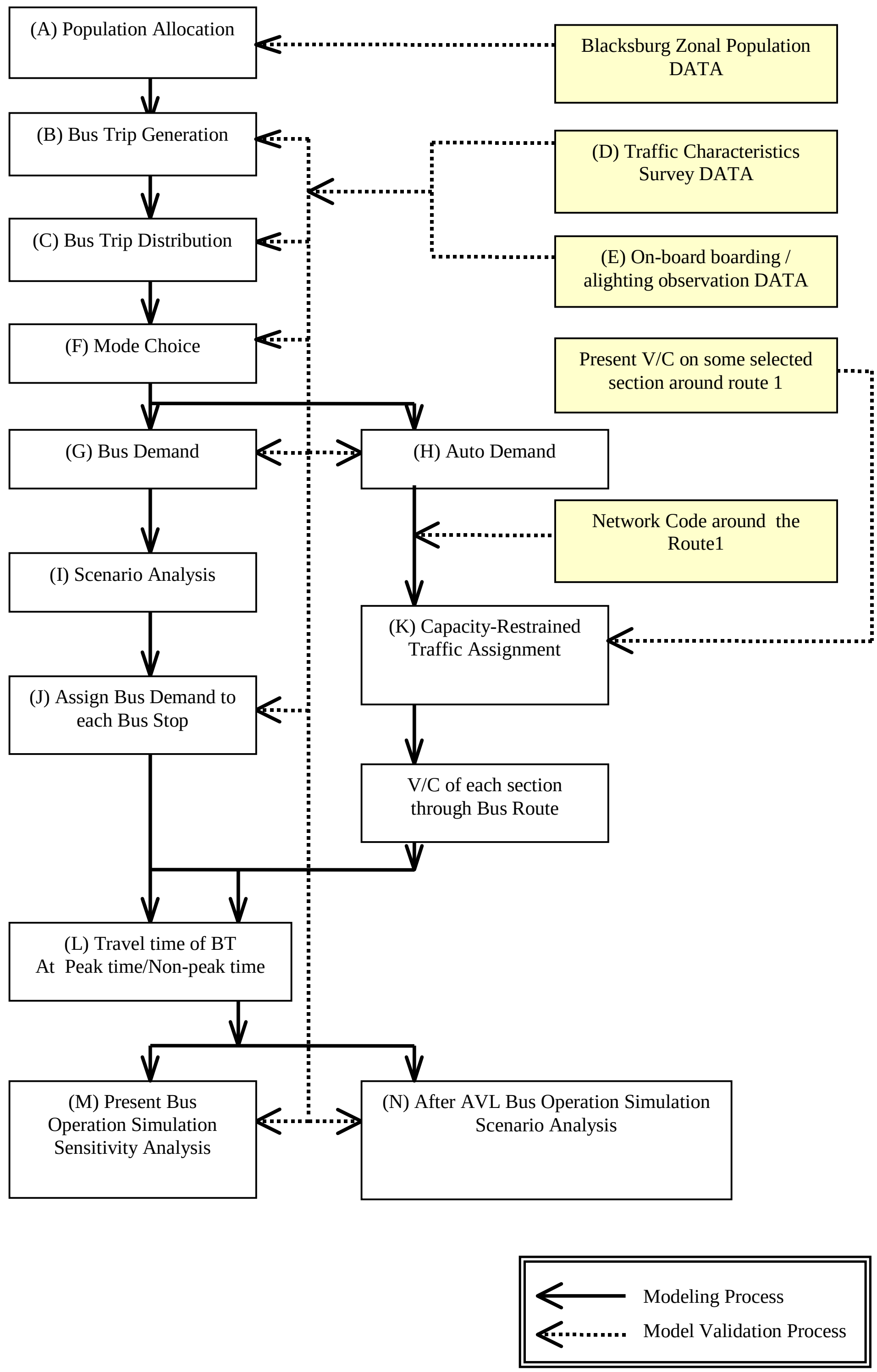


Figure 5.5 ITPM Modeling and Model Validation Process Using Actual Data.

Table 5.10 Blacksburg Zonal System.

County	District	town	Tract		Zone Description
Montgomery	Mount Tabor	Blacksburg	203	A*	Par northern area of Blacksburg
Montgomery	Prices Fork	Blacksburg	207	B	Virginia Tech Airport
Montgomery	Mount Tabor	Blacksburg	205	C	Northern area of North.Main Street
Montgomery	Prices Fork	Blacksburg	204	D	Northern area of North.Main Street
Montgomery	Prices Fork	Blacksburg	201	E	Virginia Tech
Montgomery	Mount Tabor	Blacksburg	206	F	Cross the Virginia Tech
Montgomery	Mount Tabor	Blacksburg	207	G	Ridgewood APT
Montgomery	Prices Fork	Blacksburg	203	H	Terrace View APT
Montgomery	Prices Fork	Blacksburg	212	I*	Par southern part of Blacksburg
Montgomery	Prices Fork	Blacksburg	202	J*	Foxridge APT, Montgomery Hospital
Montgomery	Mount Tabor	Blacksburg	213	K*	Par Eastern area of Blacksburg

* : Not served by route 1

The Lowry model estimated zonal population allocation as seen in Table 5.13. Figures D.1 through D.4 in Appendix D show the C++ programming source code of the Lowry model and its data formats.

Table 5.11 Blacksburg Socio-Economic Data (1997).

Zone	Area (Sq Mi)	Population	Persons/ HouseHold	Persons/ Sq Mi	Median Income	Total Employ.	Retail Employ	Non-retail Employ	Housing Units
A	4.23	842	2.1	199.2	$26,896	133	27	106	400
B	2.03	1,574	2.1	775.5	$25,880	248	51	197	735
C	2.62	3,145	2.1	1200.4	$21,556	1,537	256	1,281	1,492
D	0.95	4,027	2.1	4239.4	$10,751	961	197	763	1,910
E	1.26	10,409	2.1	8261.0	$ 6,728	7,948	1,633	6,315	4,937
F	2.45	3,631	2.1	1482.2	$16,114	834	291	543	1,722
G	1	2,626	2.1	2625.6	$25,999	1,364	475	889	1,246
H	1.4	4,059	2.1	2899.6	$20,681	1,548	318	1,230	1,925
I	3.22	901	2.1	279.7	$26,896	455	93	362	427
J	1.54	5,529	2.1	3590.0	$14,797	367	75	292	2,622
K	3.81	912	2.1	239.4	$26,896	17	3	14	433
Total	24.51	37,656	2.1	1536.4	$22,702	15,410	3,420	11,990	17,847

Table 5.12 Blacksburg Zonal Population / Employment.

Zone	Retail Employment	Non-Retail Employment	Total Employment	Total Population
A	106	27	133	842
B	197	51	248	1,574
C	1,281	256	1,537	3,145
D	763	197	961	4,027
E	6,315	1,633	7,948	10,409
F	543	291	834	3,631
G	889	475	1,364	2,626
H	1,230	318	1,548	4,059
I	362	93	455	901
J	292	75	367	5,529
K	14	3	17	912

Table 5.13 Predicted Zonal Population Allocation in Blacksburg.

Zone	Service Employment		Total Employment		Total Population	
	Actual	Predicted	Actual	Predicted	Actual	Predicted
1	27	40	133	146	842	489
2	51	57	248	254	1,574	1,677
3	256	295	1,537	1,576	3,145	3,264
4	197	173	961	936	4,027	3,312
5	1,633	1,277	7,948	7,592	10,409	11,865
6	291	498	834	1,041	3,631	4,854
7	475	418	1,364	1,307	2,626	2,571
8	318	248	1,548	1,478	4,059	3,905
9	93	47	455	409	901	570
10	75	362	367	654	5,529	4,763
11	3	3	17	17	912	381
Total	3,419	3,419	15,412	15,411	37,655	37,652

5.3.2 Trip Generation and Trip Distribution

Estimated population and employment parameters from the population allocation analysis are used in both trip productions (See Table 5.14) and trip attractions (See Table 5.15). For bus trip productions, the regression model in Equation 5.2 reveals a positive relationship between population and bus trip production while the level of income has a negative relation to bus trip production.

$$\text{Bus Trip production} = \underset{(0.090^{*})}{17.2} + \underset{(0.004^{*})}{0.00362} \times \text{Pop.} - \underset{(0.090^{*})}{0.000638} \times \text{Median Income} \qquad (5.2)$$

R^2 : .775
F : 37.09 {F(2,7) = 4.74}
* : Level of Significance : P(<.10)

Table 5.14 Estimated Trip Productions for Main Street Route.

Zone	Population	Median Income	Total Employ.	Retail Employ.	Non-retail Employ.	Housing Units	Observed O_i	Estimated O_i
A	489	26896	146	40	106	400	–	2
B	1677	25880	254	57	197	735	11	7
C	3264	21556	1576	295	1281	1492	15	15
D	3312	10751	936	173	763	1910	23	22
E	11865	6728	7592	1277	6315	4937	57	56
F	4854	16114	1041	498	543	1722	21	24
G	2571	25999	1307	418	889	1246	7	10
H	3905	20681	1478	248	1230	1925	19	18
I	570	26896	409	47	362	427	–	2
J	4763	14797	654	362	292	2622	–	25
K	381	26896	17	3	14	433	–	1
Total	37651	223194	15410	3418	11992	17849	153	182

The number of retail and non-retail employment is shown in Table 5.15. These were used as input to obtain the number of trip attractions in each zone. Equation 5.3 shows the relationships among them.

$$\text{Bus Trip Attrtn.} = \underset{(0.019^{*})}{6.98} + \underset{(0.098^{*})}{0.0179} \times \text{Retail Emp.} + \underset{(0.046^{*})}{0.00455} \times \text{Non-retail Emp.} \qquad (5.3)$$

R^2 : .679
F : 44.82 {F(2,7) = 4.74}
* : Level of Significance : P(<.10)

Table 5.15 Estimated Trip Attractions for Main Street Route.

Zone	Population	Total Employ.	Retail Employ.	Non-retail Employ.	Housing Units	Observed D_i	Estimated D_i
A	489	146	40	106	400	–	8
B	1677	254	57	197	735	5	9
C	3264	1576	295	1281	1492	17	18
D	3312	936	173	763	1910	16	14
E	11865	7592	1277	6315	4937	58	59
F	4854	1041	498	543	1722	17	18
G	2571	1307	418	889	1246	21	19
H	3905	1478	248	1230	1925	19	17
I	570	409	47	362	427	–	9
J	4763	654	362	292	2622	–	15
K	381	17	3	14	433	–	7
Total	37651	15410	3418	11992	17849	153	193

In the next trip distribution step, using those estimated trip productions and attractions (O_i, D_j), a double-constrained Gravity Model presented in Equation 4.1 was adopted to represent the distribution pattern of Blacksburg's bus traffic demand on route 1. Tables 5.16 and 5.17 shows the estimated Blacksburg traffic demand output near the study route. Figures D.5 through D.8 in Appendix D show C^{++} programming source code of the trip generation/ distribution analysis and its data formats.

Table 5.16 Distribution Table of BT Traffic.

Zone	Zone Description	A	B	C	D	E	F	G	H	I	J	K	O_i
A	Par upper part of Blacksburg	1	0	0	0	0	0	0	0	0	0	0	2
B	Virginia Tech Airport	0	1	0	0	2	1	1	0	0	0	0	7
C	Under part of North.Main Street	1	1	3	2	5	1	1	2	0	0	1	16
D	Upper part of North.Main Street	1	1	3	1	8	2	2	2	1	1	1	23
E	Virginia Tech	2	3	5	5	21	6	5	7	2	2	1	59
F	Cross the Virginia Tech	1	2	2	2	8	5	3	2	1	1	1	25
G	Ridgewood APT	0	1	1	0	2	1	4	1	1	0	0	11
H	Terrace View APT	1	1	3	2	6	2	1	1	1	1	1	19
I	Par left part of Blacksburg	0	0	0	0	0	0	0	0	1	0	0	2
J	Foxridge APT, Montgomery Hospital	1	1	1	1	5	1	2	2	2	10	1	27
K	Par right part of Blacksburg	0	0	0	0	0	0	0	0	0	0	0	1
D_j		8	9	18	14	59	18	19	17	9	15	7	192

Table 5.17 BT Trip Distribution Pattern among Zones served by Main Street Route.

Zone	Zone Description	B	C	D	E	F	G	H	O_i
B	Virginia Tech Airport	1	0	0	2	1	1	0	5
C	Under part of North.Main Street	1	3	2	5	1	1	2	15
D	Upper part of North.Main Street	1	3	1	8	2	2	2	19
E	Virginia Tech	3	5	5	21	6	5	7	52
F	Cross the Virginia Tech	2	2	2	8	5	3	2	24
G	Ridgewood APT	1	1	0	2	1	4	1	10
H	Terrace View APT	1	3	2	6	2	1	1	16
D_j		10	17	12	52	18	17	15	141

5.3.3 Assignment of BT Demand to each Bus Stop

Considering the geographical location and terrain conditions, all bus stops along the route were grouped and assigned to one of seven zones. If a bus stop bordered two zones, the bus stop belongs to both of them. Table 5.18 and Figure B.1 in Appendix B show examples of the bus stop allocation. Considering the distance from a stop to the zone centroid where each bus stop belongs, BT demands were assigned to each bus stop manually. In the case of two zones for one stop, demand was divided in proportion to the distances to the centroids.

Table 5.18 BT Demand on Each Bus Stop (Partial).

Rt #	BUS STOP	zone	# Boarding	# Alighting	Rt #	BUS STOP	zone	# Boarding	# Alighting
1-0	Squires West Bound	E	15	0	…	…	…	…	…
1-1	A Brodie	E,H	5	1	7-20	South Main Café	B,G	0	0
1-2	B Old-Security	E,H	1	0	7-21	B'burg Post Office	B,G	0	1
1-3	C B-lot	H	1	3	7-22	VT Entrance	E	0	2
1-4	N. Main past progress	D,H	1	3		Squires West Bound	E	0	28
1-5	N. Main wades	D,H	2	2		TOTAL		141	141

5.3.4 Mode Choice

5.3.4.1 Estimation of Modal Choice Model

In order to understand possible user choice behavior as the performance of the system changes, a multi-attribute utility function was developed including all possible variables which would be impacted by the AVL system (See Equation 5.4).

$$U = f\,(waiting\ time,\ travel\ time,\ fare,\ etc.) \qquad (5.4)$$

With the utility function model, the impact of the AVL was measured quantitatively by a change in the amounts of these independent variables. The process for the model building, calibration, and validation/verification was done according to the following steps:

Build and calibrate a Multinomial Logit Model (MLM)

- Find out the general travel pattern of Virginia Tech students according to the pilot survey
- Set all alternative transportation modes: auto, Blacksburg Transit (BT), and other modes (walk, bicycle)
- Set the independent variables of the utility function: in-vehicle time, out-vehicle time, waiting time, level of service, cost, and income, etc.
- Collect data from the survey and BT Authority
- Select significant independent variables to be used in the utility function and set up the model.
- Check statistical significance of the parameters of selected variables

Verification and validation of the MLM for BT ridership

- Compare the model output with real data in the case of pre-AVL technology
- Check the relationship between independent variables and ridership
- Check the behavior of the model through sensitivity analysis

Estimate the expected BT ridership before- and after-AVL according to the scenario analysis

- Compare the values of the independent variables after AVL technology from data (e.g. change of travel/waiting time, change of LOS)
- Run the model with changed value of the independent variables and compare changes of ridership
- Check the behavior of the model by performing sensitivity analysis

5.3.4.2 Survey Analysis

A passenger survey was conducted to estimate the Blacksburg residents' behavioral characteristics in choosing transportation modes. This survey could predict passenger modal changes after BT implements its full AVL/ATIS systems. First, two pilot surveys were conducted through e-mail to figure out passenger reaction to AVL and to develop a questionnaire. For this, there were 4 surveys. The first two surveys were pilot surveys administered to students to understand their initial reactions to AVL technology. The pilot surveys and fare-box revenue data from BT authority show that more than 95% of the bus riders are Virginia Tech students. With these preliminary findings, the Virginia Tech students were considered as the main customers of the BT system. The two main surveys were conducted at the Newman Library and various student halls Virginia Tech. The final questionnaire form is presented in Appendix C.1. The main surveys generated a total 557 respondents out of 1,800 showing a 31 % response rate.

Preliminary statistical analysis was done to estimate BT passenger travel patterns. Table 5.20 shows student auto ownership by selected mode. More than three-fourths (77.99 %) of Virginia Tech students own a car whereas a little bit more than half (54.85 %) of the total students use auto as primary transportation mode. However, less than a quarter (21.64 %) of the total students are using BT. Among those BT riders, more than half (53.45 %) are captive riders who do not have a car. The number of students who use other modes such as bicycle or walk to school is more than those riding BT (23.51%; other modes, 21.64 %; BT).

Table 5.19 Schedule of BT Survey.

<table>
<tr><th>Process</th><th>Date</th><th>Population</th><th># of data</th><th>Survey Location</th></tr>
<tr><td>Pilot survey 1</td><td>Fri. 2/7/97</td><td rowspan="2">Undergraduate students in civil Engg. Dept.</td><td>34</td><td>e-mail</td></tr>
<tr><td>Pilot survey 2</td><td>Wed. 2/12/97</td><td>26</td><td>e-mail</td></tr>
<tr><td>Main survey I</td><td>Tue. 2/25/97
11:15AM ~ 3:05 PM</td><td rowspan="2">All students in VT</td><td>330</td><td>Newman Library lobby</td></tr>
<tr><td>Main survey II*</td><td>Thu. 3/13/97
10:00AM ~ 2:50 PM</td><td>227</td><td>On-Campus Burger King</td></tr>
</table>

- accompanied with interview

Table 5.20 Basic Statistics of Survey Data.

Variable			N	N miss	Mean	Minimum	Maximum
CAR		Access Time	215	12	2.89	1.00	17.50
		In-Vehicle Travel Time	211	16	9.11	1.50	29.00
		Egress Time	208	19	6.84	1.00	19.50
		Total Journey Time[1]	202	25	18.22	3.50	58.00
		Relative Time[2]	202	25	0.46	1.10	0.92
		Los[3]	220	7	2.70	1.00	7.00
BT	Before AVL	Access Time	197	30	3.92	1.00	19.50
		Waiting Time	200	27	5.79	1.00	19.50
		In-Vehicle Travel Time	197	30	9.77	1.50	29.00
		Egress Time	200	27	6.09	1.00	19.50
		Total Journey Time[4]	189	38	25.38	4.50	87.50
		Relative Time[2]	189	38	0.39	0.04	0.73
		Los[3]	187	40	5.19	1.00	7.00
	After AVL	Waiting Time	208	19	3.27	0.00	19.50
		Total Journey Time[4]	189	38	23.48	3.50	70.00
		Relative Time[2]	189	38	0.43	0.04	0.81
		Los[3]	194	33	5.73	1.00	7.00
OTHER (Walk, Bicycle)		Travel Time	213	14	36.20	3.50	60.00
		Total Journey Time[5]	213	14	40.73	3.50	60.00
		Relative Time[2]	213	14	0.91	0.22	1.00
		Los[3]	227	0	2.87	1.00	7.00

(1) Access time + in-vehicle travel time + egress time
(2) In-vehicle travel time / total journey time
(3) 7; excellent ; 1: poor
(4) Access time + waiting time + in-vehicle travel time + egress time
(5) Walk : walking time
Bicycle : access time + in-vehicle travel time + egress time

Table 5.21 Student Auto Ownership Estimation by Mode (unit : person).

Frequency Percent Row Pct Col Pct	Mode Selection	AUTO	BT	OTHER	Total
Auto Ownership	Have Car	11,302 50.37 64.59 91.84	2,259 10.07 12.92 46.55	3,935 17.54 22.49 74.60	17,496 77.99
	No Car	1,005 4.48 20.34 8.16	2,596 11.57 52.54 53.45	1,339 5.97 27.12 25.40	4,940 22.01
	Total	12,307 54.85	4,855 21.64	5,274 23.51	22,437 100.00

Table 5.21 shows that the average number of trips per weekday per bus rider is 1.43 trips and this value (7,185 trip/day) correlates well with the data obtained from the BT Authority when the proportion of students is considered. Students believe that full information of BT bus location after AVL implementation would change their choice behavior on BT. They responded that the waiting time and total journey time of BT after AVL implementation would be reduced from 5.79 to 3.27 minutes (a 43% decrease) and from 25.38 to 23.48 minutes (7.5% decrease), respectively. However, no change of travel time is expected for auto and other modes. Students also expect that AVL/ATIS would increase efficiency of travel time by increasing the relative in-vehicle travel time of BT by 9.9% (from 0.3899 to 0.4286). In this context the relative in-vehicle travel time is the ratio of the in-vehicle travel time to that of the total travel time and various studies has been used this figure as an indicator of the willingness for a user to take the mass transit mode or not. Students also indicate that AVL/ATIS could increase the BT LOS from 5.19 to 5.73 (LOS 1: poor, 7: Excellent) with no change of LOS expected for auto and other modes.

5.3.4.3 Calibration of Modal Choice Model

The actual values of regression constants in the Multinomial Logit Model are presented in Equations 5.5 through 5.7. The model was calibrated using standard maximum likelihood statistical techniques implemented in the SAS statistical analysis package. Appendix C.2 shows the actual SAS language source code. Judging the results of the model calibration it is evident that BT users value the efficiency of the travel mode (relative travel time ; in-vehicle travel time / total journey time) and quality of service as main decision variables in modal choice.

With Equations 5.5 through 5.7, the probabilities of mode choice were ascertained using the logit model discussed in Chapter 4.2.3.

$$\underset{(U_{Auto})}{\text{Utility of Auto}} = \underset{(.0001)^{**}}{2.205} + \underset{(.0302)^{**}}{1.758} \times RELT^{*} + \underset{(.0001)^{**}}{0.667} \times LOS \qquad (5.5)$$

$$\text{Utility of BT} = -1.129 + 1.758 \times RELT^{*} + 0.667 \times LOS \quad (5.6)$$
$$(U_{BT}) \qquad (.0475)^{**} \; (.0302)^{**} \qquad (.0001)^{**}$$

$$\text{Utility of Other} = 1.758 \times RELT^{*} + 0.667 \times LOS \quad (5.7)$$
$$(U_{Other}) \qquad (.0302)^{**} \qquad (.0001)^{**}$$

RELT*: Relative Time (In-vehicle travel time/total journey time)
LOS: Level of Service of the BT
** (p - value <.05) : p - value for all parameters is less than .05, which is significant at the .05 level.

Probability of Auto selection =

$$\Pr(Auto) = \frac{e^{U_{Auto}}}{\sum_{i=1}^{3} e^{U_i}} = 0.6965 \quad (5.8)$$

Probability of BT selection =

$$\Pr(BT) = \frac{e^{U_{BT}}}{\sum_{i=1}^{3} e^{U_i}} = 0.1154 \quad (5.9)$$

Probability of Other mode selection =

$$\Pr(Other) = \frac{e^{U_{Other}}}{\sum_{i=1}^{3} e^{U_i}} = 0.1880 \quad (5.10)$$

To validate the model, the estimated values were compared with the output of simple extrapolation from the survey data. The results are shown in Table 5.22. The estimated values show relatively small discrepancies (at most 5 % difference in case of auto) with those obtained from the survey.

Table 5.22 Validation of the Mode Choice Model (unit : person).

Methods	Auto	BT	Other	Total
Simple Extrapolation from Survey Data (A)	11,302 (0.65)	2,259 (0.13)	3,935 (0.22)	17,496 (1.00)
Estimation from the logit model (B)	12,186 (0.70)	2,020 (0.12)	3,290 (0.19)	17,496 (1.00)
Difference (A-B)	– 884 (-0.05)	239 (0.01)	645 (0.04)	0

Using this mode choice model it is found that after full AVL/ATIS implementation, there could be an increment of up to 19% riders (898 trip/day) in the BT system. The increased riders are mainly from choice-riders who have autos (44% increase; See Table 5.23). This estimation is based on the following assumptions:

1. Full Reliability of AVL : There is no time discrepancy between observed and real bus operation schedule so passengers 'perceive' full reliability.
2. Full Accountability : With information available to users, every passenger tries to reduce total journey time and feels an improved LOS.
3. 100% Market penetration : All bus riders have precise and full information without any cost about the real-time bus location and arrival time of the buses to each stop they are boarding. In the scenario analysis of this dissertation, the impact of AVL on various implementation stages of AVL is measured.

Table 5.23 Comparison of Mode Selection by Students between Before and After AVL Implementation (Estimate).

Condition		Auto	BT	Other	Total
Before AVL Implementation (A)	Own Car	12,186 (1.00)	2,020 (1.00)	3,290 (1.00)	17,496
	Total*	13,191 (1.00)	4,615 (1.00)	4,629 (1.00)	4,940
After AVL Implementation (B)	Own Car	11,479 (0.94)	2,918 (1.44)	3,099 (0.94)	17,496
	Total*	12,484 (0.95)	5,513 (1.19)	4,438 (0.96)	4,940
Difference (A-B);		–707	898	–190	–

* : Own Car + No Car

The first two assumptions are heavily dependent on the AVL technology used. When AVL is fully implemented, those assumptions can be accepted without any question. However, in the real world, the market penetration of information alluded to in third assumption is affected by numerous factors.

5.3.4.4 Sensitivity Analysis Evaluation

To qualify to what degree the independent variables in the utility function impact the BT demand function, a sensitivity matrix table is presented (See Table 5.24). On each row, from the left to right, LOS increases at 0.5 intervals. On each column, moving down, relative travel time varies from 0.54 to 0.24. As expected, BT demand increases as LOS and BT relative travel time increase. Under current conditions the values of LOS and relative travel time are 5.19 and 0.39, respectively. The estimated BT demand shows 141 persons per round trip. Assuming LOS and relative travel time improvements to 5.69 and 0.44 respectively, the demand is estimated to be 202 persons.

Table 5.24 Sensitivity of BT demand by LOS and Relative Travel Time.

Probability of BT Demand *		BT LOS						
		6.69	6.19	5.69	5.19	4.69	4.19	3.69
BT Relative Travel Time	0.54	0.3158 (2.738) 386 pers.	0.2485 (2.154) 303 pers.	0.1916 (1.661) 234 pers.	0.1451 (1.258) 177 pers.	0.1084 (0.940) 132 pers.	0.0801 (0.695) 98 pers.	0.0587 (0.509) 72 pers.
	0.49	0.2972 (2.576) 363 pers.	0.2325 (2.015) 284 pers.	0.1783 (1.546) 218 pers.	0.1345 (1.166) 164 pers.	0.1002 (0.869) 122 pers.	0.0739 (0.641) 90 pers.	0.0541 (0.469) 66 pers.
	0.44	0.2791 (2.420) 341 pers.	0.2172 (1.883) 265 pers.	0.1658 (1.437) 202 pers.	0.1246 (1.080) 152 pers.	0.0926 (0.802) 113 pers.	0.0681 (0.590) 83 pers.	0.0497 (0.431) 61 pers.
	0.39	0.2618 (2.269) 320 pers.	0.2026 (1.756) 247 pers.	0.1540 (1.335) 188 pers.	0.1154 (1.000) 141 pers.	0.0854 (0.741) 104 pers.	0.0627 (0.544) 77 pers.	0.0458 (0.397) 56 pers.
	0.34	0.2452 (2.125) 299 pers.	0.1888 (1.636) 230 pers.	0.1429 (1.239) 174 pers.	0.1067 (0.925) 130 pers.	0.0788 (0.683) 96 pers.	0.0578 (0.501) 71 pers.	0.0421 (0.365) 51 pers.
	0.29	0.2293 (1.987) 280 pers.	0.1757 (1.523) 214 pers.	0.1325 (1.148) 162 pers.	0.0986 (0.855) 120 pers.	0.0727 (0.630) 89 pers.	0.0532 (0.461) 65 pers.	0.0387 (0.335) 47 pers.
	0.24	0.2141 (1.856) 261 pers.	0.1633 (1.416) 199 pers.	0.1227 (1.063) 150 pers.	0.0911 (0.789) 111 pers.	0.0670 (0.580) 82 pers.	0.0489 (0.424) 60 pers.	0.0355 (0.308) 43 pers.

From the output of our survey, the student estimated BT LOS and BT relative travel time to be 5.73 and 0.43 respectively after AVL (See Table 5.20). These values would yield a probability of bus ridership of 0.167 or equivalent to 205 persons. This would represent a 45% increase in demand after an increase of just 0.0516 in total market share. This means that the elasticity of the model is quite large and sensitive to the two independent variables. Perhaps this shows that people surveyed have tendency to be optimistic on AVL technology and its benefits. However, this figure might only be possible if a 100% market penetration is achieved. This would require a high degree of AVL reliability, good accessibility to, and willingness of users to use the information. In real world conditions it is difficult to expect all these circumstances exist simultaneously. To reflect these conditions, the market penetration variable is applied to reflect the constraints.

5.3.5 Bus Operation Simulation Model for Blacksburg Transit

Using the bus simulation model described in Chapters 3 and 4 in conjunction with the demand data derived at each bus stop, several bus performance parameters were estimated. These include route travel time, acceleration, and fuel consumption. The simulation model was ran under current conditions first and then to reflect four operation scenarios. For this model, a simulation package MODSIM II (MODular SIMulation II) software was used as the programming language. Tables 5.25 and 5.26 show the input data to the bus simulation model. The source code is included in Appendix D.

Table 5.25 Network Geometric and Traffic Conditions of each Section.

Section #	1	2	3	4	5	6	7
Distance (meters)	4711.5	4054.2	2886.0	4303.7	3560.8	3545.1	4304.7
No. of Stops	16	14	6	17	8	8	23
No. of Signalized intersections	4	5	0	5	2	3	5
No. of Turn/Unsignalized intersections	7	4	5	4	6	2	4
Avg. Boardings (persons)	16	39	18	33	3	4	56
Schedule time (s)	900	900	600	900	600	600	900
Avg. grade(%)	.786	-1.017	.779	-.373	.962	-.194	.328
Speed limit (*mi*/h)	45	45	15[1)]	25,45[2)]	45	45	25,45[2)]
Avg. travel time[A](without pax)	701	612	487	539	389	369	551

1) on campus circulation
2) Conditional speed limit on specific time zone in front of Blacksburg middle school

Table 5.26 Characteristics and Accuracy of Model Calibration.

Section #	1	2	3	4	5	6	7
Passenger Car Equivalent (PCE)	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Scheduled travel (s)	900	900	600	900	600	600	900
Avg. real travel time (without passenger; s)) [A]	701	612	487	539	389	369	551
Est. travel time by model (without passenger; s) [B]	695	614	480	542	393	364	554
Accuracy(B/A)	.991	1.003	.986	1.006	1.010	.986	1.005
Fuel Consumption (cc)	2490.2	2298.4	1597.4	2311.6	1690.8	1658.3	2289.7

Figures D.9 through D.12 in Appendix D show sample input/output results of the bus simulation program. The simulation model employed here is characterized as a continuous simulation model with a constant step size while traditionally MODSIM has been used for discrete event simulation model building. However, the language has continuous system capabilities in a true Object-Oriented Programming (OOP) capability.

To reflect realistic Blacksburg traffic conditions in the simulation, some parameters were tested and evaluated. To compare the speed profile and bus location model output every time interval, actual on-board observations on such variables were collected. Four data sets of arrival / departure times at each bus stop, intersection, and turns were selected. From those data, average delay time on each intersection / turn, bus position on each time interval, dwell time on bus stop, number of passengers at each bus stop were estimated. In the case of dwell time estimation, considering the results of other studies (See Table 4.2), the empirical regression model in Equation 5.11 is used.

$$\text{Dwell Time} = \underset{(.0376)^a}{4.89} + \underset{(.0291)^a}{3.48} \times \text{Max. No. of (boarding or alighting)} \qquad (5.11)$$

$R^2 = .81$

[a] (p - value <.05) : p - value for all parameters is less than .05, which is significant at the .05 level.

In Equation 5.11, the passenger count was used as input to estimate delays at bus stops, turns, and intersections. The dwell time at each stop is directly impacted by the number of boarding/alighting passenger at the stop. Speed profile and dwell time data collected in several in-vehicle trips were used to validate this model.

5.4 Model Validation

Before model application a simple model validation was conducted. To validate the reliability of bus operation model, the total travel time and fuel consumption parameters were compared using statistical goodness-of-fitness tests. Table 5.27 shows the model output comparison for travel time and fuel consumption. For travel time, the model output lies between 98.6% (section 1) and 107% (section 4) of the actual travel time, which means a reasonable representation of actual operation conditions. The model yields moderate but acceptable error terms in fuel consumption too. In section 2, the model estimated 86.4% of actual fuel consumption yielding a 14% error term in the worst case scenario. For average, the model shows only 1% and 7% errors in travel time and fuel consumption prediction, respectively.

Table 5.27 Simple Comparison between Model Output and Actual Data.

Section	Travel Time (Sec.)				Fuel Consumption			
	On-board Survey		BT Simulation Model Output		Data from BT authority (*Km*/*l*)	BT Simulation Model Output		
						Fuel Consumption (*ml*)	*Km*/*l*	
1	701	(1.000)	691	(0.986)	2.041 (1.000)	2490.157	1.892	(0.927)
2	612	(1.000)	606	(0.990)		2298.361	1.764	(0.864)
3	487	(1.000)	461	(0.990)		1597.417	1.807	(0.885)
4	539	(1.000)	579	(1.074)		2311.583	1.862	(0.912)
5	389	(1.000)	399	(1.026)		1690.792	2.105	(1.032)
6	369	(1.000)	370	(1.003)		1658.297	2.139	(1.047)
7	551	(1.000)	578	(1.049)		2289.733	1.879	(0.921)
Total	3648	(1.000)	3684	(1.010)		14336.700	1.909	(0.935)

To check the reliability of model for every time interval of bus operation, two statistical tests were conducted; correlation analysis and regression analysis. First, each of four on-board data sets along the entire study route is compared with the simulation output to test model reliability under different driver conditions such as hours of operation in a day, street traffic conditions along the route, etc. (Comparison 1). Next, the average value of four on-board travel time data sets is compared for each section (Comparison 2). This comparison tries to check model reliability for various parameters like passenger demand, section / stop distance, intersection type, grade schedule, etc..

Tables 5.28 and 5.29 show the values of the statistical analysis comparisons 1 and 2, respectively. Figure 5.6 illustrates the graphical representation of the correlation analysis with data set 1 using a time-space diagram. Figures E.2 through E.13 in Appendix E illustrate results for all remaining data sets.

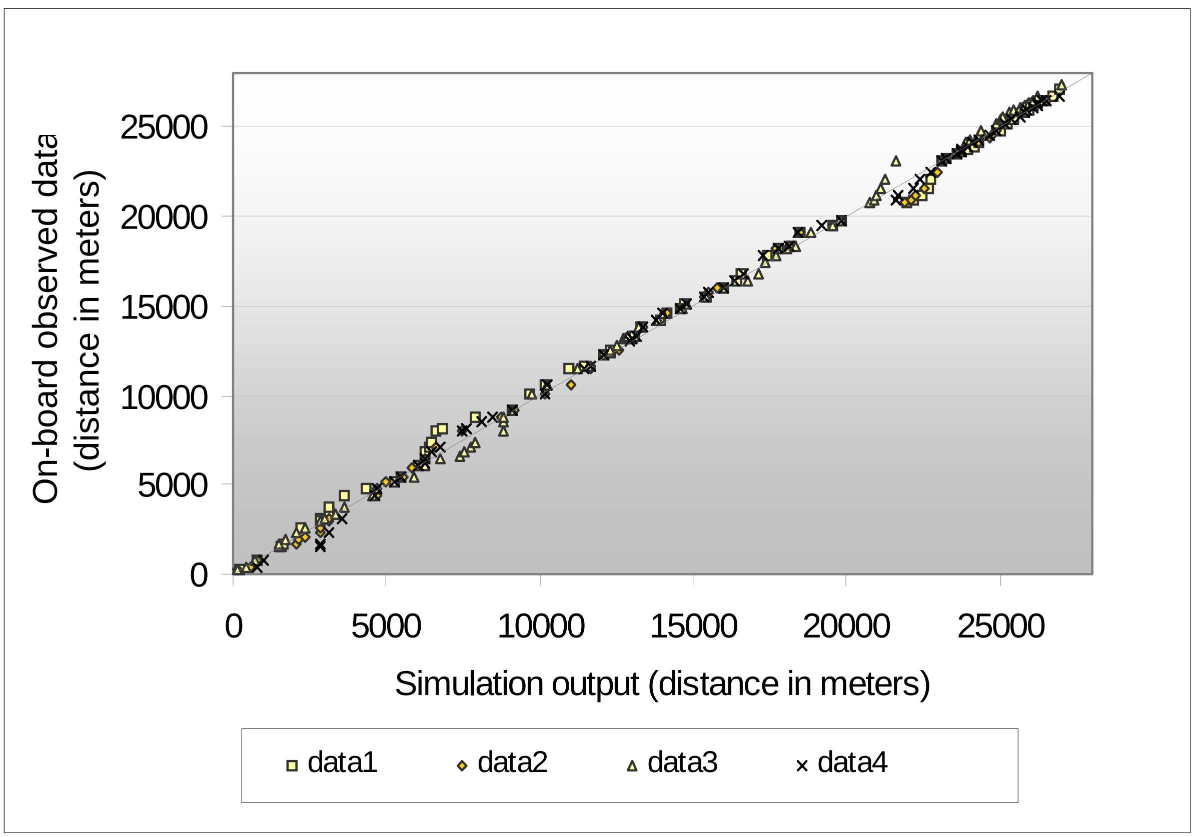


Figure 5.6 Correlation of Four Data Sets and the Simulation Output.

Table 5.28 Statistical Test Output of Simulation Model (Comparison 1).

Data #	Correlations with the simulation output (Pearson method)	Regression Analysis
Data # 1	0.9986	Simulation output = 109 + 0.989 × Observation data # 1 (0.000) (0.000) R^2 = 99.7%
Data # 2	0.9989	Simulation output = - 482 + 1.02 × Observation data # 2 (0.323) (0.000) R^2 = 99.8%
Data # 3	0.9991	Simulation output = 205 + 0.973 × Observation data # 3 (0.010) (0.000) R^2 = 99.8%
Data # 4	0.9990	Simulation output = 109 + 0.989 × Observation data # 4 (0.237) (0.000) R^2 = 99.8%

Table 5.29 Statistical Test Output of Simulation Model (Comparison 2).

Data	Correlations with the simulation output (Pearson method)	Regression Analysis
Section 1	0.966928572	Simulation output = 202 + 0.940 × Averaged Observation data* (0.096) (0.000) R^2 = 93.5%
Section 2	0.894525362	Simulation output = 914 + 0.849 × Averaged Observation data* (0.070) (0.000) R^2 = 80.0%
Section 3	0.967609711	Simulation output = 263 + 0.965× Averaged Observation data* (0.681) (0.000) R^2 = 93.6%
Section 4	0.990211245	Simulation output = - 480 + 1.02× Averaged Observation data* (0.134) (0.000) R^2 = 98.1%
Section 5	0.969061951	Simulation output = 1631 + 0.899× Averaged Observation data* (0.066) (0.000) R^2 = 93.9%
Section 6	0.771911277	Simulation output = 4198 + 0.820× Averaged Observation data* (0.159) (0.000) R^2 = 59.6%
Section 7	0.983046039	Simulation output = 2321 + 0.905 × Averaged Observation data* (0.000) (0.000) R^2 = 96.6%
All Sections	0.998820113	Simulation output = - 49.8 + 0.999 × Averaged Observation data* (0.328) (0.000) R^2 = 99.8%

* : Average value of four on-board travel timedata set

In Figure 5.6 as diagonal line implies perfect fitness between data set and model output, the less distance from the line, the better fit it shows. Both of the two results show high correlations between two data sets and model output. The net result is that the model represents well both traffic conditions and sectional route conditions. In most cases high values of R^2 were measured. For route section 6 in comparison 2, both correlation coefficient and R^2 value show lower statistics (0.772 of correlation coefficient and 59.6% of R^2, respectively). This reflects the nature of the section (from South Main street time check to the Hospital). The route shows the steepest grade (average 1.0%) and very few passengers.

5.5 Scenario Analysis

To find out how passenger demand patterns respond to various transit supply conditions, several scenarios are studied and their results compared. At present, BT uses fixed departure times at each time-check no matter when a bus arrives. Normally, drivers come earlier in order to have longer rest times. This causes irregular headways and reduces the reliability of bus schedules yielding lower LOS. Considering this, several types of operation (i.e., fixed or flexible) are considered to improve service. In this study, the time between arrival and scheduled departure times at each time-check point is named layover time, recovery time or rest time. As stated in Chapter 3, the market penetration of users is function of service infrastructure such as kiosks, internet, phone, etc. and is a major consideration in AVL implementation. Four scenarios were investigated according to the type of operation and market penetration conditions as shown in Table 5.30. Scenario 1 represents the present condition; fixed schedule without AVL implementation. Scenario 2 implies fixed schedule and 100% market penetration. In this case, everyone have actual bus location information at any time. The third scenario assumes a gradual market penetration as time passes with fixed operation schedule. Scenario 4 has flexible operation schedules with a gradual increase of market penetration. The flexible operation schedule means no rest time at the time-check. The pattern of operation at time-check is the same to that in ordinary bus stops.

In this stage, we can predict the sources of difference in values of output between scenarios. As seen in Figure 5.7 and Table 5.31, the differences between Scenarios 1 and 2 are market penetration. Zero percent for Scenario 1 and one hundred percent for Scenario 2 in market penetration (Shown as the value ‘a’). In the same context, the differences between Scenarios 1 and 3 are market penetration, too. In this case the difference is one hundred percent minus the present market penetration (As Scenario 3 indicates a gradual increase of market penetration is assumed). The differences between Scenarios 1 and 4 can be observed looking at vector value ‘c’ as having two factors at same time; the operational condition vector represented in horizontal axis and the AVL market penetration on vertical axis. With this idea, the simulation model evaluation is conducted.

Table 5.30 Conditions of Each Scenario.

Conditions	present	Scenario 1	Scenario 2	Scenario 3	Scenario 4
AVL Market Penetration	0 %		100 %	gradual increase	gradual increase
Operation schedule time	Fixed		Fixed	Fixed	Flexible

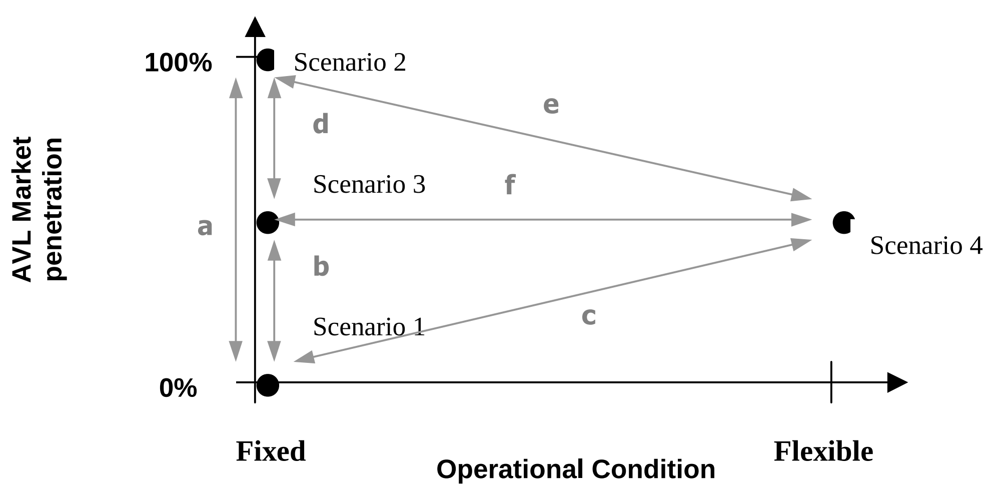


Figure 5.7 Relationships of Operational Condition and AVL Market Penetration for Each Scenario.

Table 5.31 Relationships of Operational Condition and AVL Market Penetration for Each Scenario.

Scenarios	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Scenario 1	·	Market Penetration (a)	Market Penetration (b)	Market Penetration & Operation Schedule (c)
Scenario 2	(a)	·	Market Penetration (d)	Market Penetration & Operation Schedule (e)
Scenario 3	(b)	(d)	·	Operation Schedule (f)
Scenario 4	(c)	(e)	(f)	·

5.6 Simulation Output Evaluation

According to the four scenarios tested, the ITPM model was ran under each condition. The output is evaluated and interpreted based on the MOEs; auto travel time, street LOS, probability of BT demand, number of passenger, in-vehicle travel time, and fuel consumption.

5.6.1 Auto Travel Time and Street LOS

Table 5.32 shows the predicted trend of street LOS along the BT route in question. The street LOS is the average volume-over-Capacity ratio (V/C) on the complete BT route. Auto travel time is the average time consumed when auto riders travel through the route in question. These two variables have positive and close relationships to each other as shown in Figures 5.8 and 5.9. Under current conditions (Scenario 1 or do-nothing alternative), LOS worsens and travel time increases with passage of time. A full AVL/ATPS market penetration (Scenario 2) shows a moderate improvement in the traffic conditions. This is the result of demand shifts from auto to bus mode. According to a calibrated logit model there could be a 3-5 % demand shift in Blacksburg. The rate of change in traffic conditions after the demand shift is almost same to that observed for Scenario 1. Scenarios 3 and 4 show gradual improvement as AVL market penetration is increased. In the horizon year (2020), Scenario 4 shows the best outcome in terms of street LOS.

Table 5.32 Comparison of Street LOS, Auto Travel Time for Each Scenarios.

Year	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Street LOS	AUTO Travel Time	Street LOS (V/C)	AUTO Travel Time	Street LOS	AUTO Travel Time	Street LOS	AUTO Travel Time
1998	0.5045	9.1100	0.5045	9.1100	0.5045	9.1100	0.5045	9.1100
1999	0.5091	9.1148	0.5091	9.1148	0.5091	9.1148	0.5091	9.1148
2000	0.5164	9.1228	0.4835	9.0892	0.5077	9.1133	0.5009	9.1062
2001	0.5200	9.1268	0.4850	9.0906	0.5079	9.1136	0.4989	9.1042
2002	0.5237	9.1310	0.4881	9.0936	0.5099	9.1157	0.5007	9.1061
2003	0.5274	9.1353	0.4915	9.0969	0.5103	9.1161	0.5025	9.1079
2004	0.5286	9.1367	0.4950	9.1003	0.5121	9.1180	0.5025	9.1079
2005	0.5323	9.1411	0.4986	9.1039	0.5143	9.1205	0.5048	9.1103
2006	0.5360	9.1454	0.5021	9.1075	0.5163	9.1226	0.5068	9.1123
2007	0.5399	9.1502	0.5056	9.1111	0.5183	9.1248	0.5086	9.1143
2008	0.5436	9.1549	0.5092	9.1149	0.5193	9.1259	0.5104	9.1162
2009	0.5476	9.1599	0.5127	9.1187	0.5211	9.1280	0.5112	9.1170
2010	0.5515	9.1649	0.5164	9.1228	0.5240	9.1313	0.5139	9.1199
2011	0.5544	9.1688	0.5192	9.1259	0.5258	9.1334	0.5155	9.1218
2012	0.5574	9.1727	0.5220	9.1291	0.5276	9.1354	0.5173	9.1237
2013	0.5604	9.1768	0.5248	9.1322	0.5290	9.1371	0.5190	9.1257
2014	0.5633	9.1808	0.5275	9.1353	0.5309	9.1393	0.5204	9.1272
2015	0.5664	9.1851	0.5303	9.1386	0.5334	9.1424	0.5229	9.1300
2016	0.5694	9.1893	0.5330	9.1418	0.5362	9.1457	0.5254	9.1329
2017	0.5725	9.1936	0.5359	9.1454	0.5389	9.1490	0.5278	9.1357
2018	0.5727	9.1939	0.5389	9.1490	0.5415	9.1523	0.5305	9.1389
2019	0.5758	9.1984	0.5418	9.1526	0.5439	9.1553	0.5332	9.1421
2020	0.5789	9.2030	0.5449	9.1564	0.5467	9.1588	0.5360	9.1454

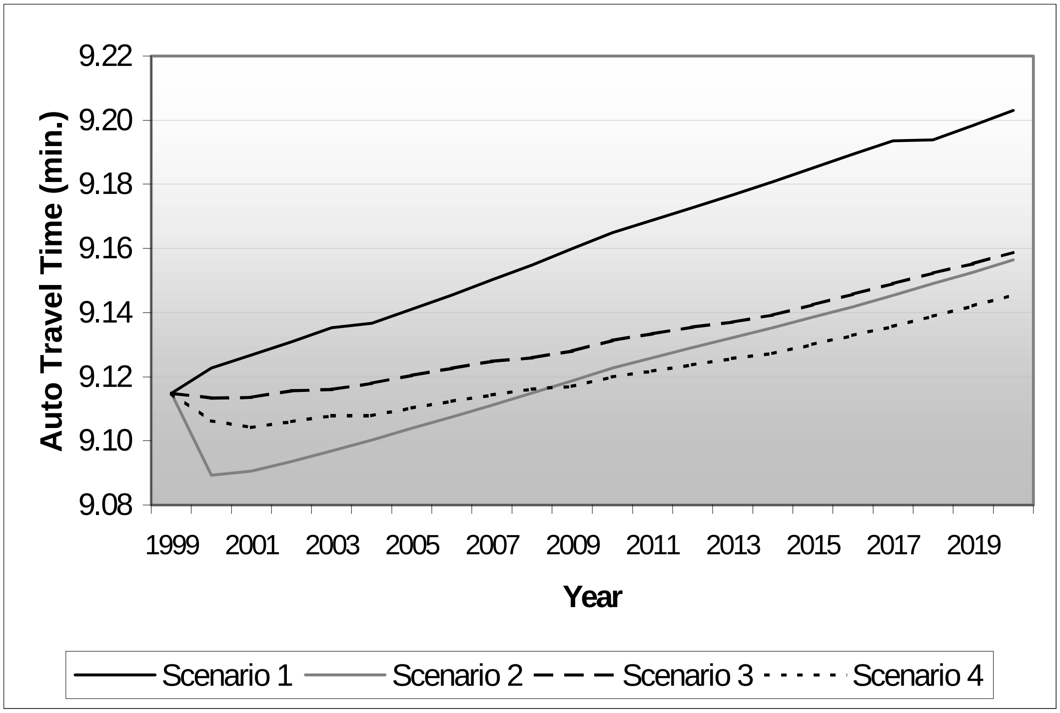


Figure 5.8 Trends of Auto Travel Time for Each Scenario.

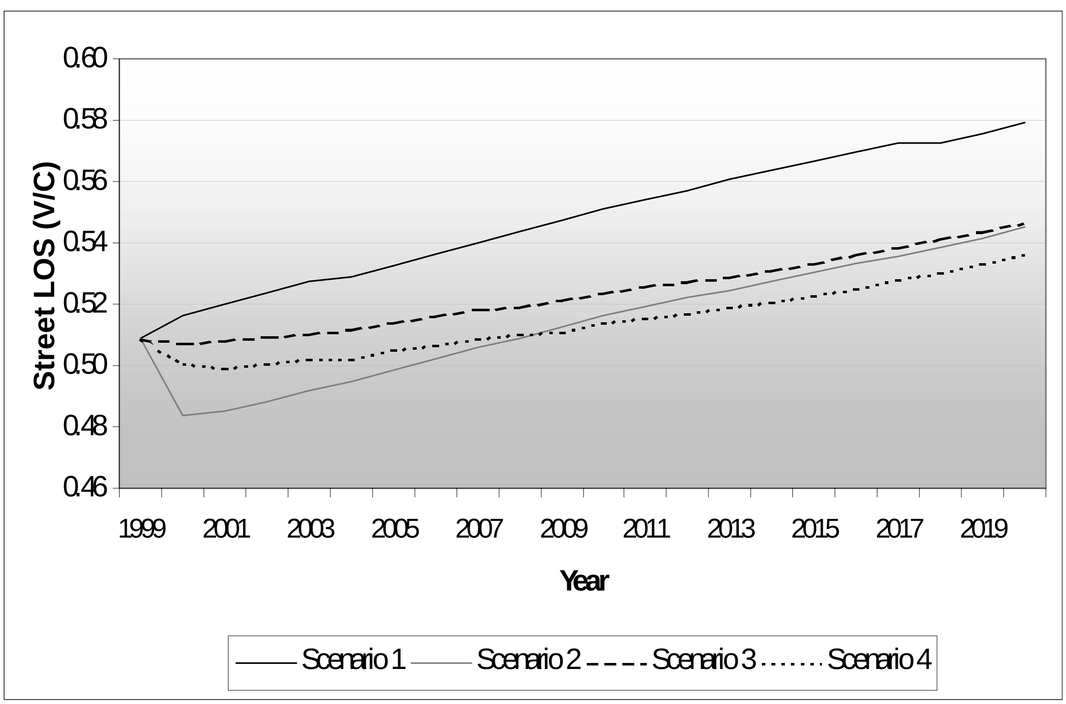


Figure 5.9 Trends of Street LOS for Each Scenario.

5.6.2 Probability of BT Demand and Number of Passenger

The evolution in the demand function over time for all scenarios is shown in Table 5.33, Figures 5.10 and 5.11. In Scenario 2 the increment of passengers in 1999 shows 205 persons, a 45% increase from the base year followed by minor increments thereon. This drastic change comes mainly from the saturation of market penetration from 0% to 100% instantaneously. However, this scenario is not meaningless as it represents a theoretical upper bound of traffic demand. In Scenarios 3 and 4, the preference for BT mode increases slightly over time as traffic conditions gradually deteriorate. With a small improvement in the BT system, passenger demand grows at an average 1.08 % during the study period. Scenario 2 shows moderate increments of BT demand attributed to mainly full service of AVL.

Table 5.33 Comparison of Probability of Selecting BT.

scenario	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
Year	Probability of BT Demand	Number of Passenger	Probability of BT Demand	Number of Passenger	Probability of BT Demand	Number of Passenger	Probability of BT Demand	Number of Passenger
1998	0.1154	141.00	0.1154	141.00	0.1154	141.00	0.1154	141.00
1999	0.1143	141.03	0.1660	204.77	0.1280	157.87	0.1386	149.62
2000	0.1145	142.60	0.1689	210.43	0.1331	165.85	0.1471	162.01
2001	0.1146	143.82	0.1693	212.55	0.1356	170.22	0.1498	167.57
2002	0.1146	144.98	0.1694	214.26	0.1406	177.87	0.1525	172.64
2003	0.1185	151.08	0.1694	215.92	0.1434	182.86	0.1579	180.69
2004	0.1187	152.45	0.1692	217.42	0.1455	186.94	0.1598	184.32
2005	0.1190	154.05	0.1693	219.15	0.1481	191.78	0.1623	190.00
2006	0.1190	155.20	0.1694	221.04	0.1506	196.53	0.1650	195.89
2007	0.1192	156.75	0.1695	222.78	0.1547	203.36	0.1677	201.36
2008	0.1193	158.09	0.1697	224.81	0.1575	208.58	0.1720	208.68
2009	0.1195	159.50	0.1697	226.49	0.1588	211.97	0.1734	212.80
2010	0.1196	160.93	0.1697	228.29	0.1603	215.62	0.1750	217.77
2011	0.1198	162.12	0.1697	229.64	0.1619	219.01	0.1765	221.46
2012	0.1200	163.27	0.1699	231.18	0.1639	223.10	0.1781	225.34
2013	0.1202	164.51	0.1702	232.96	0.1654	226.40	0.1801	229.58
2014	0.1203	165.62	0.1703	234.39	0.1659	228.36	0.1807	232.46
2015	0.1206	166.94	0.1706	236.20	0.1661	230.05	0.1812	235.61
2016	0.1208	168.21	0.1706	237.62	0.1665	231.91	0.1819	239.13
2017	0.1249	174.89	0.1706	239.04	0.1670	233.92	0.1822	241.01
2018	0.1250	176.09	0.1707	240.52	0.1678	236.48	0.1825	242.91
2019	0.1251	177.30	0.1707	241.84	0.1682	238.29	0.1827	244.44
2020	0.1253	178.65	0.1708	243.48	0.1686	240.34	0.1831	246.84

Scenarios 3 and 4 show continuous increases in passenger demand as AVL/ATIS technology is fielded. Scenario 4 shows the highest performance gain in BT demand due to the flexible operation schedule and shortened headways.

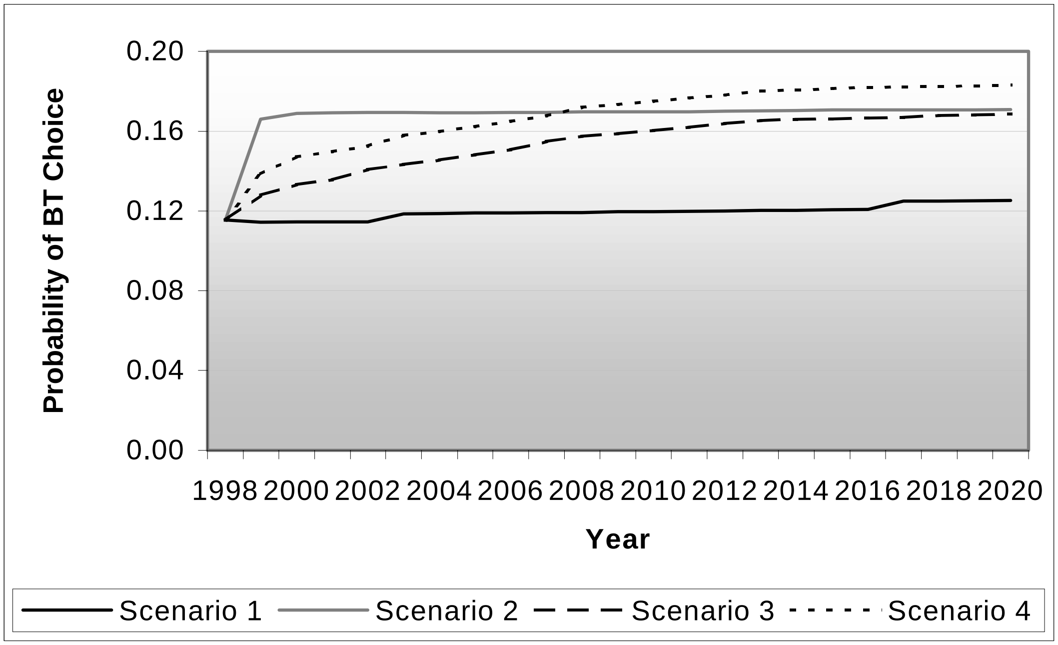


Figure 5.10 Trends of BT Demand Probability.

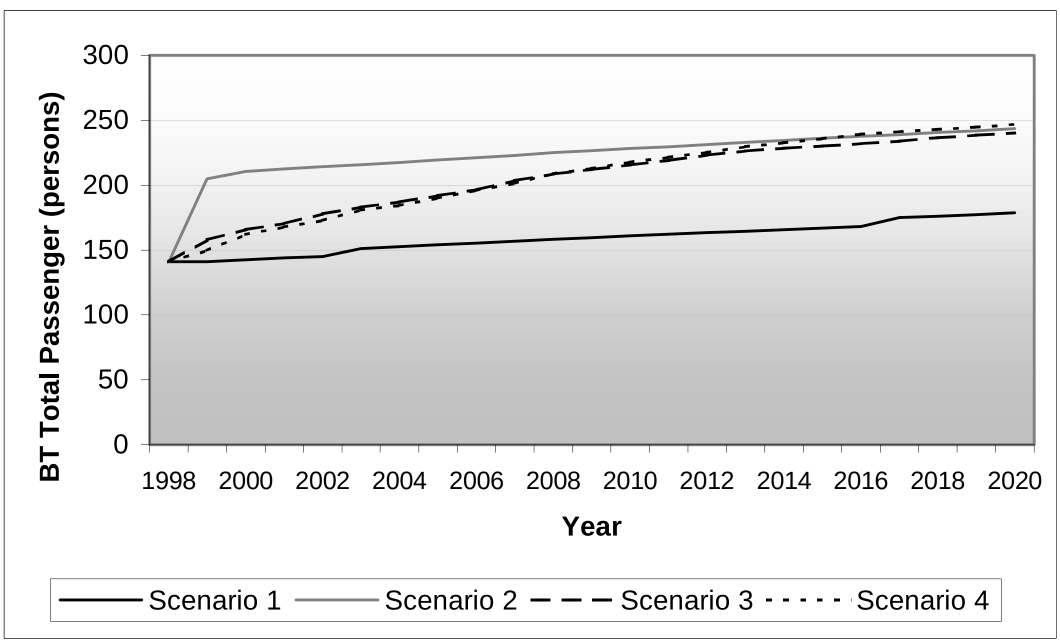


Figure 5.11 Trends of BT Total Passenger for Each Scenario.

5.6.3 BT In-vehicle Travel Time

In this study, in-vehicle travel time includes total on-board round-trip travel time except waiting time at time check. In other words, a round trip (1.5 hr. for BT case) minus rest times on all time-checks. There are very few people who continue their inter-time-check trip (most people conduct intra-time-check trips and finish their trip before or at each time-check), this indicator shows relative travel time when compared with other scenarios. Table 5.34 and Figure 5.12 show the trends of in-vehicle travel time when using BT. As expected, travel time increases for all the scenarios as the traffic network and passenger demands of BT increase. As time advances, passengers suffer deteriorating travel conditions from more dwell time on bus stops and street congestion resulting from growing traffic demand. Scenario 1 is typical of the situation experienced. Scenario 2, with 100 % AVL/ATIS benefit, shows an increase in travel time; mainly due to increased dwell times at each bus stop as more passengers board buses. After a sharp increment due to the AVL/ATIS market penetration, a stable increment in travel time continues. Scenarios 3 and 4 also show higher increments in travel time.

Table 5.34 Comparison of In-Vehicle Travel Time for Each Scenario (in Seconds).

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4
1998	4165				2010	4356	4436	4412	5007
1999	4182	4368	4206	4772	2011	4372	4448	4414	5021
2000	4193	4397	4235	4812	2012	4394	4472	4426	5028
2001	4198	4402	4246	4832	2013	4406	4477	4440	5047
2002	4219	4403	4263	4846	2014	4433	4502	4439	5070
2003	4235	4395	4279	4847	2015	4456	4505	4446	5098
2004	4268	4399	4324	4882	2016	4476	4508	4460	5100
2005	4266	4411	4342	4914	2017	4489	4514	4502	5102
2006	4294	4414	4348	4931	2018	4503	4511	4503	5098
2007	4305	4432	4366	4946	2019	4526	4524	4516	5107
2008	4320	4430	4375	4964	2020	4516	4529	4521	5120
2009	4336	4434	4393	4994					

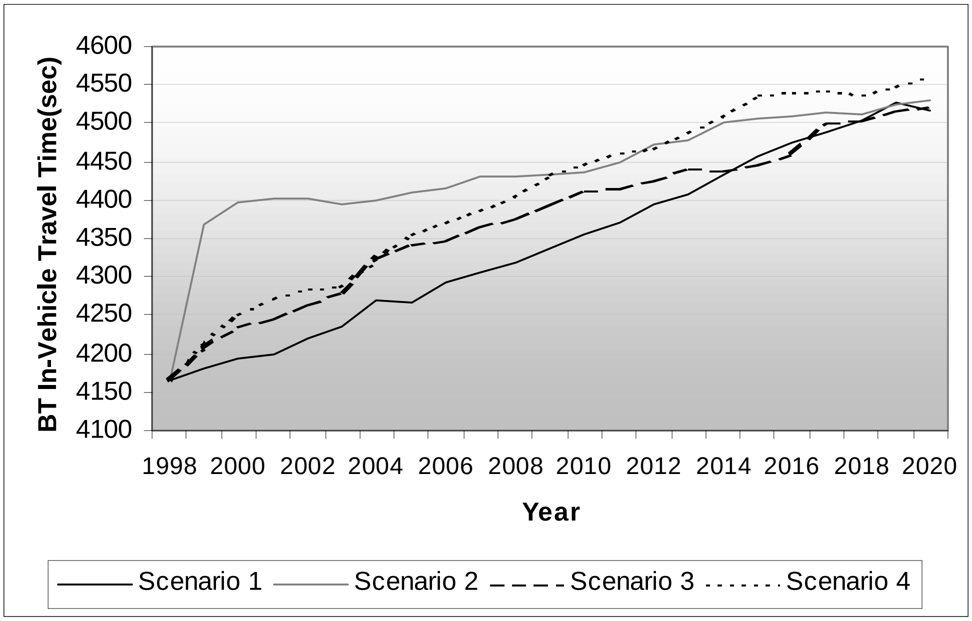


Figure 5.12 Trends of In-Vehicle Travel Time for Each Scenario.

5.6.4 BT Fuel Consumption

In the microscopic simulation mode fuel consumption is computed for all round-trips except dead-head trip between BT shop and starting/ending point of operation. Results for fuel consumption are shown in Table 5.35 and Figure 5.13. Examination of the figure indicates little difference in fuel consumption among all scenarios except for Scenario 4. Scenario 4 shows an 8 % incremental fuel consumption in 1999, just after the AVL implementation. This increase of fuel consumption can be explained considering no rest times at time-check. The bus runs continuously without engine idle cycles at each time-check point. For other scenarios, it can be seen that the change of passenger demand is not critical in fuel consumption. For example, Scenario 2 shows 45.2 % increase of passenger demand in 1999 (See Table 5.33; from 141 persons to 204.8 persons). But fuel consumption during same period shows a 1.0 % increment (from 14.695 *l* to 14.831 *l*). This shows that bus operation patterns (e.g. fixed or unscheduled operation) are more critical than the number of passengers from the fuel consumption view point.

Table 5.35 Comparison of Fuel Consumption for each Scenario.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4
1998	14695				2010	14838	14893	14870	15548
1999	14695	14831	14725	15870	2011	14849	14900	14862	15523
2000	14717	14844	14742	15808	2012	14857	14898	14888	15531
2001	14718	14862	14743	15779	2013	14866	14910	14888	15502
2002	14730	14853	14769	15763	2014	14880	14922	14895	15473
2003	14750	14860	14774	15776	2015	14885	14925	14890	15454
2004	14767	14866	14806	15713	2016	14908	14921	14904	15445
2005	14769	14864	14823	15671	2017	14928	14922	14922	15438
2006	14791	14875	14830	15665	2018	14926	14923	14925	15458
2007	14795	14878	14830	15634	2019	14934	14933	14924	15445
2008	14806	14878	14842	15607	2020	14945	14928	14924	15424
2009	14814	14880	14856	15564					

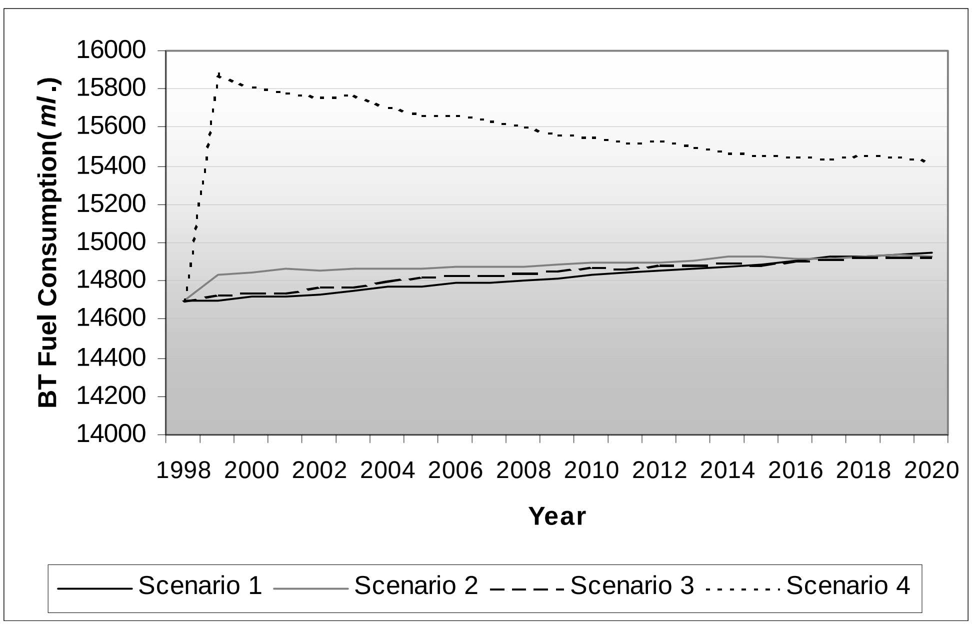


Figure 5.13 Fuel Consumption for Each Scenario.

5.7 Cost-Benefit Analysis

An example Cost-Benefit analysis was conducted for each alternative condition. With data from BT authority the average fare per person and general cost per gallon assumed to be $0.50 and $10.0, respectively. B/C ratio results are shown in Table 5.36.

Applying an annual interest rate of 5 %, the total fare-box revenue for Scenario 1 is $3321.9 while the fuel cost shows $1619.5. Those figures yield 1.989 of B/C ratio. Other scenarios show little improvement over Scenario 1. Which says more efficient when considering only fare box income and fuel cost comparison. Scenario 2 shows 39% better efficiency than Scenario 1 showing the highest value among the four alternatives. Scenario 4, though it shows one of the best fare-box incomes (the highest demand), the fuel consumption is also higher resulting in moderate benefit/cost ratio.

Table 5.36 Operation Times and Fuel Consumptions of All Scenarios.

Scenario	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
year	Passenger (Person)	Fuel Consumption (*l*)	Passenger (Person)	Fuel Consumption (*l*)	Passenger (Person)	Fuel Consumption (*l*)	Passenger (Person)	Fuel Consumption (*l*)
1998	141.00	146.95	141.00	146.95	141.00	146.95	141.00	146.95
1999	141.03	146.95	204.77	148.31	157.87	147.25	149.62	158.70
2000	142.60	147.17	210.43	148.44	165.85	147.42	162.01	158.08
2001	143.82	147.18	212.55	148.62	170.22	147.43	167.57	157.79
2002	144.98	147.30	214.26	148.53	177.87	147.69	172.64	157.63
2003	151.08	147.50	215.92	148.60	182.86	147.74	180.69	157.76
2004	152.45	147.67	217.42	148.66	186.94	148.06	184.32	157.13
2005	154.05	147.69	219.15	148.64	191.78	148.23	190.00	156.71
2006	155.20	147.91	221.04	148.75	196.53	148.30	195.89	156.65
2007	156.75	147.95	222.78	148.78	203.36	148.30	201.36	156.34
2008	158.09	148.06	224.81	148.78	208.58	148.42	208.68	156.07
2009	159.50	148.14	226.49	148.80	211.97	148.56	212.80	155.64
2010	160.93	148.38	228.29	148.93	215.62	148.70	217.77	155.48
2011	162.12	148.49	229.64	149.00	219.01	148.62	221.46	155.23
2012	163.27	148.57	231.18	148.98	223.10	148.88	225.34	155.31
2013	164.51	148.66	232.96	149.10	226.40	148.88	229.58	155.02
2014	165.62	148.80	234.39	149.22	228.36	148.95	232.46	154.73
2015	166.94	148.85	236.20	149.25	230.05	148.90	235.61	154.54
2016	168.21	149.08	237.62	149.21	231.91	149.04	239.13	154.45
2017	174.89	149.28	239.04	149.22	233.92	149.22	241.01	154.38
2018	176.09	149.26	240.52	149.23	236.48	149.25	242.91	154.58
2019	177.30	149.34	241.84	149.33	238.29	149.24	244.44	154.45
2020	178.65	149.45	243.48	149.28	240.34	149.24	246.84	154.24
NPV (5% annual intrest rate;) ($)	3221.09$^{(A)}$	1619.5$^{(B)}$	4504.55$^{(A)}$	1627.4$^{(B)}$	4064.43$^{(A)}$	1622.0$^{(B)}$	4061.64$^{(A)}$	1704.3$^{(B)}$
B/C $^{(A/B)}$	1.989		2.768		2.506		2.383	
Comparison with Scenario 1	1.00		1.39		1.26		1.20	