FINAL

REPORT

EVALUATION OF ALTERNATE BUS ROUTING PROJECT – PHASE I

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Executive Summary

The official testing of the Alternate Bus Routing (ABR) Project on Garden State Parkway (GSP) commenced on November 17, 1997, by an evaluation team from Rutgers University. Testing lasted for a period of four weeks up to December 12, 1997. This report is a description of the testing and evaluation process, data collection and analysis, and conclusions and recommendations by the evaluation team.

The primary purpose of the evaluation is to determine the feasibility of the route guidance technology implemented by project. The map shown in Figure 1 represents the layout of the ABR system. The official evaluation test was a collaborative effort among many of the agencies involved with the ABR project and the Rutgers University evaluation team . Among the list of active participants during official testing are:

- Hughes Transportation Management Systems
- New Jersey Highway Authority
- New Jersey Transit
- TRANSCOM
- Booz-Allen & Hamilton Inc.

The main goal of the ABR project is to reduce travel time during congestion for New Jersey Transit (NJT) buses heading north towards New York City. The system accomplishes the goal by transmitting real-time routing diversion messages directly to the buses at the entrance of the project location at Raritan Toll Plaza (Figure 1). The route guidance system obtains real-time traffic information from road sensors and probe buses and makes a decision based whether or not diversion from the GSP to Route 9 is warranted. If the answer is positive, the diversion message is broadcast to the incoming NJ Transit buses through annunciators installed in the buses. The independent evaluation process consists of the following four tasks:

1. Evaluation of Operation of Sensors and Spread Spectrum Radio Communications
2. Evaluation of the Central Computer System
3. Evaluation of In-Vehicle Operations
4. Evaluation of the Performance of the Integrated System

Each of these evaluation tasks, testing approaches, and findings are discussed in detail discussed in the report. The main evaluation tests are the following: (1) Sensor Volume Data Accuracy Test, (2) Travel Time Estimation Accuracy for GSP and Route 9, (3) Bus Travel Time Reduction, (4) Customer Surveys, and (5) Equipment problems. The findings of each of these tests are summarized below.

1. **Sensor Volume Data Accuracy Test:** This test reached the conclusion that both the system and the evaluation team's volume counts do not have a statistically significant difference of means. The average volume value given by Rutgers counts was 3 1.93 vehicles per 30 seconds, while the ABR system value was 28.38 vehicles per 30 seconds. The ratio of volume count differences is thus 11.12% and slightly higher

than the ± 5% errors that are acceptable for the radar counts as stated on the radar manual.

2. **Comparison of Estimated and Measured Travel Times Estimation for GSP and Route 9:** This test illustrated that the differences in estimated and measured travel times on both routes are not statistically significant. However, ABR system is found to have a general trend to underestimate the travel times at GSP and Route 9. During the testing period the ABR system trip times were consistently lower that the travel times measured by the Rutgers instrumented vehicles.

3. **Reduction in Bus Travel Times due to the ABR System:** This was mainly evaluated by observing the system's output of diversion messages. Since only nine diversion messages were delivered during the testing period of 1 month, the infrequent occurrences of diversion messages make it difficult to draw conclusions regarding this issue. Therefore, a final conclusion could not be reached as result of this test.

4. **Customer Surveys of the New Jersey Bus Operators and System Operators:** The results of this test conveyed the fact that both bus operators and system operators have faith in the route guidance technology. However, they did not believe the system was very useful for this specific ABR network topology and conditions.

5. **Test of Various Equipment problems:** Among the major problems that were discovered during the one month testing period were the malfunctioning of the sensors. These problems included: (1) inability to assign the correct zone to a tagged vehicle, (2) sensor inability to detect a tagged vehicle, (3) multiple readings at a radar location, (4) Incorrect route assignment by the sensors, and (5) inability to compute travel time for a tagged vehicle that is traveling on the network. In addition, the customer survey for Bus Operators revealed that the annunciators did not always transmit the messages adequately.

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ABR System Overview and Evaluation Methodology

1.1 Alternate Bus Routing System Overview

Alternate Bus Routing (ABR) project is concerned with the development of a bus routing system which will provide real-time alternate routing information to the New Jersey Transit (NJT) buses traveling north bound on the Garden State Parkway (GSP). The location of the project is between GSP milepost 125.4 and New Jersey Turnpike interchange 11 (NJT-11).

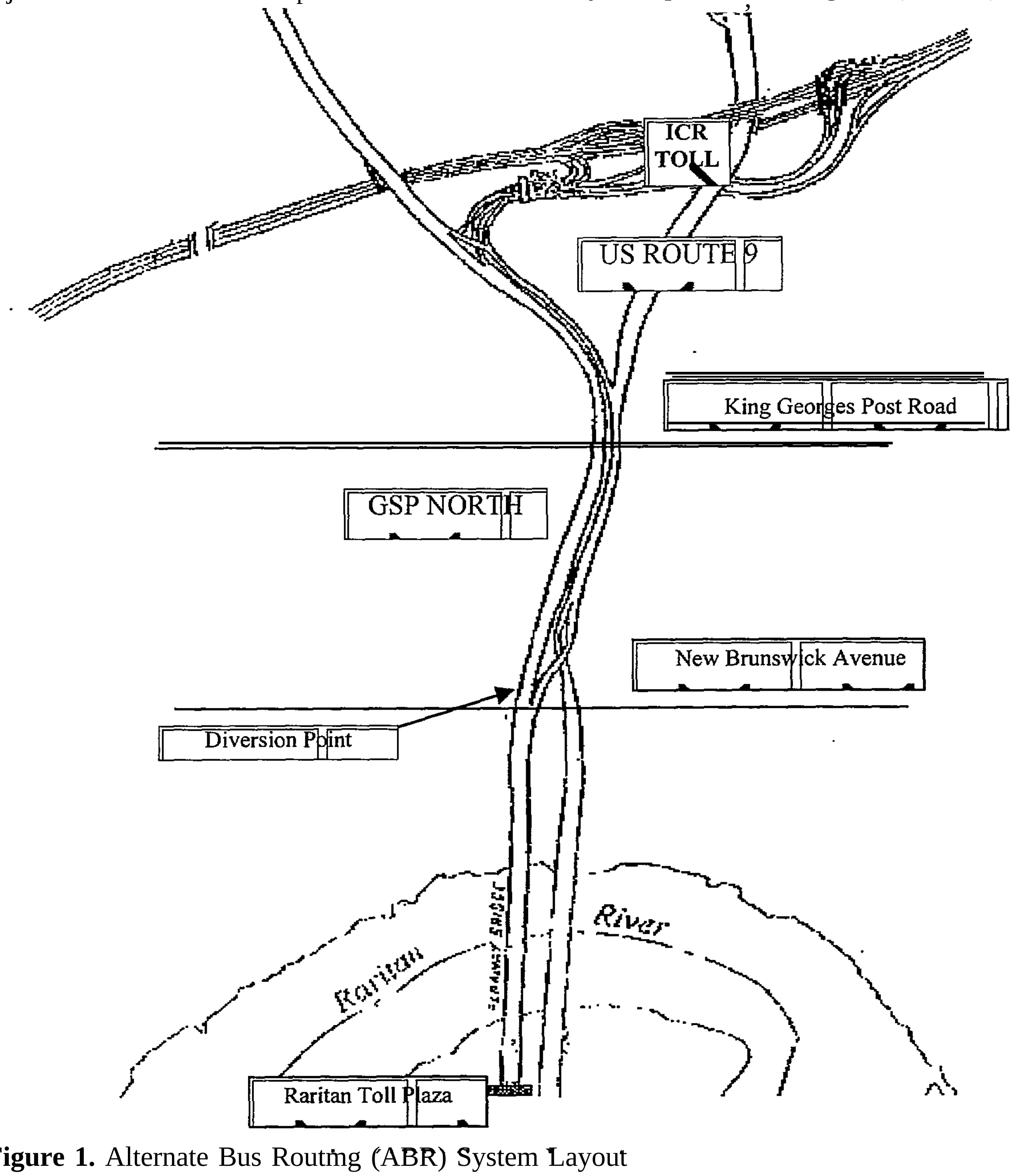

Figure 1. Alternate Bus Routing (ABR) System Layout

Figure 1 shows the map of the road network. The main objective of the ABR system is to divert NJ Transit buses from GSP to a parallel alternate US Route 9 in the event of excessive traffic congestion, which is prominent during a.m. rush hours. In the absence of diversion messages, all the NJ Transit buses will use GSP, which is the primary route according to the ABR system.

1.1.1 ABR System Description

The ABR system physical architecture is comprised of the following components:

1) Remote Traffic Microwave Sensors (RTMS)
2) VRC Transponder/Reader
3) Audio Annunciators
4) Surveillance Camera

A diagram and associated functional details of the system are shown in Figure 2. RTMS sensors detect traffic flow parameters. As a secondary source of information, VRC transponders attached to buses will provide additional travel time information, namely, bus travel times. These two sources of real-time traffic flow data are directly linked to the communication hub and system controller at New Jersey Highway Authority's (NJHA) Executive Office in Woodbridge, where the decision making software will estimate the traffic flow features and generate bus routing advisory messages. Functional capabilities of ABR system are summarized on Table 1.

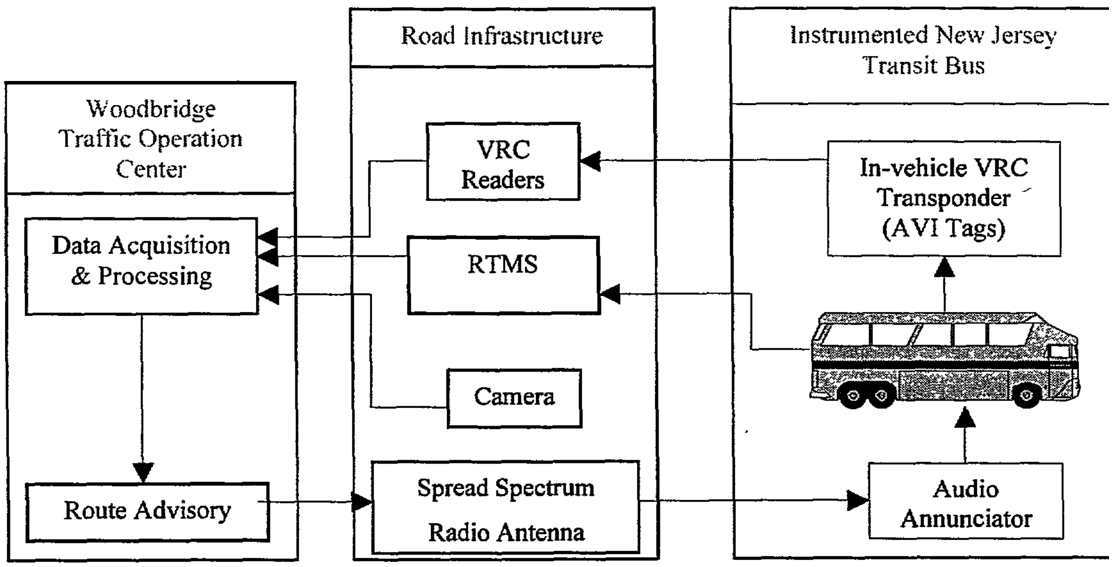

Figure 2. System Architecture of ABR Project

1.1.2 ABR System Bus Routing Algorithm (Gardener Rowe Systems, 1995)

The following 30-second traffic flow data are generated for each RTMS sensor and location as Detector Number, Lane Zone:

- Flow (vehicles/30 second)
- occupancy (%)
- Average Speed (miles/hour)

Table 1. Functional Capabilities of Data Processing Centers

Raritan Toll Plaza - Mile Post 125.4
· RTMS sensor – GSP data monitored · VRC Reader - Bus message transmission antenna · Radio communications between TOC and equipment at Raritan Toll Plaza - Inner roadway has 3 lanes, and the outer roadway has 4 lanes · Equipment is placed and installed on the variable message sign
New Brunswick Avenue - Mile Post 128.4
, Surveillance Camera - RTMS sensor - US Route 9 and GSP data monitored - VRC Transponder · Equipment **is** mounted on southern face of the New Brunswic k Avenue overpass , Radar and VCR Transponder cover all 5 inner lanes of GSP and all 4 outer lanes of US Route 9 - Radio communications with TOC and New Brunswick Avenue overpass
King George's Post Road – Mile Post 129.1
, RTMS radar traffic data – GSP and US Route 9 data monitored - Radar is mounted at the overpass abutment to give complementary traffic information - Detector covers both ramps from US Route 9 to New Jersey Turnpike and the outer lanes of GSP that feed the ramp to the Turnpike. · Ramps from US Route 9 - 3 lanes · GSP-North lanes - 5 lanes
New Jersey Turnpike Tower # 2 – 100 ft. West of the Toll Plaza
, RTMS radar traffic detector is mounted at the tower – monitors GSP and US Route 9 · Garden State Parkway and US Route 9 merges at this **point**
New Jersey Turnpike Sign Structure - 2500 ft. East of the Toll Plaza)
· VRC Reader · Bus message transmission antenna - Sign structure at the northbound New Jersey Turnpike entrance ramp - VCR beacon mounted over the sign - All three lanes of the ramp are covered by the VCR Transponder
New Jersey Turnpike Headquarters - New Brunswick
· Send bus messages - at exit 11 only · Summary of traffic data and reports • Ability to view surveillance video form the camera placed at New Brunswick Avenue
New Jersey Transit Operations - Maplewood
· Bus message override - Summary of traffic data and reports - Ability to view surveillance video from the camera placed at New Brunswick Avenue
TRASNCOM Jersey City
· Ability to view surveillance video from the camera placed at New Brunswick Avenue
New Jersey Highway Authority TOC – Woodbridge
· Connects all above cited sites. - Recording of voice messages - Display traffic data - Generate statistical reports - Analyze real-time traffic data - Determine optimum advisory message - Ability to override messages - Ability to control camera at **New Brunswick Avenue**

The information is then stored on the basis of route number, station, and lane. Thereafter, the average flow, occupancy, and speed for each active lane is calculated. At five-minute intervals, traffic features are calculated for flow, occupancy, and speed. After estimating travel time and delays for each route, recommendation is given for diversion. GSP is invariably the primary route. However, if the following two conditions are met, the central computer system will recommend diversion to the alternate route, US Route 9:

1. Delay on the GSP must be more than a pre-set threshold value
2. Estimated travel time savings by using US Route 9 must also be more than a pre-set threshold value

The flowchart in Figure 3 shows the logic of route diversion recommendation algorithm developed by Gardener Rowe Systems (1995). Only substantial savings in time due to traffic conditions analysis in both GSP and US Route 9 will produce a diversion decision. TOC has the capability of overriding messages when necessary.

The travel times of each route are calculated by using the input from two distinct data sources: RTMS sensors and Automatic Vehicle Identification (AVI) readers installed in participating 50 NJT buses. However, in order to increase the accuracy of the travel time estimations, the "system algorithm" proposes the use of delay instead of travel time. The delay at each measurement station $"r"$ for corresponding section, $"s"$, at time $"t"$ is determined as follows:

$$StaDly[r, s] = \left[\frac{SectDist[r, s] * 60}{SmSpd[r,s,t]}\right] - \left[\frac{SectDist[r, s] * 60}{FreSpd[r, s, t]}\right] \quad (1)$$

where,

$StaDly[r,s]$ = Delay estimate for Station "r" and section "s"

$SectDist[r,s]$ = Section Length (Distance between two adjacent stations)

$SmSpd[r,s,t] = (SmSpd[r,s]*(1.0-k) + (k*StaSpd30s[r,s,t])$

$StaSpd30s[r,s,t]$ = Speed Measured by RTMS at Station "r" for section "s" for current period "t"

$FreSpd[r,s,t]$ = Normal Average Free Flow Speed for Section "s" (6.5 mph)

The overall estimated route travel time (delay) for each route $"r"$ is determined by adding the estimated section travel times (delays). However, the final travel time (delay) estimation for each route "r" is done by combining two travel time (delay) estimations obtained using RTMS and AVI data. The estimation of route travel times using a linear combination of the two travel times (delays) obtained from two different sensors is done as follows:

ALGORITHM FOR ROUTE DIVERSION RECOMMENDATION

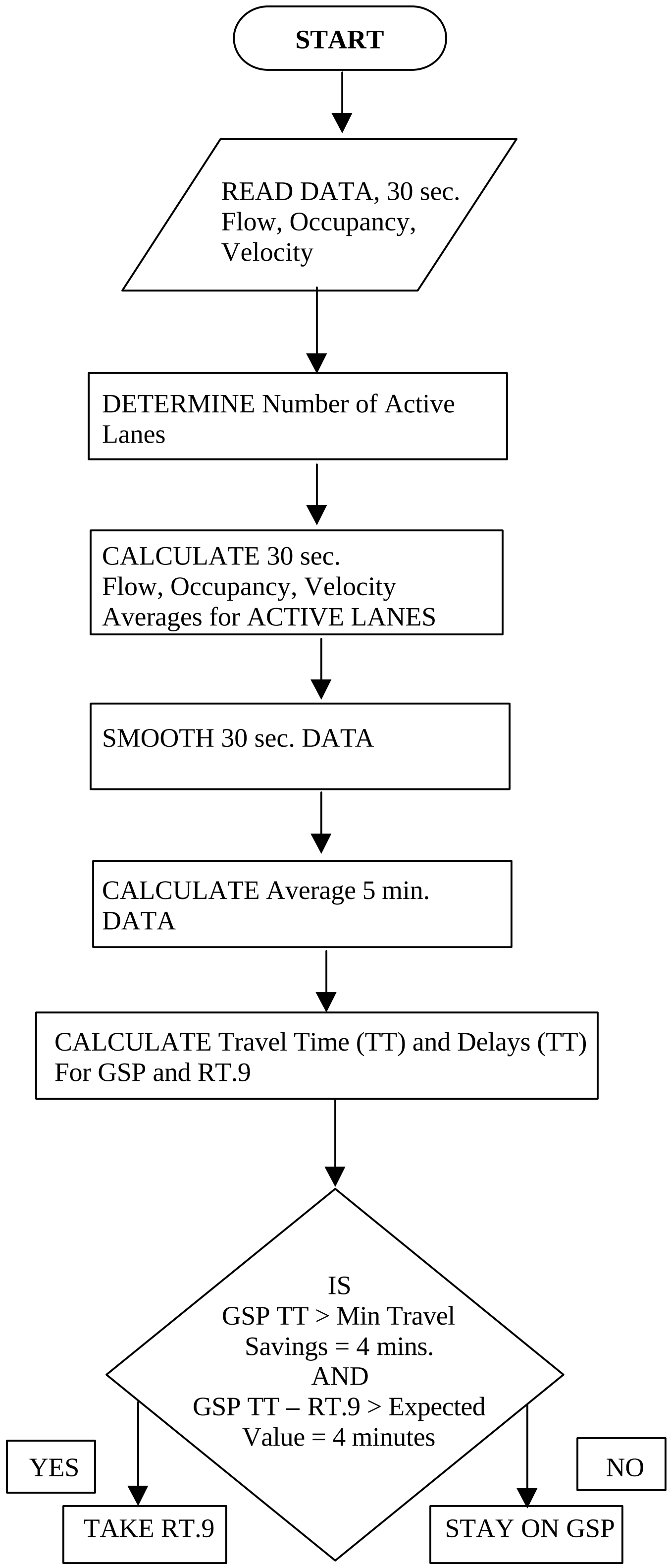

Figure 3. Flow Chart of Diversion Logic

$$\begin{aligned}&\textit{IF the last } AviTT[r] \le Xage\_old \textit{ Then} \\ &TT[r] = j * RtmsTT[r] + (1.0 - j) * AviTT[r] \\ &ELSE \\ &TT[r] = RtmsTT[r]\end{aligned} \tag{2}$$

where

$TT[r]$ = Final Estimated Travel Time for route " r"

$AviTT[r]$ = Most Recent Reader Based Travel Time for Route "r"

$Xage\_old$ = Pre - Determined Aging Time for AVI Data (15 mins)

j = Weighing Constant ($0.0 \le j \le 1.0$ andj = 0.33)

Once the travel times on both routes are calculated the diversion decision have to be made. Buses are diverted to Route 9 if and only if the following two conditions of the ABR system diversion algorithm are satisfied:

$$\begin{aligned}&\text{IF } (TT[r = 1] - Norm[r = 1]) > McPDly \text{ THEN} \\ &\text{IF } (TT[r = 1] - TT[r = 2]) > MnDelta \text{ THEN} \\ &\text{Divert To } r = 2\end{aligned} \tag{3}$$

where

$r = 1$ is the Primary Route (GSP)

$r = 2$ is the alternate route (Rte 9)

$McPDly$ = Maximum Delay Allowed on the Primary Route (GSP)

$MnPDly$ = Minimum Travel Time Savings

In the decision rule shown in (3), the numeric values of the two pre-determined parameters namely, MCPDly and MnDelta are extremely important since the diversion recommendation is solely based on the values of those two parameters.

1.2 Alternate Bus Routing (ABR) System Evaluation Methodology

The primary objective of the ABR system is to reduce NJ Transit bus travel time during the morning rush hour by transmitting real-time diversion information directly to the participating NJ Transit buses. The ABR system was expected to meet the following three goals to obtain positive evaluation results:

1. System Performance
2. System Reliability
3. User Acceptance

The ABR Project is identified as an Intelligent Transportation System (ITS) deployment initiative. The Federal Highway Administration identifies six national goals for ITS projects'[1]:

1. Improve safety of the nation's surface transportation system.
2. Increase the operational efficiency and capacity of the surface transportation

1Williams, T. Evaluation Plan - Alternate Bus Routing System (Draft), Rutgers University, October 1995

system.
3. Reduce environmental costs associated with traffic congestion.
4. Enhance present and future productivity.
5. Enhance the personal mobility and convenience and comfort of the surface transportation system.
6. Create an environment in which the development and deployment of ITS can flourish.

Table 2 shows the relationship of the goals of the ABR Project to the national ITS goals.

Table 2. Relationship between ITS Goals and ABR Goals

ITS Goals / ABR Goals	Improve Safety	Increase Efficiency	Reduce Environmental Costs	Enhance Productivity	Enhance Personal Mobility	Promote ITS
System Performance	✓	✓	✓	✓	✓	✓
System Reliability	✓					✓
User Acceptance		✓		✓	✓	✓

1.2.1 Evaluation Tasks and Data Collection

Four tasks were identified for the successful completion of the evaluation of the Phase I of ABR Project:

1. Evaluation of Operation of Sensors and Spread Spectrum Radio Communications
2. Evaluation of the Central Computer System
3. Evaluation of In-Vehicle Operations
4. Evaluation of the Performance of the Integrated System

Tasks 1 through 4 were designed to evaluate the three goals of the ABR project during official testing period. This report provides extensive descriptions of each of the evaluation tests starting on Chapter 3. Table 3 shows the relationship between the evaluation tasks and project goals.

Table 3. Relationship between Evaluation Tests and ABR Goals

TASKS / ABR Goals	TASK I	TASK II	TASK III	TASK IV
System Performance	✓		✓	
System Reliability	✓	✓	✓	
User Acceptance				✓

Data collection is an integral aspect of the overall evaluation process. Data for the ABR project was obtained from two main sources listed below:

Rutgers University Instrumented Vehicle Data
ABR System Data

These two types of data are discussed in detail in the next two sections.

1.2.2 Rutgers University Instrumented Vehicle Data

Two vehicles instrumented with AVI tags were used by Rutgers University to collect independent travel time data along the study site on GSP and US Route 9. Experimental configuration of an instrumented vehicle is shown in Figure 4. Data was obtained during the peak rush hour periods of 6:30-9:00 a.m. when a diversion condition was most likely to occur.

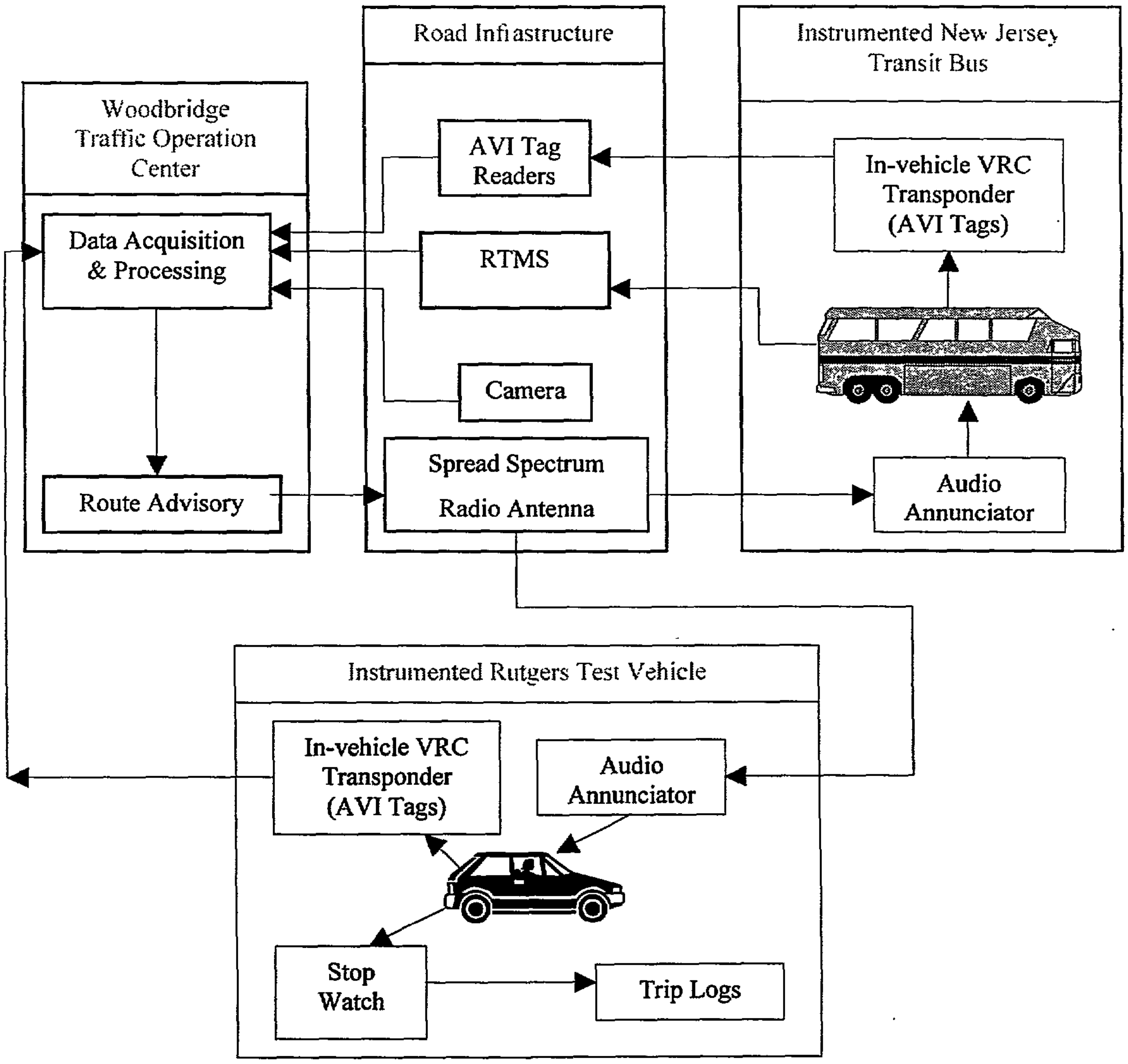

Figure 4. Experimental Configuration of Instrumented Rutgers Test Vehicle

The instrumented vehicles were used to perform synchronized, parallel runs to determine travel time differences between the primary (GSP) and alternate route (US Route 9). The two test vehicles entered Raritan Toll Plaza on GSP simultaneously, then separated at the diversion point, and met at the end of each run after the Interchange-l 1 at New Jersey Turnpike. Both drivers completed travel logs with each run, and included the test time (synchronized with the ABR system) and the length of travel times for each pre-determined station point along the route. The travel time data was then compared with the ABR system output to evaluate system travel time data accuracy.

The instrumented vehicles were equipped with transponders, with the identification numbers 813718444 and 8 13718504. The transponders were turned on, once a day for a complete run for the following reasons: (1) testing the messaging function of the system and (2) testing the accuracy of the 'tagged' travel times. The transponder was not turned on during all the test runs to avoid the risk of introducing bias to the travel time estimation of the ABR system due to additional probe data. A transponder test sheet was filled by drivers of the instrumented test vehicles to verify the functionality of the communication systems and the clarity of the audio messages.

1.2.3 ABR System Data

Steve Pearson of Hughes, manning the Traffic Operation Center, at the New Jersey Highway Authority provided the following information daily for the 6:00- 9:00 a.m. time period:

1. Detector Data
2. Tag Data
3. Log Data
4. Video Output

Each of these ABR system data will be described in the next four sections.

1.2.3.1 Detector Data

Detector data is the RTMS sensor output for average speed, occupancy, and volume data for each location aggregated over each thirty second interval. Table 4 contains a sample of computer output of the detector data.

Table 4. Detector data from the ABR system

Date	Time	Station	Counter	Zone	Speed	Volume	Occupancy	V_Speed	VPresence
18/11/97	6:53:06 AM	ICR	1933	4	47	16	20	0	0
18/11/97	6:53:07 AM	ICR	1934	5	22	8	16	0	0
18/11/97	6:53:08 AM	ICR	1935	6	35	11	20	0	0
18/11/97	6:53:09 AM	ICR	1936	7	64	13	24	0	0
18/11/97	6:53:10 AM	RAR2	3868	2	47	19	18	0	0
18/11/97	6:53:10 AM	ICR	1937	8	33	9	21	0	0
18/11/97	6:53:10 AM	NBA2	3860	2	83	13	10	0	0
18/11/97	6:53:10 AM	RAR2	3867	1	65	10	12	0	0
18/11/97	6:53:11 AM	NBA1	3867	1	67	10	5	0	0
18/11/97	6:53:11 AM	RAR2	3870	4	149	0	0	0	0

1.2.3.2 Tag Data 1.2.3.2 Tag Data

Automatic Vehicle Identification (AVI) tag data provide travel time information of the NJT buses. The highlighted row on Table 5 shows current time, location, bus identity number, route choice, total trip time for each bus, and the current routing message generated by the ABR system.

Table 5. Tag data from the ABR System

Date	Time	Station	Tag ID	Lane	GSP TT	US 9 TT	Message
18/11/97	5:27:07 AM	TAGRAR	813718773	1			Garden State Parkway
18/11/97	5:30:36 AM	TAGNBA	813718773	1			Garden State Parkway
18/11/97	5:32:53 AM	TAGNBA	813718800	1			Garden State Parkway
18/11/97	5:33:02 AM	TAGICT	813718773	1	355		Garden State Parkway
18/11/97	5:45:38 AM	TAGRAR	813718748	1			Garden State Parkway
18/11/97	5:48:21 AM	TAGRAR	813718757	1			Garden State Parkway
18/11/97	5:49:20 AM	TAGNBA	813718748	1			Garden State Parkway

1.2.3.3 Log Data

Log data consists of four-minute summaries of the ABR system output. The data includes estimated travel times for GSP and US Route 9, station delays, and five-minute aggregated volume, occupancy and speed data as shown on Table 6.

Table 6. Log data from the ABR system output

12/8/1997	05:58:14	Station delay (StaDly[2][1]) = 0
12/8/1997	05:58:14	Station delay (StaDly[2][2]) = 0
12/8/1997	05:58:14	Station delay (StaDly[2][3]) = 0
12/8/1997	05:58:14	Station delay (StaDly[2] [4]) = 0
12/8/1997	05:58:14	RtmsTT= 5, r = 2, s = 2
12/8/1997	05:58:14	RtmsTT = 5, r = 2, s = 3
12/8/1997	05:58:14	No Avi TT, TT[2] = 5
12/8/1997	05:58:14	The algorithm selected to remain at: GSP
12/8/1997	05:58:14	TT[GSP] = 5, TT[US9] = 5
12/8/1997	05:58:14	5 minute traffic features:
12/8/1997	05:58:14	Spd5m [GSP][Raritan] =46
12/8/1997	05:58:14	Flow5m[GSP][Raritan] = 600
12/8/1997	05:58:14	Occ5m [GSP][Raritan] = 3

1.2.3.4 Video Data

Traffic conditions at New Brunswick Avenue were video taped from 6:30 - 9:00 a.m. daily. Apart from enabling visual access to the system from the traffic operations center, these video images were used for traffic volume data accuracy testing.

1.2.4 Description of Overall Evaluation Testing

The following two classes of tests were conducted to evaluate the ABR project (Table 7):

1. Functional and Performance Testing
2. System-Wide Performance Testing

Functional and performance testing incorporates four types of tests, and System-Wide Performance testing incorporates two. Table 8 describes each of the six evaluation tests. The relationship between the evaluation tests and the ABR project goals are also shown on Table 9. The tests are designed to evaluate if the ABR system meets its project objectives.

Table 7. Summary of Evaluation Tasks

Functional and Performance Testing	FPT-01: Bus Routing
	FPT-02: Audio Messaging
	FPT-04: Traffic Volume Data Accuracy
	FPT-05: Travel Time Data Accuracy
System-Wide Performance Testing	SW-01: Bus Travel Time Reduction
	SW-03: Consumer Satisfaction

Table 8. Evaluation Test Numbers, Names, and Symbols and Descriptions

Test Number	Test Name	Test Description
FPT-01	Bus Routing	This test verifies that the routing system is functioning properly under a range of conditions.
FPT-02	Audio Messaging	This test verifies that the audio messages received by the bus drivers are comprehensible to the drivers. This test should include both normal conditions (e.g., weather, traffic, etc.) and some acceptable range of stress conditions.
FPT-04	Traffic Volume Data Accuracy	This test verifies that the traffic volume collected by the automatic system is accurate to a given degree of accuracy.
FPT-05	Travel Time Data Accuracy	This test verifies that the travel time data collected by the automatic system is accurate to a given degree of accuracy. The degree of accuracy should be established prior to the test execution.
SW-01	Bus Travel Time Reduction	This evaluation procedure will analyze and determine the reduction (if any) in bus travel time due to the automatic traffic management system. If possible, this test should take into account a wide range of possible scenarios reflecting normal traffic conditions, high peak (e.g., during holiday) conditions, etc.
SW-03	Consumer Satisfaction	This evaluation procedure will analyze and determine the consumer satisfaction due to a better bus routing and reduced travel time

Table 9. Evaluation and Testing of the ABR Goals and Objectives

Goal 1	***Evaluate System Performance***	Tests
1.	Assess reduction in bus travel time due to routing change.	SW-01
2.	Assess algorithm capability of selecting the correct route.	SW-01
Goal 2	***Evaluate System Reliability***	
3.	Assess traffic volume data collected by the system.	FPT-04
4.	Assess travel time data collected by the system.	FPT-05
Goal 3	***Evaluate User Acceptance***	
5.	Assess quality of the audio messages.	FPT-02
6.	Assess acceptance of the routing information by the users.	SW-03
7.	Assess the best audio message to transmit.	FPT-02

The next four chapters are dedicated to the discussion of each of the four tasks identified above for the successful completion of the ABR Project Evaluation.

CHAPTER 2
Evaluation of Operation of Radar Sensors and Spread Spectrum Radio Communications

2.1 Background

Radar data provides the ABR bus routing algorithm with volume, occupancy, and speed data for each of the four locations on the study site. Based on previous project meetings with all the participating members of the ABR project, the accuracy of volume counts was used to evaluate the operation of the RTMS sensors. Volume data is also used for travel time estimation by the ABR system algorithm.

The rest of this section follows the information provided by the Gardner and Rowe Systems Inc. report that describes the algorithmic route diversion procedure of the ABR project (Gardner and Rowe Systems Inc. 1995). Radar units collect and aggregate traffic data every thirty-seconds. The sensors count the number of vehicles passing the radar unit within a thirty-second interval to perform volume counts. For each lane, the system assigns a lane zone [z] index. Then the system receives and stores detector data from each RTMS detector [i] and lane zone [z] as follows:

DetZnCnt[i,z] {veh/hr}
DetZnOcc[i,z] {%}
DetZnSpd[i,z] {avg. mph)

For each roadway [r], station[s], lane [I] the traffic operation center will store the 30-second data as follows:

*Flow30s[r,s,l,t]{veh/hr) = DetZnCnt[i,z] *120*
Occ30[r,s,I,t]{%} = DetZnOcc[i,z]
Spd[r,s, I, t] (avg. mph) = DetZnSpd[i,z]

This data is available as detector data for the system as shown on Table 9. Thirty-second station-wide averages for each roadway and station are summarized as follows:

For each roadway “r”, station “s”, time slot “t”:

StaFlow30s[r,s,l] = ($\Sigma_{\text{for active lanes}}$ Flows30s[r,s,l,t]) / ActLans

StaOcc30[r,s,l] = ($\Sigma_{\text{for active lanes}}$OCC30s[r,s,l,t] / Act Lans

StaSpd30[r,s,l] = ($\Sigma_{\text{for active lanes}}$Spd30s[r,s,l,t]*Flow30s[r,s,l,t])/ ($\Sigma_{\text{for active lanes}}$Flow30s[r,s,l,t])

Where, ActLan = Number of Active Lanes. The detector ‘flow’ data has been rearranged by each station as shown on Table 10.

Table 10. ABR Volume data Rearranged by Station (*)

Average of Volume	**Station**						
Time	ICR	NBA1	NBA2	RAR1	RAR2	TOC	Grand Total
06:53:00	12.1	14.4	7.8	15	14	9.3	12.2
06:54:00	15.6	14.7	10.8	15.8	13.3	9.5	13.8
06:55:00	12.1	13.6	6	16.7	12.5	10.5	12.5
06:56:00	14.3	14.2	11.5	16.8	15.5	10	13.9
06:57:00	14.6	12.7	8.5	15	10	11.8	12.7
06:58:00	15.4	14.3	9	17.8	15.4	11.4	14.4
06:59:00	11.6	16.1	9	16.3	12.1	11.9	12.9
07:00:00	12.3	14.4	9.3	16.3	6.8	13	12.1
07:01:00	12.8	13.6	9	15.5	8.5	13.9	12.5
07:02:00	11.7	14.6	9.8	15.7	10.5	12.8	12.6
07:03:00	13.1	15.7	9	13.3	8.8	12.6	12.6
07:04:00	11.8	13.8	8.5	18	13.8	12.4	13
07:05:00	14.8	15.5	5	17.3	16.9	15	15

(*) The data has been rearranged in sixty second intervals

At 30-second intervals, the data is exponentially smoothed as follows:

For each roadway [r], station [s]:

If *StaFlow30s[r,s,t]* is valid for current period "t" then:

SmFlow[r,s] {veh/hr} = (SmFlow[r,s](1.0-k)) + (1.0-k) + (k*StaFlow30s[r,s,l])*

If *StaOcc30s[r,s,t]* is valid for current period "t" then:

SmOcc[r,s]{veh/hr}= (SmOcc[r,s](1.0-k)) + (1.0-k) + (k*SmOcc30s[r,s,l])*

If *StaSpd30s[r,s,t]* is valid for current period "t" then:

SmSpd[r,s]{veh/hr}= (SmSpd[r,s] (1.0-k)) +(1.0-k) + (k*SmSpd30s[r,s,l])*

At five-minute intervals, five-minute features shall be calculated as follows:

For each road [r], station [s], lane [1]:

$Flow5m\ [r,s,\ l]\{veh/hr\} = ((\ E_{for\ t = 1\ to\ 10}\ Flow30s[r,s,\ l,\ t])/10$

$Occ5m\ [r,s,l]\{\%\} = (E_{for\ t= 1\ to\ 10}\ Occ30s[r,s,l,t])/10$

$Spd5m[r,s,I]\{avg.\ mph\} =$

$((å_{for\ t = 1\ to\ 10}\ Spd30s[r,s,\ l,\ t]*Flow30s[r,s,l,t])/\ ((E_{for\ t = 1\ to\ 10}\ Flow30s[r.s,l,t]*$

Total estimated travel time for each route is **then** calculated as follows:

RtmsTT[r]{minutes} = NormTT[r] + (__ StaDly[r,s]) + AddedDly[r]) where,

AddedDly{minutes}= ((StaFlow5m [at Raritan] * NormTT[r]/60 SmFlow30s[at KGP]) *60

If addedDly[r]<o then AddedDly = 0

NormTT[r] = a user modifiable parameter, reflecting total normal route free flow travel time.

StaDly[r,s] =
(SectDist[r,s]*60/SmSpd[r,s,t])-(SectDist[r,s]*60/FreSpd[r,s])

Where, SectDist [r,s] {miles} = section length
FreSpd[r,s] {mph}=Normal Average free flow for the section

5-minute data is available in the system log file as shown on Table 11.

Table 11. 5-Minute Data from the ABR System Log File

12/8/1997	05:58:14	Spd5m [GSP][Raritan] = 46
12/8/1997	05:58:14	Flow5m[GSP][Raritan] = 600
12/8/1997	05:58:14	Occ5m [GSP][Raritan] = 3

Note that the Alternate Bus Routing algorithm has been modified by deleting 'addedDly[r]' from the travel time equation:

RtmsTT[r] {minutes} = NormTT[r] + (∑ StaDly[r,s]) + AddedDly[r]

Thus, travel time equation becomes:

RtmsTT[r] {minutes} = NormTT[r] + (∑ StaDly[r,s])

2.2 Testing Approach

Traffic volume counts were performed at New Brunswick Avenue, using video camera images obtained from the traffic operation center. The purpose of the test is to verify the accuracy of the RTMS sensor volume readings transmitted to central computer system.

Two lanes were selected to count the total number of cars passing at thirty-second intervals during peak hours (from 6:50 a.m. to 8:20 a.m.). This time period yielded a range of traffic conditions from heavy (6:50 a.m. to 7:50 a.m.) to mild (around 8:10 a.m.). An imaginary, perpendicular line was placed on the road, parallel to the volume sensor. Vehicles passing the imaginary line during each 30-second interval were counted using a VCR and TV. The volume counting was performed in two aggregated lanes to minimize counting errors due to lane changes.

The ABR system counts cars for each lane. To get values for two lanes, the volume for two individual lanes were added to form a single aggregated value.

Volume-of-System = Volume(lane-4) + Volume(lane-5)

The system collects and stores volume data every thirty second interval. Due to the internal computer procedure in gathering and processing volume data, the system presents some minor variations of time when collecting the data. For instance, the system starts to collect volume data at the zero, first, second, or third seconds of every minute. The Rutgers evaluation team started counting the cars every zero or thirtieth second of every minute. This may cause differences in volume counts of the system and by the Rutgers evaluation team. However, the average differences should be minimal for volume counts over a long period of time.

The selected lanes for volume counting were the most inner lanes at GSP. These lanes are identified by the system as lanes of:

- Station NBA1 (1 meaning the lanes of GSP)
- Zones 4 and 5 (most inner lanes of GSP, of a total of five lanes at New Brunswick Avenue)

2.3 Findings

Table 12 contains summary information about the individual volume data for every thirty-second interval. The summary of the statistical analysis of the volume data is also presented on Table 12. A sample size of 177 points provided a good basis for statistical analysis. This analysis was performed to test differences in volume counts based on the data collected by Rutgers evaluation team and the ABR system sensors. Assuming a t-student distribution for the differences in volume counts, it is possible to test if there are statistically significant differences between the volume counts of the ABR system and Rutgers evaluation team.

Table 12. Volume Counting Differences between Rutgers and the System

Date of Volume Data Collection	November 25, 1997
Average of difference of volume counts: *Volume (Rutgers) – Volume (System)*	*3.553672316*
Maximum value of difference of volume counts: *Volume (Rutgers) – Volume (System)*	20
Minimum value of difference of volume counts: *Volume (Rutgers) – Volume (System)*	-15
Total Volume (Rutgers)	*5653*
Total Volume (System)	*5024*
Standard deviation of difference of volume counts: *Volume (Rutgers) – Volume (System)*	6.05267602
Number of observation points	177
Sum of difference of volume counts: *Volume (Rutgers) – Volume (System)*	629
% Difference	11.12%

Specifying an alpha-value of 5%, the confidence interval for the volume count differences are calculated as follows:

μ = 3.553672316 (mean)
σ = 6.05267602 (standard deviation of the sample)
α = 0.05
η = 177 (number of data points)
$t_{\alpha/12.\eta}$ = 1.96

The true mean, with a confidence of 95%, is placed in the following interval.

Lower-Bound = $\mu - t_{(\alpha/2,\eta - 2)} \sigma$ = -8.30957 + 0
Upper-Bound = $\mu - t_{(\alpha/2,\eta - 2)} \sigma$ = 15.4691
Confidence Limits = (0,15.4691)

The confidence interval does cover zero. It means that data values do not supply enough evidence to affirm that the Rutgers volume counts versus the system volume counts had different means. Considering this result of the t-test, it can be concluded that both the ABR system and Rutgers volume counts do not have a statistically significant difference of means. According to the collected data, the ABR system has a smaller average volume value than the real average volume value, assuming the Rutgers counts represented the real values. However, the volume differences were not large, considering the average volume value (given by Rutgers counts) was 3 1.93 per interval. The ratio of volume differences versus the average value is given below.

$$\text{Ratio of Volume Difference and Average Volume} = \frac{3.5536}{31.9378} = 0.111266 = \%11.1266$$

Thus, the real volume is, on the average, 11.1266% larger than the volume counts supplied by the ABR system. A detector calibration procedure would help to reduce the difference between the real and system volume counts. However, the magnitude of the average difference is not likely to have a large impact on the travel time estimates given by the system algorithm. Also the radar manual states that errors up to +5% will be acceptable for the RTMS counts.

A list of equipment / hardware problems related to the radar sensors was identified based on the careful observation of ABR system output. The improper functioning of the sensors may jeopardize the quality of the travel times estimates. Also, the analysis of differences between trip times estimated by the ABR system and the Rutgers test vehicle have shown a consistent underestimation of travel times. This underestimation of trip times by the ABR system could also be partially due to the problems listed below:

1. Inability to assign the correct zone to a tagged vehicle
2. Sensor inability to detect a tagged vehicle
3. Multiple readings at a radar location
4. Incorrect route assignment
5. Absence of computation of travel time for a tagged Vehicle.

These equipment / hardware problems that are discussed below are identified using the data obtained from ABR system data files and / or Rutgers instrumented vehicles. .

Problem 1. Sensor Inability to Assign the Correct Zone to a Tagged Vehicle

Every time a tagged vehicle passes a radar point, a specific zone is identified. The zone identification will determine if the vehicle is traveling across the GSP or US9. The following example shows a typical system failure due to its inability to assign the correct zone to a tagged vehicle. Zone '0' indicates that the system could not identify which route the vehicle was traveling on. The inability of the system to determine the travel time for the bus 8 1378745 at NBA station is shown on Table 13.

Table 13. Sensor Inability to Determine the Correct Zones of Tagged Vehicles

Date	Time	Station	Bus Id	Zone	Trip Time [GSP]	Trip Time [US9]	Bus message
Nov/l7/97	6:47:10 AM	TAGNBA	813718745	0			Garden State Parkway
Nov/17/97	6:50:05 AM	TAGNBA	813718806	0			Garden State Parkway
Nov/17/97	6:42:01 AM	TAGRAR	813718745	1			Garden State Parkway
Nov/l7/97	6:47: 10 AM	TAGNBA	8 13718745	0			Garden State Parkway
Nov/l7/97	6:49:50 AM	TAGICT	813718745	I			Garden State Parkway

Table 14 provides statistical analysis of the probability of occurrence of this failure mode. For eight selected testing days, the sensor inability to determine the correct zone to a tagged vehicle was 9.3% on average.

Table 14. Data Analysis for sensor inability to determine correct zones of tagged vehicles

Number of testing days	8
Number of data points (identification of bus tag)	1096
Number of zeros at RAR station	0
Number of zeros at NBA station	102
Number of zeros at ICT station	0
Total number of zeros at all stations	73
Average number of zeros at all stations	9.3 %

Problem 2. Sensor Inability to Detect a Tagged Vehicle

Each time a tagged vehicle passes a sensor location, it should be detected in order to perform travel time calculations. The highlighted lines shown on Table 15 indicate that several tagged buses were detected only at NBA station and not detected at other sensor locations. On December 2, no buses were identified at ICT1 1 station. This inability to detect a tagged bus at all the sensor locations prevents the system from using the probe vehicle travel time for travel time estimation. This in turn reduces the number of probe vehicles and the accuracy of travel time estimation procedure which heavily relies the data from probe vehicles.

Problem 3. Multiple Readings at a Radar Location

Multiple readings of tagged buses occur at some radar locations, mainly at toll Plazas at

Raritan and Interchange 11. Based on these readings, the system may estimate several different travel times for the same tagged vehicle. Table 16 illustrates this error. The bolded rows indicate that the tagged vehicle was read more than once at one station during a particular run.

Table 15. Example of Sensors Inability to Detect a Tagged Vehicle

Date	Time	Station	Bus Id	Zone	Trip Time (GSP)	Trip Time (US 9)	Bus message
Nov/17/1997	7:29:30 AM	TAGNBA	813718811	1			GSP
Nov/17/1997	8:36:38 AM	TAGRAR	813718811	1			GSP
Nov/17/1997	8:45:12 AM	TAGNBA	813718811	1			GSP
Nov/17/1997	8:47:09 AM	TAGICT	813718811	1	631		GSP
Nov/18/1997	5:32:53 AM	TAGNBA	813718800	1			GSP
Nov/18/1997	8:07:35 AM	TAGRAR	813718800	1			GSP
Nov/18/1997	8:15:36 AM	TAGNBA	813718800	1			GSP
Nov/18/1997	8:17:53 AM	TAGICT	813718800	1	618		GSP

Table 16. Multiple readings at a radar location

Date	Time	Station	Bus Id	Zone	Trip Time (GSP)	Trip Time (US 9)	Bus message
Nov/26/1997	6:38:54 AM	TAGNBA	813718504	1			GSP
Nov/26/1997	6:41:35 AM	TAGICT	813718504	1	383		GSP
Nov/26/1997	6:41:39 AM	TAGICT	813718504	1	387		GSP
Nov/26/1997	7:31:38 AM	TAGICT	813718736	1			GSP
Nov/26/1997	7:32:47 AM	TAGNBA	813718736	1	320		GSP
Nov/26/1997	7:33:05 AM	TAGICT	813718736	1	338		GSP
Nov/26/1997	7:33:12 AM	TAGICT	813718736	1	345		GSP

Problem 4. Incorrect Route Assignment

Incorrect route assignment occurs when vehicles traveling on GSP are assigned as vehicles traveling on US Route 9. This error has been observed only at New Brunswick Avenue, and is due to the placement angle of the sensor at this location. If this error occurs frequently, it may completely affect the systems' capability of detecting travel times differences accurately. The highlighted rows on Table 17 shows that tagged vehicles traveling on GSP were identified as vehicles traveling at US9 during official testing.

Table 17. Incorrect Determination of the Route of a Tagged Vehicle

Date	Time	Station	Bus Id	Zone	Trip Time (GSP)	Trip Time (US 9)	Bus message
Nov/26/1997	6:56:34 AM	TAGRAR	813718800	1			GSP
Nov/26/1997	7:00:30 AM	TAGNBA	813718800	2			GSP
Nov/25/1997	8:11:35 AM	TAGRAR	813718774	1			GSP
Nov/25/1997	8:21:17 AM	TAGNBA	813718774	2			GSP

Problem 5. Inability to Compute Travel Time of a Tagged Vehicle

The system provides better travel time estimates if tagged vehicles are present in the system. The number of tagged buses in the system is relatively small at 50 vehicles. Therefore, it is important to calculate the travel time of all buses traveling across the project section. The occurrence of incorrect readings or inability to detect a probe vehicle will cause valuable travel time data to be lost. Table 18 illustrates this problem of not being able to estimate the travel time of a probe vehicle due to previously mentioned hardware / equipment failures.

The Table 19 contains statistical information regarding equipment problems. The number of zeros refer to the system's inability to assign the correct lane zone to a tagged vehicle.

Table 18. Inability to Commute Travel Time of Tagged Vehicle

Date	Time	Station	Bus Id	Zone	Trip Time (GSP)	Trip Time (US 9)	Bus message
Nov/25/1997	5:25:22 AM	TAGICT	813718761	1			US 9
Nov/25/1997	5:25:42 AM	TAGRAR	813718773	1			Garden State Parkway
Nov/25/1997	5:31:06 AM	TAGICT	813718773	1			Garden State Parkway
Nov/25/1997	7:05:31 AM	TAGNBA	813718773	1			Garden State Parkway
Nov/25/1997	5:45:38 AM	TAGRAR	813718774	1			Garden State Parkway
Nov/25/1997	5:51:46 AM	TAGICT	813718774	1			Garden State Parkway
Nov/26/1997	7:30:29 AM	TAGRAR	813718751	1			Garden State Parkway
Nov/26/1997	7:34:55 AM	TAGNBA	813718751	0			Garden State Parkway
Nov/26/1997	7:36:38 AM	TAGICT	813718751	1			Garden State Parkway
Nov/26/1997	5:00:30 AM	TAGNBA	813718753	0			Garden State Parkway
Nov/26/1997	5:02:56 AM	TAGICT	813718753	1			Garden State Parkway
Nov/26/1997	6:35:26 AM	TAGNBA	813718753	1			Garden State Parkway
Nov/26/1997	8:54:23 AM	TAGNBA	813718753	0			Garden State Parkway
Nov/26/1997	8:55:25 AM	TAGICT	813718753	1			Garden State Parkway

2.4 Conclusions

The Sensor Volume Data Accuracy Test concluded that both the system and the evaluation team's volume counts do not have a statistically significant difference of means. The average volume value given by Rutgers counting was 3 1.93 vehicles per 30 seconds, while the ABR system value was 28.38 vehicles per 30 seconds. The ratio of volume differences is found to be 11.12% which is slightly higher than the acceptable range of errors identified by the RTMS manual as +5%.

Hardware / equipment problems were mainly caused by sensor malfunction. Problems included: (1) Inability to assign the correct zone to a tagged vehicle, (2) Sensor inability to detect a tagged vehicle, (3) Multiple readings at a radar location, (4) Incorrect route assignment, and (5) Absence of computation of travel time for a tagged Vehicle.

CHAPTER 3
Operation of the Central Computer System

3.1. Background

The ABR project provides route guidance based on the analysis of current traffic conditions and pre-established threshold values coded into the ABR software. Therefore, the routing decision making process is based on the following factors:

1. Quality of traffic information gathered;
2. Accuracy of the travel time estimation model used to calculate both US9 and GSP travel times;
3. Initial settings established for the prediction model.

The model settings will largely affect the precision of the travel time estimation process and should be a result of the best settings combination for that particular road section. Among these settings, one could cite the following ones:

- minimum travel time difference between GSP and US9 necessary to warrant a diversion message
- minimum total travel time on GSP necessary to initiate the need for a diversion message
- default diversion message when the conditions for route diversion are not met.

The evaluation of the central computer system can be performed effectively by analyzing the impact of the main central computer output namely, *"the routing decisions"*. If the routing decisions are appropriate for most of the traffic patterns experienced by the actual ABR system, the central computer system can be considered as successful in achieving its main objective.

3.2 Evaluation Approach

The major requirement for the generation of a diversion message is the presence of significant travel time difference between GSP and US Route 9. The evaluation of the central computer system was based on the analysis of estimated differences in travel time given by the system and actual (observed) travel time differences. Furthermore, the actual travel times were also compared to the system estimated travel-times, since the second requirement for the generation of a diversion message is the requirement that the travel time on GSP exceeds a certain threshold value. The analysis of these results guided the evaluation process as well helped to design two specific testing activity (FTP-01 and FTP-05) applied to this part of the evaluation of the ABR project.

The main purpose of the bus routing test (FTP-01) is to evaluate if the routing system is operating accurately. The ABR project sends diversion messages to buses traveling across the project section only if:

- The difference between the system estimated trip time at GSP and US9 is larger than a pre-established value (currently set at four minutes)
- If the trip time at GSP is greater than a pre-established value (currently set at 5 minutes)
- If the diversion message is not overridden by the system operators.

The main system performance function is then defined as *"to correctly estimate the bus trip times for both routes, and to determine the travel time differences between the two routes."*

The Rutgers evaluation team used two test vehicles to evaluate the real travel time for both routes. The trips were conducted during the official testing period. The two vehicles started parallel runs before the radar placed at the Raritan Toll Plaza. After the diversion point, one of the vehicles used the GSP, and the other one traveled along the US Route 9.

The data collection was performed from 6:40 a.m. to 9:00 a.m., during the rush hour period with a larger probability of experiencing a substantial difference in travel times between two routes. The trip times were calculated based on the following formula.

TT(GSP) = Time(ICT / GSP) -Time(RAR/ GSP)

TT(US9) = Time(ICT /US9) -Time(RAR/US9)

where,
TT (GSP) = Travel time for the Rutgers vehicle traveling at GSP.
TT (US9) = Travel time for the Rutgers vehicle traveling at US9.
Time (ICT/route) = Time the Rutgers vehicle crossed the radar placed at interchange 11. The "/route" indicates which route was taken (GSP or US9).
Time (RAR/route) = Time the Rutgers vehicle crossed the radar placed before the Raritan Toll Plaza. The /route indicates which route was taken (GSP or US9).

The system estimates travel times every four minutes. Each estimate is valid until another travel time estimation is computed by the system. Measures of system performance are defined as follows (All travel times and differences in travel times are given in seconds):

- **Travel time difference between GSP and US9 based on system estimation:** This is the difference in travel times based on system estimations for GSP and US Route 9. Travel Time Difference between GSP and US9 based on Rutgers Test Runs: Difference of travel times based on the travel times measured by two Rutgers test vehicles, one traveling at GSP and the other on US9. Since Rutgers travel times are considered as ground truth, they will determine the difference in trip times between estimated and real travel time values for this section of the project.
- **Travel time difference between Rutgers GSP and System GSP:** Difference in travel time of the Rutgers vehicle traveling on GSP and GSP travel time estimated by the ABR at a particular point of time. The starting and ending time of the Rutgers vehicle is registered and the current travel time is estimated by the difference of the trip starting and completion times.
- **Travel time difference between Rutgers US Route 9 and System US Route 9:** Difference in travel times of the Rutgers vehicle traveling on US Route 9 and US Route 9 travel time estimated by the ABR at a particular point of time.

3.3 Findings

An important function of the ABR project is the system's ability to accurately estimate travel times using information from the tagged buses and RTMS traffic data. Considering that the real travel times for both routes are given by the travel times collected by the Rutgers test vehicles, an analysis of the differences of Rutgers test vehicle travel time and estimated system travel times provided several insights for the system evaluation,

3.3.1 Differences in Travel Times at GSP

The difference in travel times can be seen the error of the system estimates. The following table summarizes the travel time differences between Rutgers' test vehicles and the system's estimated travel times on GSP.

Table 20. Summary of GSP Travel Time Differences Measured by the Test Vehicle and Estimated bv the Svstem

Number of Data Points	54
Minimum travel time difference	-33
Max travel time difference	336
Sample Mean	125
Sample Standard Deviation	87.3

Distribution Summary of the best fitted distribution for the errors:
- Distribution: Normal
- Expression: NORM(125, 86.5)
- Square Error:0.008774

A Chi-Square test was performed to test the goodness-of-fit of the travel time differences to the normal distribution. The confidence intervals for the true value of the mean differences was also computed. If the confidence interval is around zero, the corresponding p-value should be larger than an acceptable margin of error. For most statistical analysis, an acceptable margin of error is 5%. Therefore, obtaining a p-value smaller than 0.95 shows that the true mean is not larger than zero, with an error margin of 5%.
- Number of intervals = 5
- Degrees of freedom = 2
- Test Statistic = 1.81
- Corresponding p-value = 0.423

Hence, based on the above results, it can be said that the differences in travel times are not statistically significant. However, it is still expected that 92% of the travel time differences will be larger than zero. The general trend of the system is then to underestimate the real travel times at GSP. Notice that the data analysis was performed by withdrawing one data point from the data set, considered as an outlier. Although there is not enough statistical evidence to show that the travel time estimated by the system is different from the real travel time, it can be intuitively observed that the system trip times are consistently lower that the real travel times measured by the Rutgers Instrumented Vehicle.

3.3.2 Differences in Travel Times at US Route 9

A similar data analysis is applied to the travel times at US Route 9. Table 21 summarizes the travel time differences measured by Rutgers vehicles traveling at US Route 9 and US Route 9 travel times estimated by the ABR system.

Table 21. Summary of US Route 9 Travel Time Differences measured by the Test Vehicle and Estimated by the System

Number of Data Points	53
Minimum travel time difference	3
Max travel time difference	423
Sample Mean	189
Sample Standard Deviation	111

A normal distribution was fitted to the data points. The summary of the distribution for the errors is shown below:

- Distribution: Normal
- Expression: NORM(189, 111)
- Square Error:0.018303

A Chi-Square Test was performed to test if the goodness of fit of the data to a normal distribution. The test results are summarized as follows:

Chi Square Test
Number of intervals = 5
Degrees of freedom = 2
Test Statistic = 5.38
Corresponding p-value = 0.0721

Therefore, based on the results of statistical tests, it can be concluded that the differences in travel times are not statistically significant. Moreover, it is expected that 95.4% of differences in travel times values will be larger than zero, which may reveal a trend of the system to underestimate the real travel times at US Route 9. Although there is not enough evidence to show that the travel time given by the system is different from the real travel time, clearly the system trip times are consistently lower that the real travel times. No data value (difference in travel times) was smaller than 3 seconds.

3.3.3 ABR System Travel Times vs. Tagged Bus Travel Times on GSP and US Route 9

The tagged bus travel times are found to be approximately equivalent to the Rutgers test vehicle travel times. Therefore, the comparisons of system travel times with tagged bus travel times can be performed by extrapolating the conclusions drawn in the previous two sections. The system consistently underestimates the travel times. However, in statistical terms, the difference in the mean travel time is not large. Such phenomenon occurs because there is a large variation in the data points (travel times differences), which affects the capability to provide definitive conclusions by using statistical procedures. This is typical in the analysis of traffic engineering problems because of the very dynamic behavior of traffic.

3.3.4 Tagged Bus Travel Times vs. Test Vehicles Travel Times on GSP and US Route 9

For each test day, travel time data for tagged buses and the Rutgers test vehicles was analyzed using graphs similar to the one shown in Figure 5. The visual analysis of the graphs shows that the travel times experienced by the Rutgers test vehicle and the tagged buses are comparable whenever both vehicles have close starting times. However, this observational conclusion cannot be statistically proven because of two factors:

1. Large data dispersion mainly due to the limited number of tagged buses
2. It was not realistically possible to synchronize the starting times of Rutgers test vehicles and tagged buses. Due to the dynamics of the traffic, a comparison should be made only for the cases where tagged buses and the Rutgers Test Vehicles start their runs at very close points in time. An analysis of Figure 5 shows that whenever the starting times of a tagged bus and an instrumented Rutgers vehicle are close their total trip times are close too. But, there are not too many points of that nature to be able to statistically compare them.

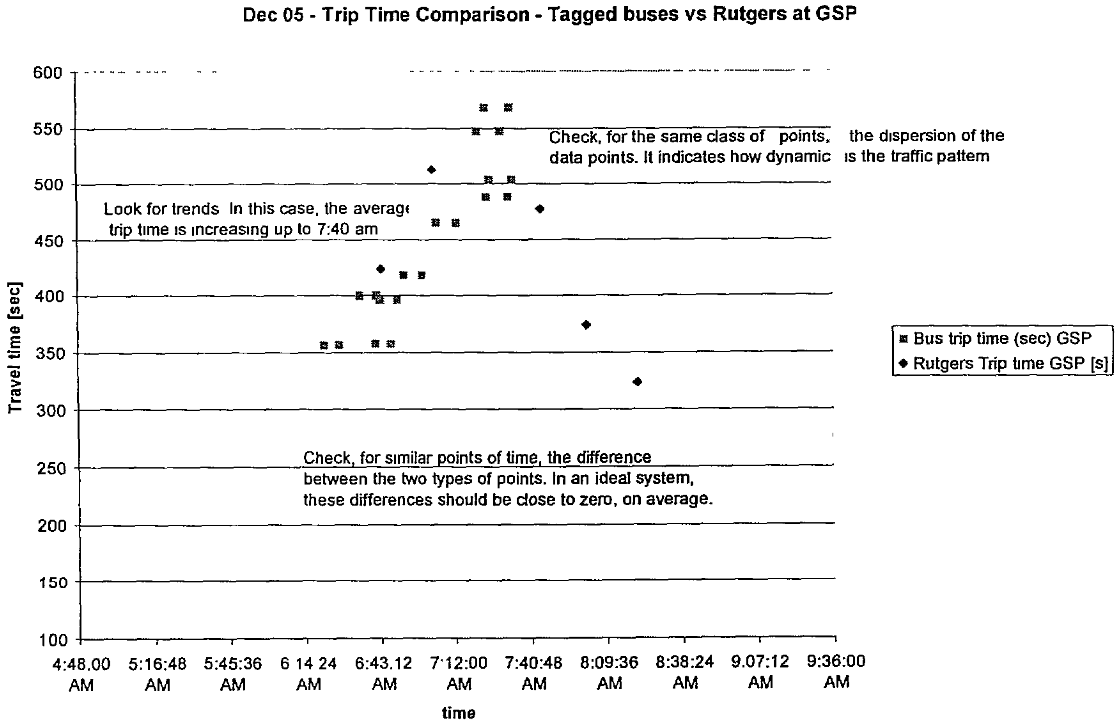

Figure 5. Trip Times Measured by Rutgers Test Vehicle and Tagged Busses

An interesting point should be made considering data points at US Route 9. Due to the error in assigning routes to the tagged buses traveling on GSP, the system may have characterized these buses as traveling on US Route9, which may lead to untrue conclusions in terms of travel time comparisons.

3.3.5 FPT-05: Travel Time Data Accuracy Test Results

Ground truth travel time data was collected by the Rutgers evaluation team using two instrumented vehicles to conduct synchronized, parallel runs on GSP and US Route 9 from 6:30 a.m. to 9:00 a.m., in order to analyze the travel time estimation process. Travel time data from the Rutgers vehicle was matched against data from the ABR routing system. An sample data sheet that shows the travel time data collected by the Rutgers team is shown in Figure 4.

Statistical analysis applied to the travel time differences helped to characterize the accuracy of travel time data. Table 22 summarizes the average travel times values for both Rutgers test vehicles and system.

Table 22. Summary of travel times differences

Route	Mean Rutgers Travel Time	Mean System Travel Time [sec]	Difference
GSP	505	382	123
US9	516	337	179

3.4 Conclusions

The analysis of the central computer system outputs revealed relevant information to provide insights regarding the degree of accuracy of the system's travel time estimations. As previously shown, the system trend **is** to underestimate the travel times, with reasonable order of magnitude. The difference in travel times given by the system and by actual travel times can be reasonably modeled as a normal distribution. Additionally, the system shows more variability when comparing estimated and actual travel times at US9 than GSP, according to analysis of the standard deviation of the travel time differences. A summary of the main results obtained with the evaluation of the central computer system was shown in this section.

CHAPTER 4
In-Vehicle Operations

4.1 Background

The NJT buses that were part of the ABR project were equipped with on board transponders and annunciators. These devices provided direct communication to the equipped buses to transmit route guidance messages. Similar devices have been used in other ITS projects, and the proper functionality of these on board devices are crucial to assure the complete link between the central computer system (responsible for the decision making process) and the bus operator (agent responsible by the implementation of the diversion instructions).

ALTERNATE BUS ROUTING PROJECT

TEST NUMBER__________________TIME_______________DATE Dec/02/97

TEST NAME: Road Test (Runs)

TEST OBJECTIVES :

1) **Record travel time for all interest points (US9)**

TEST PROCEDURES

Record the initial travel time and difference (in seconds) of trip times between two consecutive measurement points

TEST RESULTS

					Travel	Time	[sec]	
			From/To	From/To	From/To	From/To	From/To	From/To
Run #	Date	Starting time	RAR/126.2	126.2/127.0	127.0/127.8	127.8/NBA	NBA/KGPR	KGPR/ INT11_before toll
1	12/02/97	6:41:01 AM	115	73	70	41	51	49
2	12/02/97	7.02:41 AM	155	73	61	39	49	56
3	12/02/97	7:19:21 AM	163	82	72	40	52	57
4	12/02/97	7:39:39 AM	183	108	100	39	50	59
5	12/02/97	7:58:24 AM	216	166	104	50	50	57

			Travel	Time	
			From/To	From/To	Remark
Run #	Date	Starting time	INT11_before /after toll	*RAR/INT 11 final point*	
1	12/02/97	6:41:01 AM	56	455	ok
2	12/02/97	7:02·41 AM	38	471	ok
3	12/02/97	7:19:21 AM	41	507	ok
4	12/02/97	7:39:39 AM	47	586	ok
5	12/02/97	7:58:24 AM	49	692	ok

REMARKS

Figure 6. Sample Travel Time Data Collection Sheet

4.2 Approach

The evaluation of in-vehicle operations encompasses the analysis of message quality sent to participating buses. The following points were investigated for a complete evaluation of the quality messages:

1. Length and time of message sending
2. Clarity of messages
3. Location the message is transmitted
4. External facts affecting the messages quality

The length and time of message sending was analyzed through the use of a customer satisfaction survey to the bus operators. According to the sample of bus operators that filled the questionnaire, the length and time of message sending did not achieve excellent marks, therefore leaving room for further improvement. Detailed results of the customer satisfaction survey are discussed in the next chapter, where the questionnaires are also presented.

Audio message testing was performed by activating the transponders on the instrumented vehicles during test runs to verify that messages could be received at normal highway speeds at Raritan Toll Plaza and Interchange 11. This test was designated as "Audio Message Testing (FTP-02)". Figure 7 is a blank transponder test sheet.

4.3 Findings

When transponder tests were conducted using Rutgers test vehicles, the initial message was heard at the proper location, right before the Raritan Toll Plaza. The message was also heard clearly under a variety of weather conditions such as, clear and rainy. The intensity of the volume and clarity of the message were acceptable during the test vehicle runs.

Sometimes the evaluation team heard diversion messages while traveling southbound on GSP, past Raritan Toll Plaza. These messages were erroneous since this is not a point of diversion for the ABR project. At Interchange 11, the fmal message was not heard several times at the exit point of the system. This was due to the vehicle not using the two most right lanes at' Interchange 11 Toll Plaza exit. *To make sure that the messages are heard at Interchange 11, the buses need to travel on the two right most lanes.* This may create a minor difficulty for bus drivers, as they may not be able to switch to the right most lanes at the message communication point at Interchange 11.

4.4 Conclusions

According to audio message testing results conducted by the Rutgers evaluation team, the length, time and road position of messages sent are adequate for the project purposes. However, the results of the questionnaire from the bus operators highlight that the system requires further improvement. This difference is due to the fact that bus operators that are new or not familiar with the GSP ABR study section have difficulty in understanding the diversion messages. They may also be surprised with the message, sent before the Raritan Toll Plaza. The system designer has to provide an additional capability to the transponders that permit bus drivers to repeat messages by pressing a button on the transponder. This additional feature was not known by all the participating bus drivers.

Another problem with the audio message transmission is that the system issues messages at inappropriate locations such as GSP southbound lanes. In addition, messages sent at Interchange 11 were not heard sometimes, especially if the equipped vehicle was not traveling in the right most lanes. For safety reasons, it is recommended that the system be able to send the messages through all the extensions of Interchange 11. As a result of the latter reason and complaints from the bus operators, messages at Interchange 11 was interrupted in the middle of the official testing period.

ALTERNATE BUS ROUTING PROJECT

TEST NUMBER__________________ **TIME**_______________ **DATE** ___________

TEST NAME: Transponder Test

TEST OBJECTIVES :

1) **Reliability of the transponder**
2) **Quality of the diversion message**

TEST PROCEDURES

TEST RESULTS

REMARKS

Figure 7. Sample Transponder Test Sheet

CHAPTER 5
Performance of the Integrated System

5.1 Background

The ABR project is a system that consists of several components that perform specific functions. As a system, the ABR project integrates all these components in order to produce system outputs directly related to the project goals. Among these outputs, it is necessary to provide effective bus travel time reduction through the correct assignment of routes to the participating buses. Other important aspects of the system are:

1. Capability to produce diversion messages that reduce travel time;
2. Ability of the system to be understood and interact with its users namely , bus drivers and system operators
3. Capability of creating a positive perception among the system users regarding the system outputs, such as messages quality and number of diversion messages issued.

The evaluation of the integrated system was performed on the official testing period. The tests were conducted during morning rush hours, at a maximum level of system requirements. The design of the tests to evaluate the performance of the integrated system as well as the analysis of the test results reflects this situation.

5.2 Approach

The evaluation of the performance of the integrated system was split in two major testing activities:

1. Analysis of bus travel time reduction (SW-01)
2. Consumer satisfaction evaluation (SW-03)

SW-01: Bus Travel Time Reduction test was performed by analyzing the system's output of diversion messages. During the testing days, system diversion messages, advising the use of the alternate route (US9) were issued. The occurrence and the time it affected a tagged vehicle traveling in the system at that time were collected and the results were summarized and analyzed. SW-03: Consumer Satisfaction test was designed to measure the success of implementing new technology that basically depends on the user acceptance. Therefore customer satisfaction is an important aspect of the integrated system evaluation. The main users of the ABR system are the NJ Transit bus operators, and the system operators, who monitor the system.

Surveying is a very useful tool in providing insights for the evaluation of customer satisfaction, mainly when several qualitative aspects are involved. Therefore, both bus drivers and system operators were surveyed to understand their perception of the ABR technology. The surveys were also useful in identifying areas of improvement for the system.

5.3 Findings

The results obtained as a result of testing activities designed to evaluate the performance of the Integrated System (SW-01 and SW-03) are discussed in this section.

Test of Bus Travel Time Reductions (SW-01): In order to test "bus travel time reductions (SW-01)" due to the diversion messages, a summary of diversion messages shown in Table 21 was prepared. According to this table, no diversion message, except the one on The 1 lth of December, 1997, did last more than fifteen minutes. It is important to point out that the real length of the diversion message is a multiple of four minutes, because the system issues new diversion messages at this rate. However, Table 23 shows the effective length of the diversion message, which is the length of time between the first and the last bus that heard a particular diversion message. The effective length of diversion message is equal or small than a multiple of four minutes and may be used as a measurement of system performance, because it also counts the rate that buses enter the system. This rate is proportional to the number of participating buses in the project.

Table 23. Complete List of Diversion Messages Issued by the System during the Test Days

Date	Diversion Message	Time the Diversion Messages are Detected by Tagged Vehicles	Effective Length of Diversion Message (min.)	Period of Observation (Tag File)
11/17/97	One	8:10:28 - 8:18:28 AM	8	5:25 - 8:47 AM
11/18/97	One	8:23:33 - 8:26:01 AM	2:28	5:27 - 8:59 AM
11/19/97	None			5:25 - 9:13 AM
11/20/97	One	7:20:11 - 7:33:52 AM	13:41	5:01 - 9:01 AM
11/21/97	None			5:02 - 9:01 AM
11/25/97	One	7:23:00 - 7:29:32 AM	6:32	5:25 - 9:00 AM
11/26/97	None			5:00 – 9:00 AM
12/02/97	None			4:54 –8:14 AM
12/05/97	None			6:03 – 8:55 AM
12/08/97	None			5:55 – 8:58 AM
12/l 1/97	One	8:10:35 – 8:29:34 AM	18:59	5:55 – 8:57 AM
12/l 0/97	None			5:58 – 8:46 AM
12/12/97	One	7:24:49 – 7:26:50 AM	2:01	5:59 – 8:58 AM
12/l 5/97	One	8:36:31 – 9:02:47 AM	26:16	6:00 - 9:17 AM
12/16/97	One	8:3 1:26 – 8:32:47 AM	1:21	6:58 – 8:58 AM
12/17/97	One	8:31:43 - 8:41:15 AM	9:32	5:53 – 8:50 AM
12/l 8/97	None			6:01 - 8:52 AM

Table 24 shows that not all buses that heard the message at the Raritan Toll Plaza diverted as advised by the system. However, relatively low number of diversion messages during the testing period makes it difficult to draw conclusions regarding this issue. Table 24 shows that the most important factor for the system to be effective is the capability of transmitting the diversion message to the buses at the right time and at the right place. For example, although there were 9 buses traveling during the time period when diversion message was broadcast by the system, only three buses received the message. This might be partly due to the fact that they were not at the right location at the right time. Thus, it is extremely important to choose the best locations and most effective timing for disseminating diversion messages to the buses.

Table 24. Summary of Diversion Messages

Date	No. of Tagged Vehicles that Diverted	No. of the Tagged Vehicles in the System during the Diversion Message	No. of Tagged Vehicles that the Messages was transmitted to at Raritan Toll Plaza
11/17/97	2	9	3
11/18/97	0	1	0
11/20/97	3	11	5
11/25/97	1	6	6
12/11/97	0	5	1
12/12/97	0	4	0
12/15/97	1	3	1
12/16/97	0	2	0
12/17/97			

During the regular testing period, the system recommended the alternate route only one time when it should not have warranted a diversion message. One of the conditions for the diversion message to occur is that the difference in system travel times at GSP and US Route 9 should be greater than four minutes. Based on the analysis of system log files for the test days, it was observed on December 15, during the period of diversion (8:36:31 – 9:02:47 AM), the system travel time estimations were as follows:

System travel time estimate for GSP: 5 [minutes]
System travel time estimate for US9: 5 [minutes]
Difference is system travel times (GSP - US9) = 0

Based on these estimations, system should not have recommended a diversion.

Test of Customer Satisfaction (SW-03): Customer Satisfaction survey was done in two parts. One set of surveys were designed for the bus operators, and another for system operators. The NJT bus operators were surveyed and interviewed on the 11th of December, the final week of official testing at the Howell garage. Ms. Allison Crowell, Operating Systems Manager, of NJT coordinated the effort between the NJ Transit and Rutgers University. The evaluation team obtained 21 completed surveys. The survey shown in Figure 6 was designed to query the bus operators in three areas:

1. Message transmission
2. Routing Information
3. Equipment

ALTERNATE BUS ROUTING SYSTEM - SURVEY FOR NJT BUS OPERATORS

Thank you very much for taking the time to fill out this survey giving us feedback on the Alternate Bus Routing Project on Garden State Parkway. Your input will be invaluable as we continue to evaluate this system.

A = Agree
SD = Strongly Disagree
SA = Strongly Agree

MESSAGE TRANSMISSION

	SD		A		SA
1. The diversion message is understood.	1	3	5	7	9
2. The sound quality (volume) is acceptable. If not, **the** volume is: __**Too loud** __**Too low**	1	3	5	7	9
3. The diversion message is clear.	1	3	5	7	9
4. The message is given at the appropriate location.	1	3	5	7	9
5. Sufficient time is available for execution of message.	1	3	5	7	9
6. The length of the message is appropriate. If not appropriate, it **is:** __**Too long** __**Too short**	1	3	5	7	9

7. Do you replay the message a second time? __Yes __No

8. Would additional information be useful? __Yes __No

If yes, please explain: ____________________

ROUTING INFORMATION

9. Do you know that an alternate route exists? __Yes __No

10. How long have you driven an operational tagged bus?

__**less than 1 week** __**1-2 weeks** __**2-3 weeks** __**3-4 weeks** __ **4 weeks**

11. How many times approximately have you driven an operational tagged bus on this section of the Garden State Parkway? [ ]

12. On the average, how many times a day, do you approximately hear a message requesting a diversion to the alternate route? (times) [ ]

Figure 8a. NJ Transit Bus Operators Survey

ALTERNATE BUS ROUTING SYSTEM - SURVEY FOR NJT BUS OPERATORS CONT.

	SD		A		SA
13. Do you feel this system is useful in improving your travel time?	1	3	5	7	9

14. Which percentage of the time did you follow the diversion message? __ 0-25% __ 26-50% __ 51-75% __ 76-100%

	Not Accurate			Accurate	
15. How do you rate the accuracy of the information?	1	3	5	7	9

16. Have you ever diverted to Rt.9 after receiving a message to stay on Garden State Parkway? __ Never __ **Sometimes** __ **Always**

If yes, please explain : ____________________

17. Time of day diversion messages are heard in general:

__ 5:00- 9:00 a.m. __ 9:00 a.m. - 4:00 p.m. ___4:00-7:30 p.m. ___7:30-12:00 p.m.

18. Does the alternate route provide any advantage after the diversion instruction? ___Yes __ No

	SD		A		SA
19. Does the system operation save travel time?	1	3	5	7	9

20. Have you identified ways of improving the system? __ Yes __ No

If yes, please explain: ____________________

EQUIPMENT

	SD		A		SA
21. The transponder is placed at a reachable location.	1	3	5	7	9
22. Speaker is placed at an appropriate position.	1	3	5	7	9
23. The speaker functions appropriately.	1	3	5	7	9

ADDITIONAL COMMENTS

Figure 8b. NJ Transit Bus Operators Survey (Cont'd)

The following table shows a summary of the results from each of the 23 questions on the survey. Question number 11 (How many times have you driven an operational tagged bus on this section of the Garden State Parkway) was excluded from the analysis, as the bus operators found it difficult to reply to this question.

Table 25a. ABR Customer Survey Results

ABR CUSTOMER SURVEY RESULTS

MESSAGE TRANSMISSION

I. The diversion message is understood.

SD1	3	A5	7	SA9	Total
6	3	6	0	4	19

47% of the bus operators did not understand the diversion message.

2. The sound quality (volume is acceptable) : low

SD 1	3	A5	7	SA9	Total
6	3	8	0	2	19

47% of the operators thought the sound quality could be improved by increasing the volume.

3. The diversion message is clear.

SD 1	3	A5	7	SA9	Total
5	7	4	0	3	19

63% of the bus operators did not find the diversion message clear.

4. The message is given at the proper location.

SD 1	3	A5	7	SA9	Total
3	2	9	2	4	20

75% of the bus operators though the diversion message was transmitted at a proper location.

5. Sufficient time is available for execution of message.

SD 1	3	A5	7	SA9	Total
3	4	8	1	3	19

63% **of** the bus operators agreed there was sufficient time for executing the diversion message.

6.The length of the message is appropriate.

SD 1	3	A5	7	SA9	Total
5	6	6	0	1	18

6 1% of the drivers though that the message was too short.

Table 25b. ABR Customer Survey Results (Cont'd)

ROUTING INFORMATION

7. **Do you replay the message a second time?**

Yes	**No**	Total
13	6	19

68% of the bus operators replayed the diversion message.

8. Would additional information be helpful?

Yes	**No**	Total
9	9	18

50-50% split between the percentage of bus operators, who would like additional information and not. Those who needed additional information specified weather, traffic, and construction work advisories.

9. Do you know that an alternate route exists?

Yes	**No**	Total
21	0	21

100% of the bus operators were familiar with the existence of the alternate route.

10. How long have you driven a tagged bus? (in weeks)

<l	1 to 2	2 to 3	3 to 4	>4	Total
3	6	5	3	2	19

The intention of this question was to verify how familiar the bus operators were driving tagged busses. 15% of the drivers had less than 1week of experience.

12. How many times a day do you approximately hear a diversion message?

none	once	two	Total
1	13	7	21

62% of the operators heard the message once a day, while 33% heard it twice.

13. Do you feel this system is useful in improving your travel time?

SD 1	3	A5	7	SA9	Total
4	3	7	1	6	21

67% of bus drivers were optimistic that that the ABR technology **would** improve the travel time.

Table 25c. ABR Customer Survey Results (Cont'd)

14. Which percentage of the time did you follow the diversion message?

0-25%	26-50%	51-75%	76-1 00%	Total
6	**1**	**5**	**7**	19

63% of the operators followed the message more than 50% of the time.

15. How do you rate the accuracy of the information.

NA 1	3	5	7	A9	Total
3	1	**11**	**3**	**2**	**20**

80% of the drivers thought the diversion information was accurate.

16. Have you ever diverted to Rt. 9 after receiving a message to stay on GSP?

Never	Sometimes	Always	Total
15	5	0	20

This question was designed to observe how many operators adhered to the diversion message. The surveys show that up to 25% of the drivers 'sometimes' diverted to Rt. 9 after receiving a diversion message.

17. Time of day diversion messages are heard in general?

5-9AM	9AM-4PM	4-7:30PM	7:30-12PM	Total
19	0	0	**2**	**21**

Diversion messages are heard usually during 5-9AM period. There were two responses for the 7:30-12PM time slot as well.

18. Does the alternate route provide any advantage after the diversion instruction?

Yes	**No**	Not Sure	**Total**
8	**7**	**2**	**17**

47% of the bus operators were enthusiastic regarding the feasibility of the diversion message, while 53% operators were not sure, or did not think the diversion messages provided advantages.

19. Does the system operation save travel time?

SD 1	3	A5	7	SA9	Total
6	**2**	**7**	1	**4**	**20**

60% of the bus operators agreed that the ABR system saves travel time.

Table 25d. ABR Customer Survey Results (Cont'd)

20. Have you identified ways of improving the system?

Yes	No	Total
6	14	20

30% of the bus operators had ideas on how to enhance the systems. These ideas are presented at the end of the chapter.

EQUIPMENT

21. The transponder is placed at a reachable location.

SD 1	3	A5	7	SA9	Total
2	1	10	0	7	20

85% of the drivers agreed that the transponder was positioned at a reachable location.

22. The speaker is placed at an appropriate location.

SD 1	3	A5	7	SA9	Total
2	1	11	1	6	21

86% of the operators concurred that speaker is placed at the right.

23. The speaker functions appropriately.

SD 1	3	A5	7	SA9	Total
3	0	12	1	4	20

85% of the bus operators agreed that the speakers were functioning properly.

The evaluation team also conducted informal interviews with the bus operators. From the survey results it was observed that the bus drivers differ in their opinions regarding the route guidance technology; 60% were enthusiastic about the ABR project's ability for improving the bus travel time, while the rest were pessimistic about its possible advantages. Some of the comments were very insightful and have been listed below. It should be mentioned that most drivers complained about the messages not been clear, or not hearing the message even though the transponder was turned on. The following observations are strictly perceptions of the bus drivers and not of the evaluation team and are mentioned here to provide further informal information regarding the system users opinion about the overall system.

1. If GSP is congested, then Route 9 is twice as much congested. Therefore, GSP is always the best route.
2. There are fewer lanes on Route 9, therefore, GSP is better during congestion.
3. Create a bus lane on GSP.
4. The message is not audible, even though the transponder is turned on.

5. Messages should be louder and clearer.
6. Additional information regarding weather, accidents, and construction work ahead would be useful.
7. More accurate real-time information, curtailing the four-minute lag would be useful.
8. Radio communication between bus drivers would be helpful to exchange information.

The analysis of surveys revealed the following important points:

1. 100% of the operators were familiar with the alternate route (US Route 9).
2. 63% of the operators did not find the diversion message clear, while 47% of the operators thought the sound quality could be improved by increasing the volume. 68% of the drivers replayed the diversion message.
3. 67% of the drivers were optimistic that the ABR system would improve travel time, while 47% believed that the alternate route provided an advantage after the diversion instruction.
4. 80% of the drivers thought the diversion message was accurate.
5. 60% of the bus drivers agreed that the ABR system saves travel time.
6. 25% of the drivers diverted to US Route 9, when the diversion message instructed the operators to stay on GSP.
7. 85% of the operators agreed that the equipment was functioning effectively and installed correctly.

Summary of System Operator Customer Survey Results

The system operators of the ABR Project, who monitor the system from the traffic operation center in Maple wood were also surveyed. Figure 9 is the System Operator Survey Form. The operator survey form consists of 3 main sections namely, routing information, software management, and equipment. The conclusion of the survey conducted among three operators can be summarized as follows.

Routing Information: All three operators who responded to the survey believed that the system's diversion decisions were almost but two of the operators stated that they have overridden system's diversion message once because according to them diversion was not warranted. They also ggreed that the alternate route did not save any time at all. They unanimously agreed that the system could have potentially provided useful information if the alternate route had been different. They also all agreed that the ABR system can be improved by improving the performance of the existing camera and adding new cameras.

Software Management: The software operation training and information provided by the software were rated as adequate. The volume, speed, and occupancy information displayed by the software was also found satisfactory by the system operators.

Equipment: There was a difference of opinion among the three operators regarding the functioning of the surveillance camera. One operator rated most of the camera functions as perfect while another operator rated them as barely adequate or poor. The third operator rated all camera functions as average or adequate.

ALTERNATE BUS ROUTING SYSTEM - SURVEY FOR SYSTEM OPERATORS

Thank you very much for taking the time to fill out this survey giving us feedback on the Alternate Bus Routing project on Garden State Parkway. Your input will be invaluable as we continue to evaluate this system.

ROUTING INFORMATION

1. Does the system divert buses when a diversion is warranted? _ Yes __No

2. Have you ever overridden a message? _ Yes __No

If yes, explain why? ____________________

How many times? [ ]

	Poor			Excellent	
3. How do you rate the diversion operation?	1	3	5	7	9

4. Does the alternate route save travel time? _ Yes __No

	SD		A		SA
5. Does the system provide useful information?	1	3	5	7	9

6. Do you think the system can be improved? _ Yes _ No

If yes, explain how: ____________________

SOFTWARE MANAGEMENT

7. System operation training is adequate. _ Yes __No

If no, please explain : ____________________

8. Additional information on the computer screen is necessary. _ Yes __No

If yes, please explain : ____________________

9. How do you rate the information on the screen? **__Incomplete __Complete**

If incomplete, please explain: ____________________

Figure 9a. ABR System Operator Survey

ALTERNATE BUS ROUTING SYSTEM SURVEY FOR SYSTEM OPERATORS CONT.

A = Agree
SD = Strongly Disagree
SA = Strongly Agree

10. How long do you take to override a message? [ ]

11. Do you have too much information on the screen? __Yes __No

If yes, please explain: ____________________

12.The software is user friendly in the following categories:

	SD		A		SA
a) Recording messages	1	3	5	7	9
b) Transmitting messages	1	3	5	7	9
c) Overriding messages	1	3	5	7	9
e) Travel time data presentation	1	3	5	7	9
f) Interactive change of lane status	1	3	5	7	9

13. The following traffic data from the RTMS sensors appear reasonable.

a) Volume	1	3	5	7	9
b) Speed	1	3	5	7	9
c) Occupancy	1	3	5	7	9

EQUIPMENT

14. The camera delivers clear images in good weather conditions.	1	3	5’	7	9
15. Camera deliver clear images during inclement weather conditions.	1	3	5	7	9
16. The surveillance camera functions during inclement weather.	1	3	5	7	9
17. Zooming capabilities of the camera is sufficient.	1	3	5	7	9

ADDITIONAL COMMENTS

Figure 9b. ABR System Operator Survey (Cont’d)

In summary, these results show us that the operators liked the idea of the ABR system and are satisfied with the overall performance of the system.

5.4 Conclusions

The main purpose of the ABR project which is to reduce NJ Transit bus travel times through the use of diversion messages could not be clearly demonstrated by the Phase I operational field test. The reasons for that are the following:

1. The length of the diversion route is too short and traffic conditions are generally very similar on both routes. Thus, given the ABR project location and test network characteristics, travel time differences between GSP and US Route 9 are too small to obtain substantial benefits by diverting buses from GSP to US Route 9.
2. The minimum requirement for travel time savings by diverting buses (four minutes) cannot be satisfied even during morning rush hours, based on the data collected during the official testing period. This was mainly due to the reasons mentioned in (1).
3. Due to the small and insignificant number of diversion messages, the system's efficiency and accuracy could not be determined conclusively. However, given the small number of diversion messages, the system did not show a high degree of accuracy in the computation of estimated travel time differences as discussed in the previous sections of this report.

The customers perceptions about the system were also very diverse, as the survey results show. Therefore, the main customers of the system namely, bus drivers and system operators did not show a high degree of confidence in the integrated system's experienced performance.

CHAPTER 6
Recommendations and Lessons Learned

6.1 Recommendations

6.1.1 Identification of Congested Locations on the ABR System

During a.m. travel time data collection, the following locations on GSP and US Route 9 are affected during the rush hour.

- Before Raritan Toll Plaza
- Before Driscoll Bridge
- Before Interchange -11 tollbooth.

Until the diversion point, buses traveling on GSP and US Route 9 share the same lanes and therefore, this segment does not affect the difference in travel times. The stretch between the diversion point at New Brunswick Avenue and King George's Post Road was observed to be always free of congestion, causing no difference in travel times for the two routes until King George's Post Road. The segment after interchange 11 is also free of congestion. It was observed during data collection, that the major contributor to the bus travel time differences is the queuing effect at the Interchange 11 Toll Plaza (Figure 1). Thus, the lack of different congested sections along each route explains of differences between the travel times of the two routes. However, the travel time predictions can be improved by identifying and monitoring more closely the congested locations on the network.

6.1.2 Delay in Tag Data Transmission and Use by the Routing System

Tag data is used by the system after a bus has completed a run. The diversion decisions are made based on this completed run, using basically the system conditions that existed 5 to 10 minutes before the bus entered the system. Therefore, when the next bus gets a route diversion message, this trip time information may not reflect the 'actual' real-time system conditions. This problem can be remedied by modifying the ABR system in such a way that it can receive bus travel times at intermediate locations and not just at the end of the tip.

6.2 Lessons Learned

1 Network and traffic conditions play an important role for the successful testing and evaluation of any ITS technology. Therefore, site selection for any operational field test is of great importance. Given the traffic and network conditions of the ABR system, it was found that the probability of a diversion was very low (Table 26). This could be easily determined if a simulation of the study had been performed prior the initiation of the actual field study.

2. Hardware and equipment problems are almost always site specific. The accuracy of sensors depends heavily on the appropriate installation and maintenance of the equipment. For example, RTMS sensors that are widely used at other places had several problems discussed in this report, mainly due to installation and site specific problems

Table 26. Summary of Travel Time Differences on GSP and US Route 9

Test	Mean Travel Time [sec] at GSP	Mean Travel Time [sec] at us 9	Probability that difference is greater than 4 minutes	Probability that difference is lesser than 4 minutes
Rutgers test vehicles	505	516	< 0.000 17	< 0.00017
System estimated travel time	382	337	0.048	0.0183

3. An important lesson that was learnt was the fact that hardware was the source of the major bottlenecks in this project. Due to the equipment and possibly some algorithmic estimation problems, for the testing days, travel time estimations of the ABR system were different than the ground truth travel times collected by the evaluation team. This type of equipment problems can seriously reduce the effectiveness of a real-time system. Operating conditions also play an important role in the successful implementation of even proven technologies such as annunciators used in this project. Messages were clear when tested by the test vehicles. However, 63% of the operators did not find the diversion message clear, while 47% of the operators thought the sound quality could be improved by increasing the volume. 68% of the drivers replayed the diversion message.
4. System users are found to be open to new ITS technologies. However, the actual performance of the system plays an important role in ensuring the acceptance of the system by its users in the long term. These conclusions are supported by some of the following results obtained from user surveys:
    - 67% of the drivers were optimistic that the ABR system would improve travel time, while 47% believed that the alternate route provides an advantage after the diversion instruction.
    - 80% of the drivers thought the diversion message was accurate.
    - 60% of the bus drivers agreed that the ABR system saves travel time.

Another important point is the need for involving the system users before and during the implementation of any new ITS system and make sure that the system effectively responds to the needs of the actual users.

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