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TRANSMIT SYSTEM EVALUATION

FINAL REPORT

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TRANSMIT SYSTEM EVALUATION REPORT

EXECUTIVE SUMMARY

Introduction

This report presents the evaluation results of TRANSCOM's System for Managing Incidents and Traffic (TRANSMIT). The TRANSMIT system utilizes Electronic Toll and Traffic Management (ETTM) equipment, which is compatible with the E-Z Pass system, for its traffic surveillance and incident detection purposes. The first goal of this evaluation was to assess the performance of the TRANSMIT system. The second goal was the assessment of its costs, benefits and institutional issues. The evaluation data collection period lasted for four months, from January to April 1996 with a supplementary data collection period for the communication system in September and October 1996. The evaluation was based on the evaluation plan [1], which was developed by the independent evaluator in consultation with the evaluation team and the national guidelines [2].

Evaluation Team

The **Institute for Transportation** at the New Jersey Institute of Technology (NJIT) was designated as **the independent evaluator** by the evaluation team. The NJIT team prepared the evaluation test plan and conducted the evaluation in collaboration with the evaluation team consisting of the following members:

- **TRANSCOM;** assisted NJIT during the evaluation, collected and transferred relevant data to the NJIT team, overviewed the evaluation and reviewed reports of the evaluation,

- **PB Farradyne Inc.;** overviewed the evaluation and provided assistance when needed to TRANSCOM/ NJIT,

- **FHWA;** overviewed the evaluation, reviewed reports of the evaluation and provided guidance from a national evaluation point of view,

- **Booz • Allen & Hamilton, Inc.;** overviewed the evaluation, reviewed reports of the evaluation and provided guidance from a national evaluation point of view,

- **New Jersey Highway Authority (NJHA);** overviewed the evaluation, reviewed reports of the evaluation, and provided relevant data to **NJIT,**

- **New York State Thruway Authority (NYSTA);** overviewed the evaluation, reviewed reports of the evaluation, and provided relevant data to **NJIT,**

- **New Jersey Department of Transportation (NJDOT);** overviewed the evaluation and reviewed reports of the evaluation.

TRANSMIT System Description

TRANSMIT is a multi-jurisdictional system exemplifying coordination and cooperation among the member agencies of TRANSCOM [3, 4, 5, 7]. The Transportation Operations Coordinating Committee (TRANSCOM) was formed in 1986 and now comprises 15 highway and transit safety agencies to coordinate transportation management efforts within the New York/New Jersey/Connecticut metropolitan area. The participant members in the TRANSMIT project include:

* TRANSCOM
* Port Authority of New York and New Jersey (PA)
* New Jersey Department of Transportation (NJDOT)
* New York State Department of Transportation (NYSDOT)
* New York City Department of Transportation (NYCDOT)
* New Jersey Turnpike Authority (NJTA)
* New Jersey Highway Authority (NJHA)
* Federal Highway Administration (FHWA)

The TRANSMIT system utilizes Electronic Toll and Traffic Management (ETTM) equipment, compatible with the E-ZPass system, for its traffic surveillance and incident detection purposes. The E-ZPass system is an electronic toll collection system, currently in operation along the New York State Thruway (NYST) as well as at other facilities in the NY/NJ/CT metropolitan area. The TRANSMIT system has been installed on the 21 mile route, stretching out north from the Hillsdale Toll Plaza on the Garden State Parkway (GSP) to the NYST. Along the NYST, it extends west from the Tarrytown Toll Plaza (Tappan Zee Bridge) to the Spring Valley Toll Plaza. On this route tag readers specific to the TRANSMIT system are installed at intervals of 0.5 to 2.1 miles.

Each time an E-ZPass tag equipped vehicle enters the capture zone of a Roadside Terminal (RST) location, its tag identification number (tag ID) and the detection time are recorded. Data containing tag ID, detection time, location and lane position is forwarded to the Operations Information Center (OIC) at Jersey City, NJ. Then, the tag ID is encoded at the OIC into a random number to ensure the anonymity of the motorist. Such surveillance data is acquired at 22 RST locations continuously on a 24-hour basis. The vehicle travel times between successive readers are then determined from the stored data at the OIC. The incident detection algorithm is based on statistical comparison of measured real-time travel times with continuously updated historical travel times for the same time period of the day (H-minute time intervals) and type of day (weekday, Saturday, Sunday, or holiday) . When the number of vehicles arriving late at a downstream reader of a specific link within the system reaches a predetermined level, an alarm is triggered to indicate the occurrence of a possible incident.

Once an incident alarm is triggered, TRANSCOM operators notify the corresponding agency or the state/local police. Based on communication with the agency or the state/local police. the operators either confirm the alarm as true or they classify it as false. If the alarm is confirmed as a true incident then they notify the other TRANSCOM member agencies that may be affected by the incident.

Evaluation of the Communication System

The evaluation of the TRANSMIT communication system was conducted to assess it's data transmission capability and reliability in detecting tag equipped vehicles. This assessment is quantified in terms of:

- **Transmission Rate:** the ratio of the tag ID data retrieved at the OIC to the corresponding tag ID data recorded at the Roadside Terminal (RST), per time interval.
- **Detection Rate:** the ratio of the number of readings recorded at the RST to the number of known tag equipped vehicles crossing the capture zone, per time interval.

The transmission rates for all RST locations, except one, were found to be near perfect, ranging from 98.8% to 100%, regardless of the observed hourly read rates. A site-specific anomaly of the transmission rate of 88% was observed at location 27 on the Tappan Zee Bridge. At this site (location 27) the hourly transmission rate variations ranged from 66% to 96%, and were mainly attributed to the presence of the only radio link in the system.

The current transmission capacity of the TRANSMIT system is capable to handle the maximum possible traffic flow conditions without any constraints. The maximum volume that can be observed in the TRANSMIT system is 16,100 vehicles per hour at Tappan Zee bridge, which can easily be handled by the modems being utilized currently.

The detection rate performance was tested through a limited five-day four-vehicle probe test. The majority of the RSTs exhibited detection rates near 100%. Only a few locations exhibited lower detection rates ranging from 28% to 61%. **It is concluded that lower detection rates are not problematic to the entire system but specific to a few individual locations.** Due to site specific lower detection rates, it is recommended that the antenna orientations at these locations should be further studied.

During the four-month evaluation period, six locations exhibited 20 or more hardware and software problems, including location 27 (radio link). It is noted that the evaluation took place during the transition period when TRANSMIT hardware and software switched from AMTECH to MARK IV, however the RST failures have since been rectified. A follow up study would be helpful to determine the present status of the TRANSMIT system's hardware and software.

Recommendations

- It is recommended to establish a periodic monitoring of individual RSTs as a part of the operation and maintenance of the system.

- A mechanism to detect and record the down times of the roadside terminals and the OIC should be implemented in order to improve the reliability of specific locations and of the entire system.

- Since the components of the communication system at location 27 on the Tappan Zee bridge are capable of providing 100% successful performance, an expanded study should be undertaken to identify the causes of the rather low detection and transmission rates observed.

Evaluation of Traffic Parameters

The TRANSMIT system currently provides estimates of the following traffic flow parameters:

- link mean travel time and variance,
- link space mean speed and variance.

The test of the accuracy of the link travel time estimates of the TRANSMIT system was based on a five day four probe vehicle test conducted in March 1996. The analysis of the collected data was carried out through a pairwise comparative test of the link travel time data collected by the vehicle probes and the corresponding TRANSMIT system data collected at the OIC. In addition, the probe link travel time data were compared to the TRANSMIT historical link travel time estimates.

The importance of the E-ZPass volumes lies in the minimum sample size required to determine reliable estimates of the link travel time in the TRANSMIT system for each 15-minute time period of the day. The E-ZPass market penetration rate at the Hillsdale toll plaza (GSP) varied from 1.59% to 16.50% and at Spring Valley and Tappan Zee Bridge toll plazas (NYST) varied from 5.29% to 73.84%, based on data provided by TRANSCOM for the week of November 17, 1996. In general, the GSP showed a much lower E-ZPass market penetration rate than NYST which is expected since only the NYST had installed the E-ZPass toll collection system. **Based on a comparison of the required sample size for a 95% confidence interval and a tolerance of 10% of the historical link mean travel time, 85.5% (2,111 out of 2,470 intervals) of the link travel time intervals exhibited adequate E-ZPass volumes.** The lack of adequate sample size for the remaining 14.5% time intervals will be considerably lessened as the E-ZPass market penetration rate increases with its implementation at additional facilities in the near future.

A comparison of the OIC and the corresponding probe vehicle link travel time data indicated that 92% of the link travel time data were within 3 seconds from each other. **The results of the pairwise t-test indicated that only 3 time intervals (which were associated with location 27), out of a total of 130 for all the links and time intervals failed the test. Therefore it may be concluded that the tag equipped vehicle link travel times are recorded properly at OIC.**

The TRANSMIT system belongs to the unique category of automatic vehicle location/ identification systems which **can provide direct estimates of the link travel time and link space mean speed.**

Recommendations

- It is recommended that a more comprehensive test be conducted with more probe vehicles that will provide a much larger sample size for each 15-minute period of the day, extended to include weekends and special holidays,

- A mechanism be implemented to establish the feasibility of providing estimates for the traffic volume based on the market penetration rate which can be continuously estimated in real time at each toll plaza,

- It is also recommended that the TRANSMIT system be identified as a national test bed for providing link travel time, link space mean speed, traffic volume, and origin-destination data.

Evaluation of the Incident Detection System

The evaluation of the TRANSMIT incident detection system is based on incident related data covering the time period extending from January . to April 30, 1996. This evaluation is based on a comparative analysis of incidents recorded by the TRANSMIT system versus incident record data recorded by New York State Thruway (NYST) and Garden State Parkway (GSP) personnel. These databases were reduced by excluding duplicate entries, to include true incidents, false alarms, and alarms that could not be classified either as true incidents or false alarms in the following databases:

- **TRANSMIT NYST Incident Database** - a total of 2552 records were reduced to 608,

- **TRANSMIT GSP Incident Database** - a total of 244 entries were reduced to 56,

- **NYST Incident Database -** The NYST daily logs, consisting of a total of 443 records, were reduced to 2 18 entries and furthermore were divided into two groups, minor (82 entries) and major (136 entries) incidents. Only the 136 major incidents were used in this study.

- **GSP Incident Database** - The GSP daily logs consisted of 18 incident records.

The incident detection performance of the TRANSMIT system is quantified in terms of:

Probability of Detecting Incidents

The probability of detecting an incident is the ratio of the incidents that were detected by the TRANSMIT system to the total number of incidents observed on each facility.

Based on the evaluation results, the TRANSMIT's incident detection algorithm performed very well along the NYST for the months of February to April 1996 with a range of 92% **to 95% detection rate** based on the best case scenario (non-classified alarms were treated as true incidents). Similarly, under the worst case scenario (non-classified alarms were treated as false alarms) its performance ranged from 91% **to** 95% during these months. Under both scenarios, January exhibited lower detection rates of 78% (best case) and 72% (worst case). It is noted that January was the first month that the MARK IV system was in operation, which may have contributed to the lower performance, as the system required fine tuning.

A similar analysis conducted for the GSP resulted in a probability of detection ranging from 67% to 79% per month and averaging 75% for the entire evaluation period, during which a total of 62 true incidents were recorded.

- **Probability of False Alarms and False Alarm Rates**

The probability of false alarms is the number of false alarms divided by the total number of alarms for the specified period of time. The false alarm rate is determined as the ratio of the number of false alarms to the number of cycle time intervals for the period of interest.

Following the analysis of the probability of incident detection, best and worst case scenarios were applied to study the false alarm rates and the probability of false alarms. Under the best case, all 67 non-classified alarms along the NYST were considered as true incidents yielding an average probability of false alarms of 10%, showing monthly variations between 6% and 14%. The corresponding false alarm rates varied between 0.0022% and 0.0080%. For the worst case scenario, if all 67 non-classified alarms were treated as false alarms, then the average probability of false alarms would have been increased to 22%, showing monthly variations between 17% and 33%. Similarly the corresponding false alarrn rates under the worst case scenario varied between 0.0111% and 0.0127%.

The corresponding false alarm rates for the GSP for the best and worst case scenarios were found to be between 0.0% and 0.0012%, and 0.0004% and 0.0034%, respectively. The probability of false alarms ranged from 0.0% to 50.0%, with an average of 16.0% for the best case scenario and from 5% to 67% for the worst case scenario.

A high percentage of false alarms was observed during the morning off-peak period (30%) from 9:00 to 11:00 AM and the evening off-peak period (22%) from 18:30 PM to 6:30 AM. These are rather high values and efforts should be undertaken to reduce the false alarm rate to a minimum during these time periods.

The TRAMSIT system compares very favorably among incident detection algorithms reported in the literature. The detection rates reported in the literature varied between 67% to 100% and TRANSMIT reported a detection rate of 72% to 95% on the NYST and 67% to 79% on the GSP. The TRANSMIT false alarm rates were found to be better than the best reported rate of 0.043% for an algorithm which is based on the catastrophe theory utilizing loop detector technology.

Recommendations

- The mean time to detect an incident could not be estimated for the TRANSMIT system due to the unavailability of the accurate time of occurrence of an incident from either the NYST or the GSP incident records. This is an important parameter in any incident detection algorithm and should be incorporated in a future more comprehensive evaluation,

- It is further recommended that the incident recording procedure be modified to include a more detailed and accurate description of incidents.

Evaluation of Costs, Benefits and Institutional Issues

The costs, benefits and institutional issues evaluation of the TRANSMIT system focused on:

- **The TRANSMIT system costs** for the capital field hardware and software per Road Site Terminal (RST), central equipment at the Operations Information Center (OIC), installation, maintenance and operation,
- **Comparison of the TRANSMIT system to** Inductive Loop Detection System (ILDS), Video Image Detection System (VIDS) and Microwave Radar Detection System (MRDS) for a typical six-lane freeway detection site,
- **The TRANSMIT system benefits** in terms of traffic management, traveler information and transportation planning,
- **The TRANSMIT system related institutional issues** between the involved agencies, the private sector and the general public.

Comparative Costs of Traffic Surveillance Systems

The cost comparison of a typical detection site on a six-lane highway of the TRANSMIT system to ILDS, VIDS and MRDS systems is summarized below in Table I.

Table I. Comparative Costs per Detection Site (Six-Lane Highway)

Description	TRANSMIT	ILDS	VIDS	MRDS
Capital Cost:				
• Hardware Costs	$14,700	$4,100	$24,500	$26,500
• Installation Costs	$21,700	$50,560	$45,100	$25,200
Total Capital Cost	$35,400	$54,660	$69,600	$51,700
Maintenance Costs/Year	$2,900	$7,950	$3,300	$2,900
Operations Costs/Year	$2,040	$2,040	$2,040	$2,040
Total Annual Cost	$4,940	$9,950	$5,340	$4,940
Total Cost for One Year	**$41,340**	$64,650	$74,940	$56,640

The cost for a TRANSMIT system RST site represents 64%, 55%, and 73% of the corresponding detection site costs for ILDS, VIDS and MRDS systems, respectively.

TRANSMIT System Benefits

The current and potential benefits of the TRANSMIT system offer unique opportunities in traffic management, and traveler information systems and provide the basis for more accurate transportation planning studies. Furthermore, the TRANSMIT system could be used for transit and fleet management purposes. The benefits of the currently implemented TRANSMIT system are:

- **Automated incident detection,**
- **Traffic flow parameter estimation (link travel time and space mean speed).**

The potential benefits of the TRANSMIT system that may be obtained without any substantial hardware/software modifications and costs, include the estimation of the following traffic flow characteristics:

- **Vehicle position estimation and tracking,**
- **Path travel time estimation,**
- **Origin - Destination (O-D) matrix direct estimation,**
- **Traffic volume estimation.**

The principal advantage of TRANSMIT lies in its ability to identify vehicles at successive reader locations. This capability provides the basis for the TRANSMIT system to determine real time estimates of the space mean speed, link and path travel time.

In order to operate the TRANSMIT system successfully, it is required that a sufficient number of probe vehicles be detected at the individual RSTs within the corresponding time interval of **the** day. **As more and more of the toll facilities of the metropolitan area are equipped with the E-ZPass system, the benefits of the TRANSMIT system will increase. The TRANSMIT system will be able to utilize the largest pool of probe vehicles in the country.**

Institutional Issues Associated With the TRANSMIT System

The TRANSMIT system is an example of multi-jurisdictional cooperation between different public agencies and the private sector. An alternative contracting approach utilizing a consultant for handling multi-jurisdictional projects has been developed where the member agencies have control over the review of the bid packages and the contractor selection procedure. The consultant resolves technical incompatibilities between the systems of the different agencies in a unified way that results in a simpler system. **This approach provided the flexibility to resolve administrative and technical difficulties between the agencies and to reduce the system implementation time.**

The privacy of the identity of the vehicles equipped with the E-ZPass tags was set as a requirement by TRANSCOM and the member agencies prior to the implementation of the project. The vehicle ID is encoded immediately upon reception at the OIC. This policy avoided any potential negative public reactions towards the system and lead to a smooth implementation of the TRANSMIT system.

Recommendations

- The TRANSMIT system has the potential to provide extensive data for traveler information systems. Its current capabilities in terms of real time link and path travel time estimates should be exploited.

- An effort should be made to use the TRANSMIT system data to provide estimates for the incident duration and to predict its effects on the roadway as well as adjacent roadways.

- The rapid high volume data acquisition capability of the TRANSMIT system can enhance research in advanced traffic flow theory. It could provide an unmatched opportunity to verify various proposed models with real time traffic flow data.

- The TRANSMIT system should become a case study for multi-jurisdictional type of projects. Various metropolitan areas in the US could benefit from the experiences gained through the implementation of the TRANSMIT system.

- TRANSMIT has been primarily sponsored with federal resources. Various innovative alternative-funding mechanisms should be sought for establishing public/private partnerships for future expansion and operation. For example, many of TRANSCOM's member agencies are contributing their own local and federal funds to finance the expansion of the TRANSMIT system.

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1 INTRODUCTION

This report presents the evaluation results of TRANSCOM's System for Managing Incidents and Traffic (TRANSMIT). The TRANSMIT system utilizes Electronic Toll and Traffic Management (ETTM) equipment, which is compatible with the E-Z Pass system, for its traffic surveillance and incident detection purposes. The first goal of this evaluation was to assess the performance of the TRANSMIT system. The second goal was the assessment of its costs, benefits and institutional issues. The evaluation data collection period lasted four months, from January to April 1996 with a supplementary data collection period for the communication system in September and October 1996. The evaluation goals and objectives are outlined in the next section [see also 1 and 2], which is followed by a section describing the members of the evaluation team and their responsibilities, the section on reporting and archiving procedures and the chapter concludes with an outline of the evaluation report.

1.1 TRANSMIT System Evaluation Goals and Objectives

Goa1 1: Evaluate the TRANSMIT system performance.

Objective: Assessment of the data transmission speed, capacity, and reliability of the communications system

Measures of Effectiveness: Data transmission capacity between the roadside terminals and the OIC.

Objective: Assessment of the accuracy of the estimate of average travel time, space mean speed and time mean speed based on the data processing algorithms at the Operations Information Center (OIC).

Measures of Effectiveness: Estimate of the average travel time, space mean speed and time mean speed, per link, per time interval of the day, and day of the week; mean time difference between probe vehicles and TRANSMIT system data per link and time period of the day.

Objective: Assessment of the accuracy of the TRANSMIT system incident detection algorithm.

Measures of Effectiveness: Proportion of false alarms and true incidents.

Goal 2: Evaluate the cost effectiveness, benefits and institutional issues of the TRANSMIT system.

Objective 1: Assessment of the cost of the operational test (capital, operational and maintenance) against the cost of traditional incident detection systems (loop detectors, police patrols, and service patrols).

Measures of Suitability: Costs associated with vehicles, roadside equipment/mile, data links (e.g. telephone line for modems, radio, etc.), OIC equipment, personnel, installation, operation, and maintenance.

Objective 2: Assessment of the benefits of TRANSMIT in terms of traffic management, traveler information, and transportation planning.

Measures of Suitability: Value of the TRANSMIT system to participating agencies based on the following parameters: travel route of the vehicle, origin and destination data, link travel time estimates, link space mean speed estimates, traffic flow rate estimates, and incident detection capability.

Objective 3: Assessment of the institutional issues related to the implementation and operation of the TRANSMIT system

Measures of Suitability: Contracting mechanism for the implementation of the TRANSMIT system; agency coordination; agency cooperation in the TRANSMIT system's operation and maintenance.

1.2 Evaluation Team

The evaluation team consisted of the following members:

New Jersey Institute of Technology (NJIT): Independent Evaluator.

Transportation Operations Coordinating Committee (TRANSCOM): TRANSMIT operating organization.

Federal Highway Administration (FHWA): Sponsoring agency of the evaluation.

Booz ·Allen & Hamilton Inc.: Under contract from FHWA to overview the evaluation.

PB Farradyne, Inc.: Consulting company to TRANSCOM.

New Jersey Department of Transportation (NJDOT): Member of the evaluation team.

New Jersey Highway Authority (NJHA): TRANSMIT is partially implemented on the Garden State Parkway (GSP), which is under the authority of NJHA.

New York State Thruway Authority (NYSTA): TRANSMIT is partially implemented on New York State Thruway (NYST), which is under the authority of NYSTA.

The responsibilities of each member of the evaluation team in carrying out the evaluation were:

NJIT – Independent Evaluator

- Planned and executed the evaluation, in coordination with TRANSCOM,
- Maintained all pertinent hardware and software,
- Collected , reduced and analyzed data,
- Prepared the evaluation report.

TRANSCOM

- Retrieved the TRANSMIT system data,
- Transferred data pertinent to the evaluation to the NJIT team,
- Assisted the NJIT team in the data collection phase of the evaluation,
- Overviewed the evaluation and reviewed the reports.

PB Farradyne, Inc.

- Provided assistance when needed to the NJIT team,
- Provided costs of various traffic surveillance systems to the NJIT team,
- Overviewed the evaluation and reviewed the reports.

FHWA and Booz ·Allen & Hamilton Inc.

- Provided the USDOT national evaluation guidelines,
- Overviewed the evaluation and reviewed the reports.

NJDOT

- Overviewed the evaluation and reviewed the reports.

NJHA and NYSTA

- Compiled pertinent data related to the evaluation and submitted them to TRANSCOM,
- Overviewed the evaluation and reviewed the reports.

1.3 Reporting and Archiving Procedures

Report Format

All report documentation was created using MS Word v. 7.0.

Data Format/Volume

The data format was in MS Access® v.2.0 and MS Excel® v.7.0 whereas the raw data are in ASCII Text. The total volume of the collected data is 700 MB. One 24-hour period of OIC data was roughly 9 MB whereas roadside terminal data varied between 1 to 4 MB depending on the respective tag volume at that particular location.

Hardware

The hardware used in this evaluation included:

- Three (3) PC laptop computers, 16 MB RAM and 640 KB hard disk,
- (1) Desktop PC, 4.5 GB hard disk,
- HP 9000 series 735 workstation equipped with a DAT drive,
- Ten (10) data storage tapes (DAT tapes),
- One (1) external tape drive (DAT drive)

Software

- MS Access® v.2.0, Database software,
- MS Excel® v.7.0, Spreadsheet and statistical analysis software,
- Microsoft Word 7.0.

Equipment Maintenance Procedures/Schedule

Preliminary checks were carried out daily to assure that the necessary cable connections and computers were fully functional for the testing. All clocks were synchronized prior to the vehicle probe test.

Procedures for Periodic Status Reports to Evaluation Team/FHWA

The evaluator provided weekly status reports to TRANSCOM. NJIT also informed TRANSCOM of the start and completion time and date of each test. The evaluator provided periodic status reports to Booz-Allen & Hamilton, either through e-mail or through telephone. The evaluator provided interim evaluation reports for each test to all members of the evaluation team.

1.4 Evaluation Report Outline

This report consists of an executive summary, introduction, a description of the TRANSMIT system, and the evaluation results based on the performance of

- The TRANSMIT communication system,
- The TRANSMIT incident detection system,
- The TRANSMIT system's traffic parameters estimation,
- The TRANSMIT system's costs, benefits and institutional issues.

2 TRANSMIT SYSTEM DESCRIPTION

The TRANSMIT system utilizes Electronic Toll and Traffic Management (ETTM) equipment, which is compatible with the E-Z Pass system, for its traffic surveillance and incident detection purposes. E-ZPass is an electronic toll collection system, currently in operation along the New York State Thruway (NYST) as well as at other facilities in the NY/NJ/CT metropolitan area, serving over 1.5 million vehicles equipped with RF tags. The number of vehicles equipped with electronic tags is expected to rise significantly in the metropolitan area over the next few years as more facilities are expected to install the E-ZPass system. The TRANSMIT system has been installed at the roadways shown in Figure 1, stretching out north from the Hillsdale Toll Plaza on the GSP to the NYST. Along the NYST, it extends west from the Tarrytown Toll Plaza (Tappan Zee Bridge) to the Spring Valley Toll Plaza. On these routes, tag readers specific to the TRANSMIT system are installed at intervals of 0.5 to 2.1 miles, as shown schematically in Figure 2. Figure 3 shows a conceptual diagram of the TRANSMIT system operation.

Each time an E-ZPass tag equipped vehicle passes a RoadSide Terminal (RST) location, the reader antenna radiates a signal to interrogate the RF tag in the vehicle. The vehicle equipped with an RF tag responds by sending its tag identification number (tag ID). At this RST, the recorded data containing tag ID, detection time, location and lane position is then forwarded to the Operations Information Center (OIC) at Jersey City, NJ. The tag ID is encoded immediately at the OIC into a random number to ensure the anonymity of the motorist. Such surveillance data is acquired continuously on a 24-hour basis at 22 RST locations as listed in Table 1. The vehicle travel times between successive readers are then determined from the stored data at the OIC. The incident detection algorithm is based on statistical comparison of real time estimated travel times with continuously updated historical travel times for the same time period of the day and type of day (weekday, Saturday, Sunday, or holiday). When the algorithm detects multiple successive vehicles arriving late at a downstream reader of a specific link of the system, an alarm is triggered to indicate the occurrence of a possible incident. Related description on the various components of the TRANSMIT system can be found in [3, 4 and 5].

2.1 TRANSMIT Communication System

A schematic diagram for the TRANSMIT communication system is shown in Figure 4. The major function of the communication system is to transmit data collected from RF tag equipped vehicles at the RSTs to the OIC.

The major components of this system are:

- RF tags (transponder) placed in a vehicle,

- Roadcheck™ [A] Basic Reader System (at the RST),
- Leased telephone lines,
- Radio link across the Tappan Zee Bridge,
- Multiplexers specific to certain sites,
- OIC computer and related peripherals.

RF Tag

The RF tag is a vehicle's electronic identification device. Physically it consists of an antenna and electronic circuitry designed to carry out the transaction for paying tolls. The RF tag specific to the TRANSMIT applications is used only for identification purposes. The recorded ID is converted immediately into a random number at the OIC to ensure anonymity of the motorist, and stored temporarily for further processing.

RSTs radiate interrogation pulses continuously to "wake up" the RF tags mounted in the vehicles. As a RF tag equipped vehicle approaches the capture zone of the RST, it responds back to the interrogation pulse by transmitting specific data to the RST including its identification data, ID. The RF tag transmits data at 500 kbps in the 915 MHz band.

The RF tag is a half-duplex device using the same frequency and modulation scheme for both up and down links. Its receiver is a simple AM detector while its transmitter is a single stage, on/off unit. The RF tag is a semi-active device and uses a lithium battery as a source of power giving the tag a minimum life of 10 years. It is enclosed in a molded, high-impact plastic package.

- Number of data bits: 256
- Data format: Manchester keyed carrier
- Error checking: 16 bit Cyclic Redundancy Check (CRC)
- Data rate: 500 kbps±10% per second
- Data frequency: 915 MHz
- Trigger frequency: 902-928 MHz
- Peak radiated power: 1 mW
- Operating temperature: -40 °F to +167 °F (-40 °C to +75 °C)
- Dimensions: 3.5" x 3" x 0.5" (approximately 89mm x 76mm x21mm)
- Weight: approximately 3 oz (85 gm)
- Service life: 10 years minimum (no external power required)
- Internal battery: Lithium

[A] Roadcheck™ reader is a trademark of the MARK IV Industries, Inc.

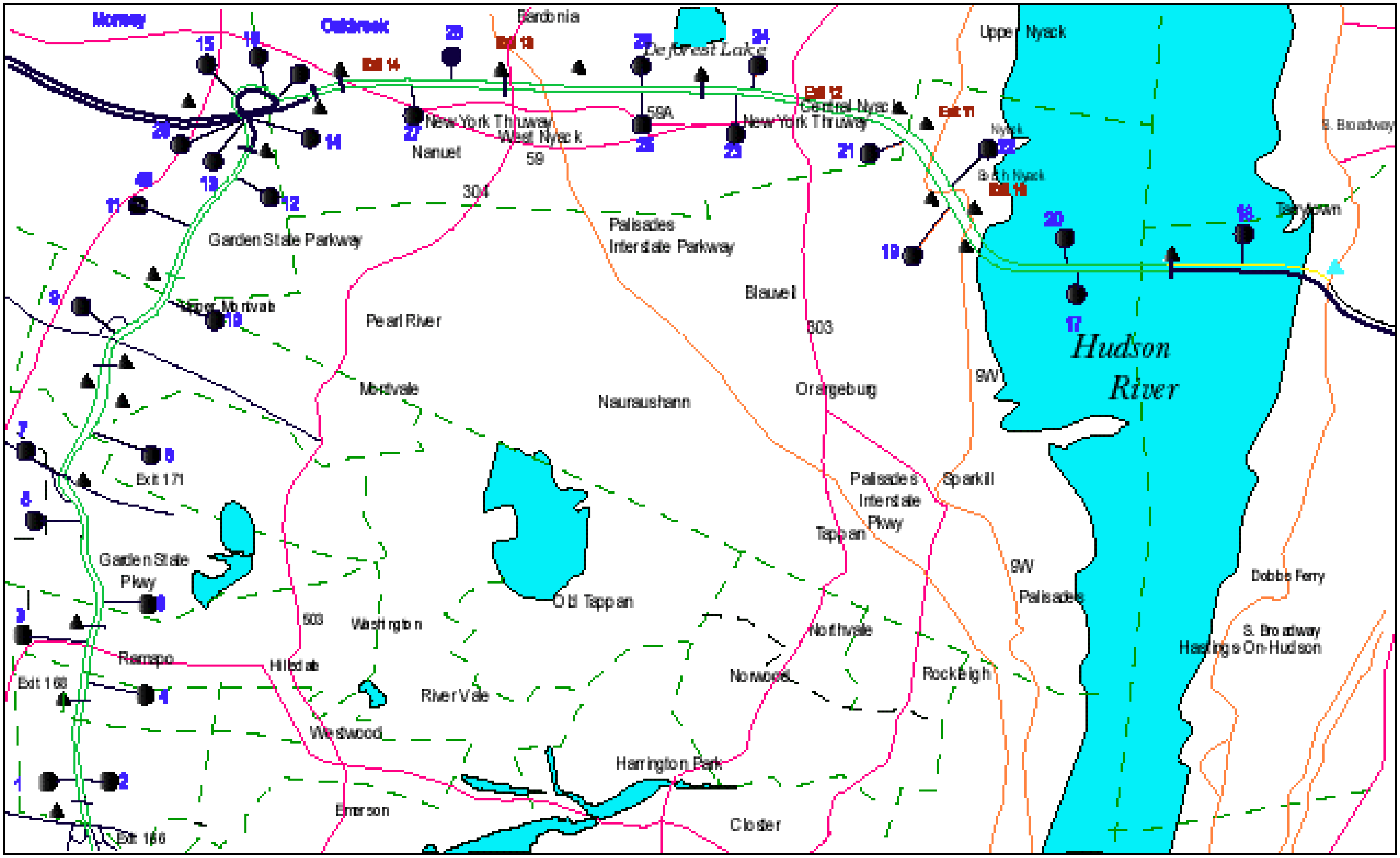

Figure { SEQ Figure * ARABIC }. Geographical Map of the TRANSMIT System

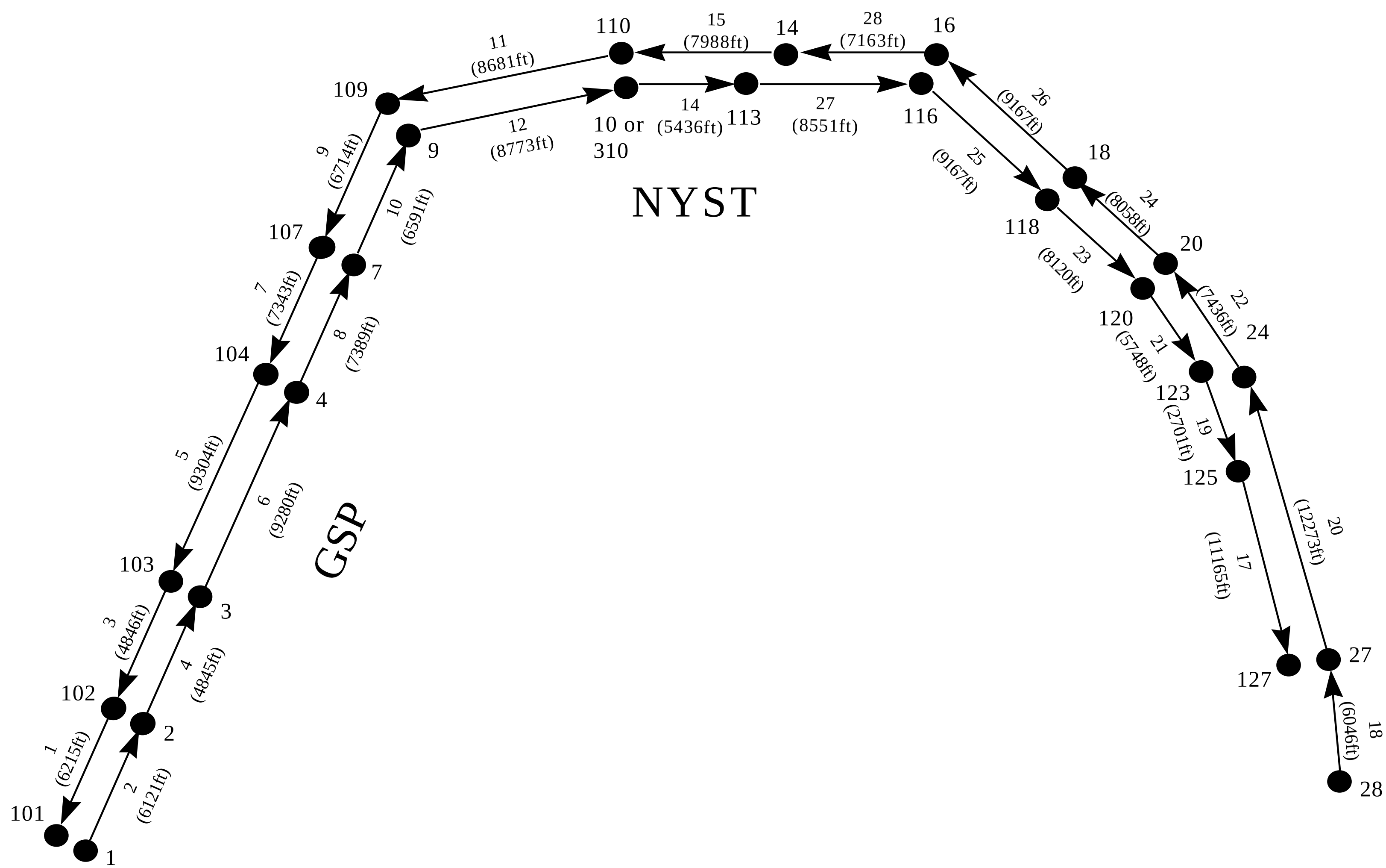

Figure **{** SEQ Figure * ARABIC **}**. TRANSMIT System Links and RST Locations at the GSP and the NYST

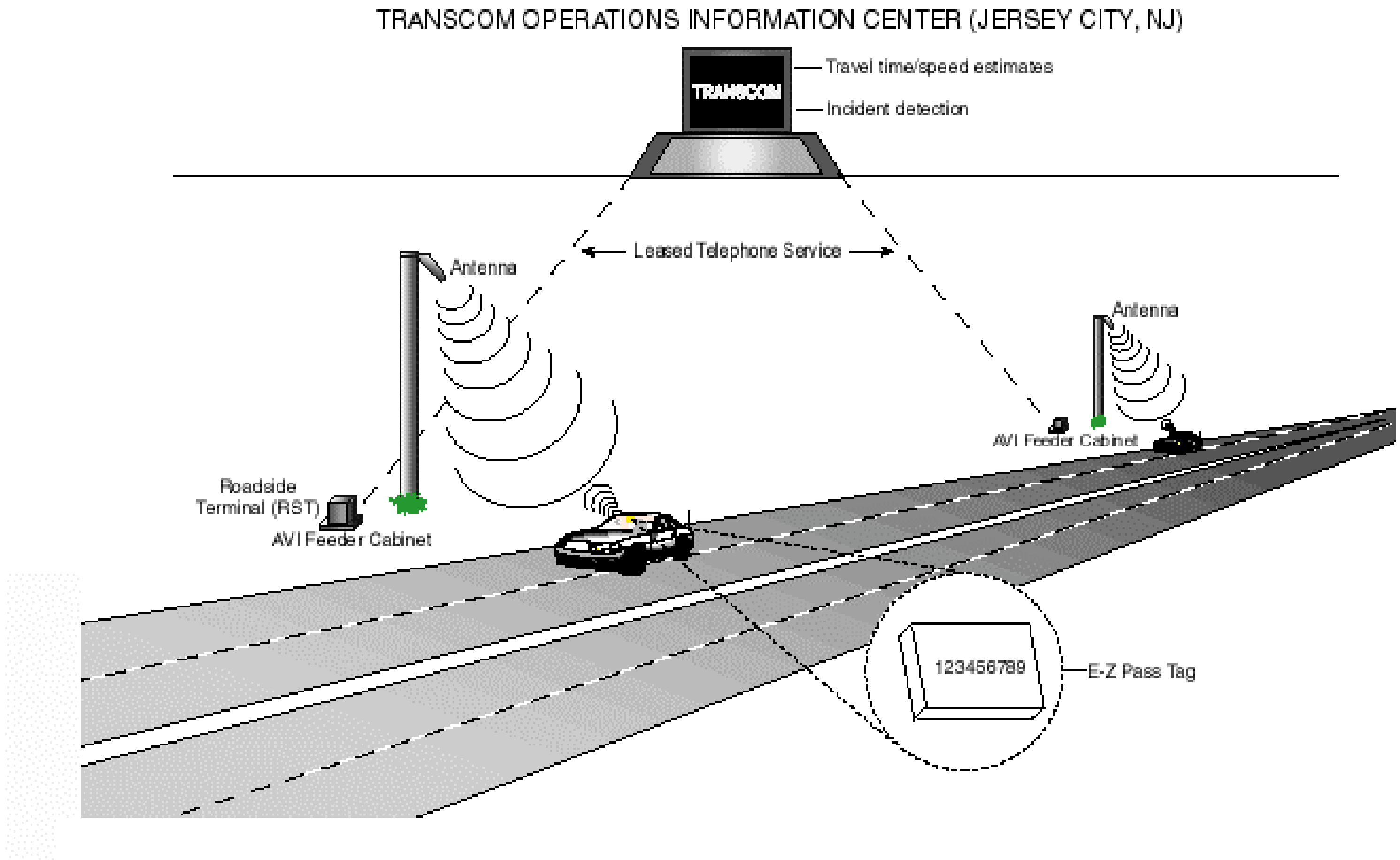

Figure 3. TRANSMIT System Conceptual Operation

Table 1 . Description of Roadside Terminals and Antenna Locations

LOCATION	DESCRIPTION	PHYSICAL LOCATION of ANTENNA	Reg/ SF	SL/ ML	DIRECTION BEING READ
1	Hillsdale Plaza	Under pass	Reg	ML	NB/SB
2	Washington Ave.	Under pass	Reg	ML	NB/SB
3	MP 168.4	Under pass	Reg	ML	NB/SB
4	MP 170.1	Metal post	SF	ML	NB/SB
5	Food/ service station entrance	Under sign	Reg	SL	NB exit
6	Food/ service station entrance	Under sign	Reg	SL	SB exit
7	MP 171.5, North of Exit #172	Metal post	SF	ML	NB/SB
8	**Eliminated**				
9	MP GS2	Metal post; headend location	SF	ML	NB/SB
10	MP GSP 04 Pkwy/Thruway split	Under pass	Reg	ML	NB/SB
11	"Pay Toll" sign; MP 24	Under sign	Reg	ML	NB/SB
12	**Eliminated**				
13	Exit #14, "Rte 59, Spring Valley Nanuet"; MP 22.8	Under sign	Reg	ML	SB
14	Exit #14, "Rte 59, Spring Valley Nanuet"; MP 22.5	Under sign & off ramp	Reg	ML	NB main line & Off ramp
15	**Eliminated**				
16	Exit #13S; Exit #13N; MP 21.3	Under pass & Under sign & Off-ramp	Reg	SL	NB/SB
17	Exit #13N	Under sign	Reg	SL	NB exit reader
18	ConRail Bridge; MP 19.5	Under pass	Reg	ML	NB/SB
19	**Eliminated**				
20	Unlabeled under pass; MP 17.9	Under pass	Reg	ML	NB/SB
21	Exit "9W"	Under sign	Reg	SL	NB exit reader
22	**Eliminated**				
23	"Tappan Zee Bridge" sign; MP 16.9;	Under sign	Reg	ML	SB
24	Exit #10, "9W Nyack, So. Nyack"; MP 16.4;	Under sign	Reg	ML	NB
25	VMS before bridge	Under VMS	Reg	ML	SB
26	**Eliminated**				
27	On Tappan Zee Bridge	Second cross member from west	Reg	SL/ ML	NB/SB
28	VMS before bridge	Under VMS	Reg	ML	NB

Reg- Regular Antenna SL- Single Lane Read MP- Milepost
SF- Side Fire Antenna ML- Multi - Lane Read VMS - Variable Message Sign

Roadcheck ä Basic Reader System

Installed at the RST, the *Roadcheckä Basic Reader* is an autonomous stationary unit linked through a telephone line to a computer at the OIC. The reader system consists of:

- Antenna(s),
- CPU board,
- RF Control board,
- Communication Boards,
- Power Module.

An optional slave unit can be added to activate the system in case of a failure of the master unit. The interrogation RF pulses generated within the reader are radiated by the roadside antenna(s), which may control single/multiple lanes. Two types of antennas are used in the TRANSMIT system: single lane and multi-lane. Either antenna can be mounted in two configurations: regular and side-fire positions. In the regular position, an antenna is located directly above the roadway aimed down on the traffic, while in the side-fire position an antenna is mounted on a pole on the roadside aimed at a side angle on the traffic (hence, the term "side-fire"). Both kinds of antennas are being used for both main line and exit readers. Multi-lane detection is designed to permit some overlap in a capture zone from an adjacent antenna whereas single lane detection is aimed at a single lane. If the antenna is located more than 200 ft from the reader, a cable with less attenuation (low-loss cable) may be required for proper operation. If complete coverage can be provided by the antennas of a single reader, synchronization of RF pulses is not required. Synchronization is achieved by 20-μsec trigger pulses separated by 800-μsec time intervals. Upon receiving a wake-up interrogation pulse (915 MHz AM pulses are generated every 6 μsec by the RF unit), produced by the RST, the RF tag in an incoming vehicle responds. The tag response, after being detected by the antenna, is down converted at the RF unit and a resulting data stream is transferred to the CPU unit for further processing. The CPU unit can store up to 1000 transactions in its battery-backed RAM of 256 Kb. The main processor in the CPU unit is 80C186 MPU. This CPU board also has a diagnostic port which allows the system operator to view or modify the system configuration using a laptop computer equipped with communication software and a null-modem cable. The diagnostic port operates at 9.6 kbps. The outcome of the transaction results in the data generated by the CPU, which is forwarded to the communication boards. These boards are connected directly to the OIC computer through the telephone lines. Their serial I/O interfaces can operate up to 19.2 kbps but currently this data rate is set to 9.6 kbps.

As long as the tag equipped vehicle remains in the capture zone of the RST, the tag information is being received repeatedly by the reader system. However, the CPU of the reader eliminates multiple readings and re-transmits data pertaining to the tag only once to the OIC. There is only a three-tag buffer in the CPU unit. The data message due to a detected vehicle has a length of 96 bits with an additional ±4 guard bits to avoid possible overlapping with the message of the following vehicle.

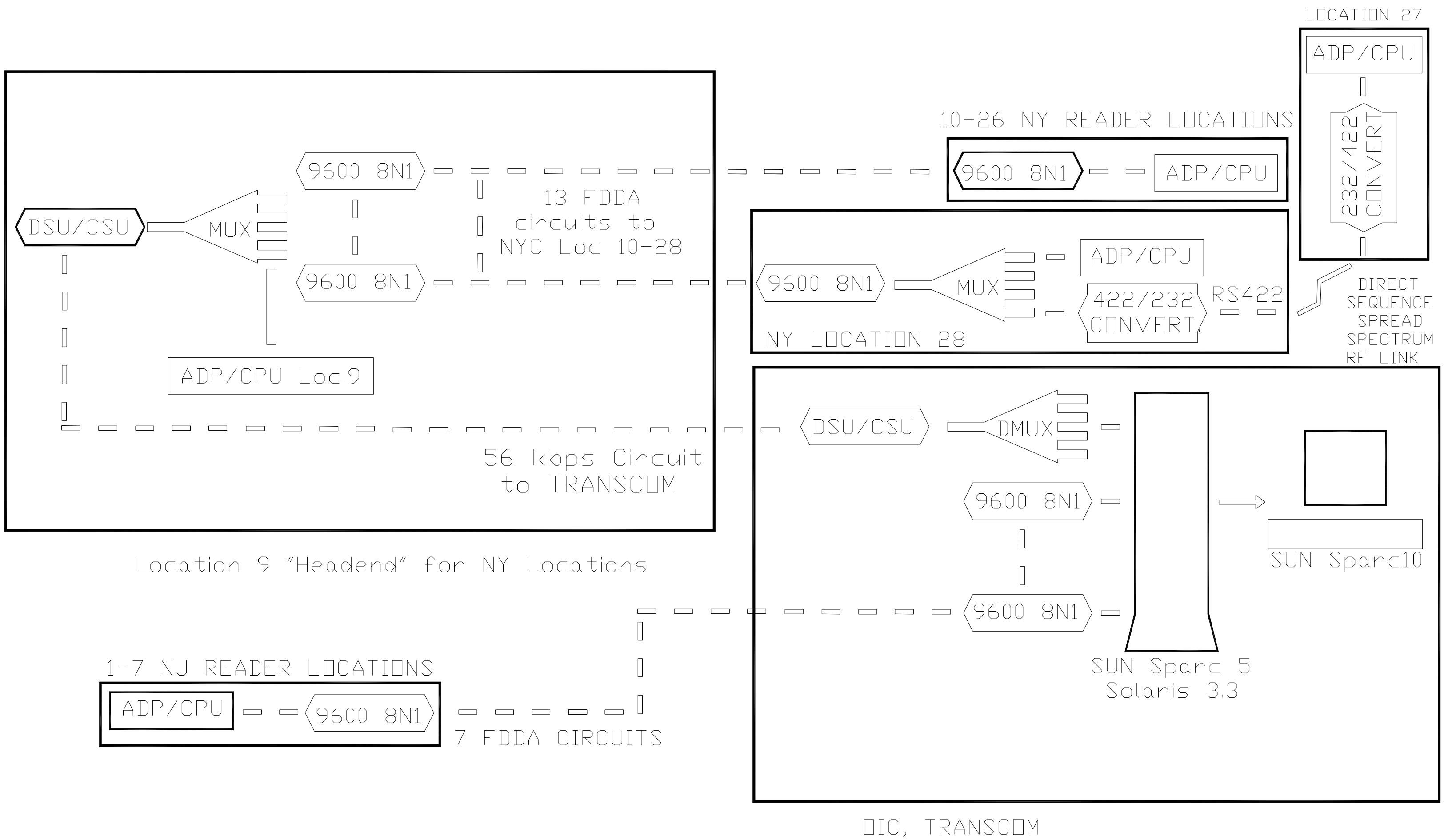

Figure 4. TRANSMIT Communication System

Telephone Line

The point to point modems (9.6 kbps, 8-N-1) at the OIC are connected to the field modems in NJ locations via full duplex, analog, leased telephone lines. The current rate of 9.6 kbps can easily be increased to 28.8 kbps with commercially available modems. These connections in the TRANSMIT system are accomplished using 7 FDDA circuits for the NJ locations, and using 13 FDDA circuits for the NY locations. There is a dedicated leased phone line (digital point to point link) between the headend location 9 and the OIC. Data compression techniques are utilized during transmission of this multiplexed data at the rate of 56 kbps. All these lines operate according to RS-232C standards.

Data collected at New York field sites (locations 10-28) is multiplexed at location 9. The input of the statistical multiplexer consists of 13 FDDA circuits, which provide data transmission from various locations at the rate of 9.6 kbps. The compressed output data rate of this multiplexer is 56 kbps and is transmitted through a dedicated leased telephone line to the OIC.

Data collected at locations 27 and 28 is multiplexed at the multiplexer housed at location 28 and further transmitted to location 9. At location 9, data received from locations 10-28 are multiplexed and further re-transmitted to the OIC via a digital point to point leased telephone line. At the OIC, data received from location 9 is demultiplexed before it is processed.

Radio Link at Tappan Zee Bridge

The radio link operates at 920 MHz and has a maximum data transmission capacity of 56 kbps. Presently, it only utilizes 38.4 kbps and provides a direct connection from location 27 on the Tappan Zee Bridge to location 28 at the toll plaza. The I/O of the radio link is based on an RS-422 format, hence to achieve compatibility with the RS-232C format of RST's, it is necessary to use a 232/422 converter at location 27 and a 422/232 converter at location 28. Data collected at locations 27 and 28 is multiplexed and transmitted over the shared leased telephone line to location 9. At location 9 data received from locations 10-28 is multiplexed and further re-transmitted to the OIC via a digital point to point leased telephone line.

Operations Information Center (OIC), Jersey City, NJ

The data at the OIC is received through 7 FDDA links from NJ locations (GSP) and one 56 kbps link from location 9 (headend location) in NY (NYT). The multiplexed data from NY locations is channeled through the Digital Service Unit/Channel Service Unit (DSU/CSU) to the demultiplexer. The demultiplexed data from NY locations together with NJ data is fed into a communications server (Sun Sparc 5 workstation). Then, it is pre-processed and forwarded to a data server (Sun Sparc 10 workstation) for further processing. The outcome of this processing is being monitored by stand-by operators on a 24 hour basis.

Presently, there is no synchronization between the roadside clocks and the OIC computer. It is assumed that lack of synchronization does not create any discrepancies between the data recorded at the roadside detector and the data received at the OIC, because of the capabilities of the MARK IV roadside equipment and its protocol with the OIC computer.

Data Flow in the TRANSMIT System

Data acquisition starts at the roadside terminal where the system software is used to configure demands of each particular site and to update information as required as well as to monitor and ensure the proper operation of the system. The RST can be reconfigured via the diagnostic port using a laptop computer. The typical roadside terminal settings are as follows:

Time: 030180 0000xx (MMDDYY HHMMSS)
Agency: 000
Plaza: 000
Reader ID (RID): 000
Reader Type: (M) Master
Synchronization: 1 (enabled)
Transponder timeout: 300 (seconds)
Traffic management program flag: 0 (disabled)
Test tag period: 30 (seconds)
Single fault threshold: 5
Multiple faults threshold: 8
Protocol timeout: 9 (0=1, 9=10 increment is 100 ms)
Host status: 0 (disabled)
Host bitrate: 9600
Host parity: none
Host character size: 8
Host stop bits: 1
Host flowcontrol: none
Config Com Port: 1
Lane Status: A (A = Active, G = Guard, O = Off-line)
Lane number: 1 thru 8
Lane test tag: 0 (0 Disabled, 1=Enabled)
Com Port status: 1 (0=Disabled, 1=Enabled)
Com Port bitrate: 9600
Com Port parity: None
Com Port Character Size: 8
Com Port Stop bits: 1
Com Port flowcontrol: None

RF Tag (transponder) Message

The following data entry is generated at the roadside terminal upon the detection of an RF tag in a passing vehicle. Such transponder messages can be viewed at the RST using a laptop computer connected through the diagnostic port to the CPU board. A typical message generated at the roadside terminal has the following format:

Time	Lane#	Function	Transaction #	Agency ID	Tag ID	Tag ID	Port
>LANE<07:05:04>-A	Lane 2	PF	Txn:61756	Ag: 4	Sn: 156199	TA2RFxxxx	>COM1

The first three columns in this message display a severity code:

no asterisk = Information (e.g. transponder activity)
***** = Warning (e.g. test tag not read)
****** = Severe (e.g. lane fault)
***** =** Fatal (switch-over)

Fourth column is a factory message:

FSM_
PROT
LANE

Fifth column is a time stamp:

<18:46:37>

Sixth column:

A = Transponder (standard 20 µsec transaction)
T = Test tag (40 µsec transaction)

Seventh column - Lane #:

Lane x = Lane 1-8

Eighth column - Function:

PGM = Program
PF = Program Failure
Non IAG Format = Non IAG Formatted tag
Decommissioned Tag = Decommissioned tag
PU = Program Unverified

Ninth column - Transaction #:

Txn: xxxx = Will vary based upon TFIELD setup

Tenth column - Agency ID:

Ag: xxx = Any user defined number between 000-127

Eleventh column - Serial Number:

Sn: xxxx = Factory programmed serial number

Twelfth column - Message Origin:

TA_ = Message from Master
TB_ = Message from Slave

Thirteenth column - Message Type:

R = Real-time message (transponder has NOT been buffered)
S = Buffered message (transponder data is from transaction buffer**)**

Fourteenth column - Write Status:

S = Successful
F = Failed
U = Unverified
X = Not attempted, tag not IAG and/or format compatible
D = Not attempted, tag decommissioned

Fifteenth column - Read Performance:

x = Number of reads (00-99)

Sixteenth column - Write Performance:

xx = Number of writes (00-99)

Seventeenth column - COM port Origin:

COMx = Communications port 1-8

COM Port Link Data

The data received by the RST from the transponder is converted into the proper format to be forwarded through the COM port of the reader to the OIC. Communication mode is serial, asynchronous, and full duplex and ASCII based. Data is sent in packets framed by ASCII 'STX' and 'ETX' codes and may not exceed 139 bytes in length (128 bytes of data and 11 bytes of framing, header and trailer).

Data transparency is assured by conversion of any binary data within a packet to ASCII code in the printable range.

The acknowledgment must be received within a "reasonable" time (T1). If no response is received, a packet is re-sent. After re-sending (N2) times, the other end is deemed "down" (<T1*N2> time-out event).

T1 is a configurable parameter (factory default 900ms). N2 is fixed at 3 tries, and is not configurable.

When it is determined that the other end is "down", a recovery sequence must be initiated in an attempt to re-establish communications.

Within the framing 'STX'/'ETX' the packet consists of 3 components; a header, a message string, and a terminator.

The layout of each packet is shown in Figure 5. The header consists of 3 fields: the sequence number field, a control field, and a count (data length) field.

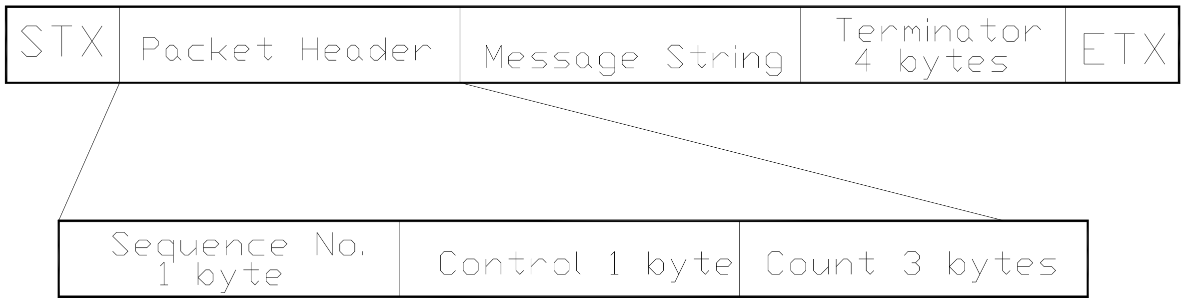

Figure **5**. General Packet Format Send from the COM Port

Data Received at the OIC

Data received from the RST's is immediately processed at the OIC. As soon as a data package is received acknowledgment is sent and the Tag ID is converted into a random number. The allocation of the random number depends on the Tag ID so that duplication or multi-assignment of random numbers is avoided within the system. The stored form of the data has the following format:

Tag ID	Date	Time	Reader ID
E0C10803E9CA12000000	Tue Mar 26 1996	18:47:02	reader 27

2.2 TRANSMIT SystemTraffic Parameters Estimation

The main traffic parameters that are currently estimated by the TRANSMIT system are the link travel time and the space mean speed, which are described below. The TRANSMIT system could also be used to obtain vehicle classification data, Origin-Destination (O-D) data, and track the path of individual vehicles.

Historical Link Travel Time Estimation

The TRANSMIT system belongs to the category of systems which can provide direct estimates of travel time for fixed length links. This estimate is determined in the TRANSMIT system for fifteen minute intervals for weekdays, Saturdays, Sundays and holidays (user specified). The travel time estimation for a particular link of a specific time interval of the day is based on the recording of individual tag equipped vehicle data at corresponding roadside readers, which are then utilized within the historical link travel time algorithm [3, 4, 5]. These estimated results form a set of new historical link travel times, which are updated continuously on a 24-hour basis. Furthermore, the individual tag equipped vehicle data are utilized in the incident detection algorithm. The characteristics of the incident detection algorithm are presented in the Incident Detection System Evaluation. The TRANSMIT link travel time estimation procedure as implemented by PB Farradyne Inc. is presented below:

Tag equipped individual vehicle data - As a tag-equipped vehicle enters the capture zone of a roadside reader, the roadside reader detects and records its tag ID. Each roadside reader supplies vehicle tag ID and time stamp information as part of a message that is forwarded to the OIC. The tag ID is encoded by the computer at the OIC to ensure the anonymity of the vehicle. A pair of an upstream and a consecutive downstream roadside reader defines a link. The travel time of an individual vehicle is determined once the system identifies the recorded time stamps of the same encoded tag ID at both the upstream and downstream roadside readers.

Historical link travel time mean and standard deviation estimation algorithm - During each 15-minute time interval of the day the system collects a sample of (up to 200) of individual link travel times. At the end of the 15-minute period the mean and standard deviation of the sample is calculated (new raw data). If there were no incidents confirmed during this period, these raw values of mean and variance are smoothed with the old historical data to form the new historical data. The smoothing equation is:

New historical data = k $\times$ (New raw data) + (1 - k) $\times$ (Old historical data)

The parameter *k* is user-specified and is currently set to 0.1. Hence, if there were no incidents during the current 15-minute period, the data for this period is used to update the historical value for the next weekday (or Saturday, Sunday, or holiday) during the same 15-minute period.

Link Mean Travel Time and Variance Estimation of the New Raw Data

The kth link mean travel time $\overline{\Delta}t_{k,j}$ in the jth time interval can be defined as

$$\overline{\Delta}t_{k,j} = \frac{1}{n}\sum_{i=1}^{n}(t_m - t_{m-1})$$

where:

- n : number of tag equipped vehicles passing through detector stations m-1 and m during the jth time interval,

- t_m : time at which vehicle i is detected at the downstream detector m,
- t_{m-1} : time at which vehicle i is detected at the upstream detector m-1.

The kth link travel time sample variance $(s_t^2)_{k,j}$ in the jth time interval can be defined as

$$(s_t^2)_{k,j} = \frac{1}{n-1}\sum_{i=1}^{n}((t_m - t_{m-1}) - \overline{\Delta}t_{k,j})^2$$

Link Space Mean Speed Estimation

The k[th] link space mean speed $\bar{v}_{k,j}$ in the j[th] time interval can be defined as

$$\bar{v}_{k,j} = \frac{d_{m,m-1}}{\overline{\Delta}t_{k,j}}$$

where:

$d_{m,m-1}$: distance between consecutive roadside terminals m-1 and m.

2.3 TRANSMIT Incident Detection Algorithm

The data collected by the TRANSMIT system at the OIC is being processed in real time to identify incidents utilizing the algorithm [3, 4, 5] developed by PB Farradyne Inc. The expected link travel times of vehicles detected by the TRANSMIT system are estimated using the probability distribution for specific time intervals. Under free flowing, non-incident traffic conditions, vehicle link travel times tend to be normally distributed. When a number of vehicles fail to arrive at the downstream detector at the expected travel times, the probability of an incident within the link increases. At the same time, as these vehicles fail to arrive at the downstream detector, the probability of a false alarm decreases. These frequent late arrivals causes the confidence level of the possible occurrence of an incident to increase to its user set threshold, triggering an alarm at the OIC computer. The principal components of the TRANSMIT incident detection algorithm are:

The probability of an incident in a specific time interval is determined as:

$$P(Inc) = 1 - P(FA_1) \times P(FA_2) \times P(FA_3) \times \ldots\ldots\ldots\ldots \times P(FA_n)$$

where:

$P(Inc)$ – the probability an incident has occurred on the link,

$P(FA_i)$ – the probability of a false alarm, which is determined for every vehicle i that arrives late,

$P(Inc) = 0$ if there are no late vehicles arriving at the downstream roadside reader.

The probability of a false alarm is determined as:

$$P(FA_i) = P(\text{E}) + P(\text{NE}) \times P(\text{LT})$$

where:

P (E) – the probability that a vehicle exits the link before reaching the downstream roadside reader and thus it is not detected. This probability is calculated for each 15 minute time interval of the day for four different day types (weekday, Saturday, Sunday, or holiday),

P (NE) - the probability that a vehicle does not exit, P(NE) = 1 - P(E),

P (LT) - the probability that a vehicle arriving late at an RST is not delayed by an incident.

For each 15-minute time interval of the day, the system maintains a historical value of the link travel times and the link travel time standard deviations. For each link in the TRANSMIT system, the following travel time threshold is set:

$$\text{T15} = \text{HT15} \times \text{MSD} \times \text{HSD15}$$

where:

T15 - 15-minute link travel time threshold for period i

HT15 - historical link travel time for link j

MSD - multiplier that is currently set to three (3) standard deviations

HSD15 - historical link travel time standard deviation for link j

A tag-equipped vehicle is treated as a late arrival if it fails to arrive at the downstream roadside reader of link *k* within the 15-minute link travel time threshold of a particular period of the day. Once a vehicle is late, the probability that this vehicle was not delayed by an incident is decremented from 1 towards 0 over a user-specified number of standard deviations (or steps).

The following link specific inputs are required:

Operator Supplied Inputs:

Calendar of Holidays - The system determines whether a particular day is a weekday, Saturday or Sunday. The user supplies a list of holiday dates to the system.
Alarm Threshold for $(PInc)$ **-** User specifies threshold for an incident alarm to be set off.
STD Multiplier- User specifies the standard deviation multiplier.
Number of Steps over Which to Decrement P **(LT) -** Number of historical standard deviations after a vehicle is flagged late over which to decrement P(LT). The user specifies the number of steps per time interval.

System Calculated Inputs:

Individual Vehicle Data - Each roadside reader supplies vehicle tag ID and time stamp information. A link is defined by a pair of an upstream and a consecutive downstream roadside readers. The travel time of an individual vehicle is determined once the system identifies its tag ID on both the upstream and downstream roadside readers. If a vehicle tag ID read at the upstream roadside reader cannot be matched at the downstream reader and the vehicle tag ID exceeds the link travel time threshold, then the vehicle tag ID is added to the *late vehicle list*. Vehicles are removed from the late vehicle list if:

they are detected at the down stream roadside reader,
the elapsed time since they were detected at the upstream reader exceeds 15 minutes,
a vehicle detected at the upstream reader later than the late vehicle is detected at the downstream reader (a vehicle passed the late vehicle, the late vehicle exited the link, or the system missed reading the late vehicle at the downstream reader).

Historical Travel Time Mean and Standard Deviation - During each 15 minute time interval of the day, the system collects a sample of (up to 200) individual link travel times. At the end of the 15-minute period the mean and standard deviation of the sample is calculated. If there were no incidents confirmed during this period, these raw values of mean and standard deviations are smoothed with the current historical data. The smoothing equation used is:

$$\textit{New Historical data} = k \times (\textit{New raw Data}) + (1 - k) \times (\textit{Old Historical Data})$$

The parameter k is user-specified and is currently set to 0.1. Hence, if there were no incidents during the current 15-minute time interval, the data for this interval is used to update the historical value for the next week day (or Saturday, Sunday, or holiday) of the same 15 minute time interval.

Historical Probability of Vehicle Exits (or missed vehicles at the downstream reader) - For each period of the day, the proportion of unmatched tags to the total number of tag reads at the upstream reader is used to determine a raw value of *P(vehicle exited).* This value is also smoothed with the historical value in a similar way as was for the link travel time mean and standard deviations.

3 EVALUATION OF THE COMMUNICATION SYSTEM

Executive Summary

The evaluation of the TRANSMIT communication system was carried out to assess the data transmission capability and reliability of the detection of tag equipped vehicles. This assessment is quantified in terms of:

- **Transmission Rate**: the ratio of the tag ID data retrieved at the OIC to the corresponding tag ID data recorded at the RoadSide Terminal (RST), per time interval.
- **Detection Rate**: the ratio of the number of readings recorded at the RST to the number of known tag equipped vehicles crossing the capture zone, per time interval.

The communication system consists of field hardware (roadside readers and antennas) transmission media (telephone lines and radio link) and computers with related peripherals at the Operations Information Center (OIC) of TRANSCOM. As a tag-equipped vehicle is detected at the RST, data identifying the tag ID, detection time and lane position are recorded. This data is forwarded to the OIC, where the tag ID is encrypted to ensure the anonymity of the detected vehicle. This data is collected for traffic flow parameters estimation and incident detection.

This evaluation was primarily based on a comparative analysis of the data collected at the OIC, RSTs and probe vehicle databases:

- **OIC Database** consists of daily data retrieved from the TRANSMIT system at OIC.
- **RST Database** consists of data retrieved from 17 out of 22 RST locations within the TRANSMIT system. Laptop computers connected through the diagnostic ports of roadside readers were used in the data collection. Data from each RST were collected for a minimum of a 24-hour period. This effort was undertaken over a period of 21 days during the months of March and September 1996.
- **Probe Vehicle Database** consists of data collected manually using 4 probe vehicles during March 1996. The probe vehicle test covered the period from 6:20 AM to 6:50 PM and was carried out for 5 weekdays. As each probe vehicle passed through an RST location the detection time was recorded. Tag ID data associated with each of these probe vehicles were identified in the corresponding data collected at OIC.

One of the measures of performance of the TRANSMIT communication system is the transmission rate, which has been determined by comparison of the data collected in the RST Database to the corresponding data in the OIC Database. **The transmission rates for all locations, except one, were found to be near perfect, ranging from 98.8% to 100%, regardless of the observed hourly read rates (maximum read rate = 4,026 tags/hour - Location 25). A site-specific anomaly of the transmission rate of 88% was observed at location 27 (maximum read rate = 5,772 tags/hour)**. At this site the hourly transmission rate variations ranged from 66% to 98%, and are primarily attributed to the presence of a radio link.

Location 27, located on the Tappan Zee Bridge, has the only radio link within the system while the remaining locations are connected through telephone lines. Other possible causes for such low transmission rates, may be attributed to the wide capture zone of the antenna configuration at the bridge and the presence of high traffic volume traveling at very low speeds, especially during the peak periods of the day.

The transmission capacity of the communication system is constrained by the modem's ability along the dedicated leased telephone line between the multiplexer at RST location 9 and the OIC. **The multiplexer handles 13 FDDA circuits (locations 10-28, NYST) with a resulting capacity of 80,575 tag equipped vehicles per hour per RST**. Similarly, the maximum capacity of 9.6 kbps modems installed at the remaining RSTs is 248,633 tag-equipped vehicles per hour per RST. **The estimates for the maximum number of tag reads per hour that may be observed at Tappan Zee Bridge with a 100% market penetration rate, based on 7 lanes, is 16,100 (1994 HCM).** The maximum hourly number of tag volumes observed on location 27 (Tappan Zee Bridge) during the evaluation period on March 1996 was found to be 5,772 tag reads (two-way volume). The above estimates were based on ideal detection, however, if error messages are generated and transmitted over the system these estimates could be decreased substantially. This decrease will not have any significant adverse effect on the successful operation of the system because of the available safety margin between the upper bound and operational transmission rates, 80,575 and 16,100 tag equipped vehicles per hour, respectively. **It can be concluded that the transmission capacity of the TRANSMIT system is capable to handle the maximum possible traffic flow conditions without any constraints.**

A limited vehicle probe test was conducted to determine the detection rate for individual RSTs. During a five-day test period, 4 probe vehicles passed each of the 28 RST locations 90 times. Out of 17 RST locations tested, 12 of them showed detection rates better than 74%, in most of them this rate was approaching 100%. However, locations 1, 101, 102, 9, 18, 118, 27 and 127 showed a detection rate variation between 28% and 61%. Locations 18 and 118 experienced power failures during the evaluation, which explains the occurrence of lower detection rates. **The detection rate of locations 27 and 127 showed significant improvement, from 48% to 83%, during a second test that was conducted six months after the first test.** This significant improvement may be attributed to better fine-tuning of the communication hardware and software. **It can be concluded that lower detection rates are not problematic to the entire system but specific to a few individual locations.**

A measure of the reliability of the system or of its specific components is the percentage of time they function under the set specifications. The time that the system was down was not made available during the evaluation period and therefore it is not reported. However, the number of occurrences that the system or specific RSTs were not functional was recorded. NYST RST locations 17, 18, 19, 24, 25, and 27, exhibited 20 or more hardware and software problems during the 4-month evaluation period. In GSP, only location 6 exhibited more than 10 hardware and software problems. **The frequency of hardware/software problems for these locations could degrade the performance of the TRANSMIT system significantly either for the specific link or the entire system as it is unable to detect possible incidents during the down time period** The severity of these problems could not be determined during this evaluation due to the lack of available data, such as the down time of each RST or the OIC. However, it is noted that the evaluation took place immediately after the changeover of TRANSMIT from AMTECH to MARK IV hardware and software. The RST failures and transformer problems have since been rectified. Therefore, a follow up study is needed to evaluate the present status of the TRANSMIT system hardware and software. Due to site specific lower detection rates, it is recommended that the antenna orientations at these locations should be further studied.

Based on the performed evaluation it is recommended to establish a periodic monitoring of individual RSTs be included as a part of the operation and maintenance of the system. Since most of the RSTs were observed to operate with 100% detection rate, this outstanding performance should be extended throughout the entire system. A mechanism to detect and record the down times of the roadside terminals and the OIC has to be implemented in order to improve the reliability of specific locations and of the entire system.

Since the components of the communication system at location 27 on the Tappan Zee bridge are capable of providing 100% successful performance, an expanded study should be undertaken to identify the exact nature of the rather low detection and transmission rates observed.

In conclusion, the TRANSMIT communication system exhibited excellent performance in terms of the transmission rates system wide. The lower detection rates observed were site specific, rather than system wide. However, due to the high number of tag equipped vehicles that are expected in the future, the lower detection rates would not have any significant impacts on the determination of the traffic flow parameters (link travel time and space mean speed) as well as the incident detection capability. The currently encountered number of occurrences of hardware and software problems were rather insignificant in the overall operation and reliability of the TRANSMIT system.

3.1 Purpose and Scope

This chapter presents the results based on the evaluation of the communication system of the TRANSMIT (**TRAN**SCOM's **S**ystem for **M**anaging **I**ncidents and **T**raffic) system. The methodology followed in this evaluation was developed in the evaluation test plan [1] to assess the data transmission, capacity, and reliability of the TRANSMIT communication system [3, 4, 5]. The data transmission capacity is primarily bounded by the baud rate of modems located at the Road-Side Terminals (RST's) and the computer at the Operations Information Center (OIC), the data handling capacity of leased telephone lines, multiplexers installed at certain junctions, and a radio link at the Tappan Zee Bridge. The transmission capability and reliability of the system was assessed in terms of the transmission rate and detection rate, respectively:

- **Transmission Rate (TR)** the ratio of the tag ID data retrieved at the OIC to the corresponding tag ID data recorded at the RST.
- **Detection Rate (DR)** the ratio of the number of readings recorded at the RST to the number of known tag equipped vehicles crossing the capture zone.

The data collection and assessment for the transmission rate was carried out subject to various traffic conditions at the New York State Thruway (NYST) and Garden State Parkway (GSP) facilities. The data collection for the detection rate of the RST's was obtained using probe vehicles equipped with known Radio Frequency (RF) tags. Estimates of the system performance were quantitatively determined and possible sources of error were identified. An estimate for the peak volume and the reserve capacity of the system for different types of facilities (two-lane, four-lane, six-lane, eight-lane and ten-lane) were suggested and recommendations were made.

This report also includes a section on RST and the OIC hardware and software problems, which were identified in TRANSCOM's incident records during the evaluation period. The principal measure of performance associated with these hardware and software failures is the percentage of time that the OIC or a specific RST is down, which tests the reliability of the system.

The contents of this report include, an executive summary, purpose and scope, the evaluation data collection procedures, a summary of the pertinent data collected and its analysis are then presented. This report concludes with a summary of results and recommendations.

3.2 Data Collection

3.2.1 Pre-Test Activities

Several field tests were conducted to familiarize the evaluation team with the route and the system in July 1995 and January 1996. The OIC facility was visited and sample data was obtained for initial preview and analysis. A 24-hour data sample was obtained from TRANSCOM and reduced to a suitable format for spreadsheet analysis on Microsoft Excel® v.7.0. The preliminary pilot test was conducted and data samples were collected at locations 1 and 10 in mid-February, 1996. OIC data was collected in the first week of January 1996. A preliminary analysis was carried out based on the data gathered during this pilot test.

3.2.2 Evaluation Test Activities

In accessing the roadside equipment at the selected sites for data collection, the members of the evaluation team were accompanied by a representative of TRANSCOM when it was found necessary. They were cautioned to be extremely careful in entering and leaving the roadside terminals and were required to wear appropriate attire (including fluorescent orange jackets). TRANSCOM assisted NJIT in obtaining permits from the NJHA and NYSTA. NJIT followed the safety procedures required by each authority.

The roadside data collection was carried out in the periods extending from Thursday, February 27 to Friday, March 31 and from September 24 to October 4, 1996. The probe data was collected during the period extending from March 12, to March 15, and also on March 28,

1996. The probe vehicle tests were conducted between the hours of 6:20 AM to 6:50 PM. During the evaluation test the following procedures were followed:

- Two student members of the NJIT evaluation team monitored and collected data at the selected RST's using laptop computers. The daily collected data were transferred to the hard disk of a desktop PC at NJIT for statistical analysis. The students were also required to record on data field sheets the daily weather conditions and any special events that may have affected the data collection process.
- TRANSCOM assigned a person for accompanying members of the NJIT evaluation team to the RST's and provided access to the cabinets when it was necessary. In addition, TRANSCOM personnel notified the NJIT evaluation team of any possible problems associated with the hardware and software that could affect the quality of the collected data.
- The probe data was collected during the period extending from March 12, to March 15, and also on March 28, 1996. The probe vehicle tests were conducted between the hours of 6:20 AM to 6:50 PM. The drivers of the four probe vehicles that participated in the test were instructed to follow the average car technique. Specifically, they were instructed that they should pass as many vehicles as the number of vehicles pass them. Each probe vehicle was equipped with a predetermined identification tag similar to the ones used in the E-ZPass system. The data collected during this phase of the evaluation was used to determine detection rates for each location.
- Two additional tests were conducted for locations 23, 27 and 28. Sample data were collected simultaneously at locations 23 and 27 beginning September 24 through October 1, 1996 by installing laptop computers at each RST location. Similarly, on October 3 and 4, 1996 data were collected simultaneously at locations 27 and 28 using laptop computers and at the OIC.
- Data collected at the OIC on a DAT tape were transferred onto the hard disk of a UNIX based Hewlett-Packard workstation and backed-up on magneto-optical disks.
- The collected data from the roadside terminals was stored on a PC and backed-up on magneto-optical disks.

3.2.3 Data Management

The necessary software to access the RST's was provided by TRANSCOM and loaded on the laptop computers. The necessary spreadsheet, database, and statistical analysis software were installed on laptop computers and a desktop PC for data analysis. Due to the limited data handling capability of the MS Excel® software, the MS Access® v. 2.0 software was used to process and analyze the information. Information obtained from the RST's was downloaded from the laptops to a desktop. The daily data collected at the OIC on a DAT tape was transferred onto a UNIX based Hewlett-Packard workstation. From there it was transferred to the hard drive of a desktop PC. The processed data were stored on the PC's hard disk and backed up on magneto-optical disks for future access and review.

3.2.4 Quality Assurance

Data obtained from the pilot testing was analyzed and processed immediately. Based on obtained results all aspects of the test were found to be satisfactory.

Data collected during the evaluation test was reviewed immediately after collection to detect possible flaws in the data collection procedure. The NJIT evaluation team was in continuous communication with TRANSCOM to stay aware of possible equipment malfunctions along the test route.

Maintenance of the TRANSMIT system hardware and software was the responsibility of TRANSCOM. During the data collection phase of the evaluation, TRANSCOM aided and informed the evaluators of any pertinent system changes.

Randomly selected samples of collected data were previewed and analyzed for any anomalies that may have resulted from the collection, recording or storage processes. When anything unexpected was revealed, the testing period was extended accordingly to correct these observed deficiencies. Such a situation occurred when location 27 was analyzed. In that case, a supplementary analysis was deemed necessary and additional data was collected. The evaluation test period was also extended accordingly.

The evaluation team at NJIT maintained a detailed test event log. The log consisted of all pertinent event information, but was not necessarily limited to the following:

- Date,
- Weather conditions,
- Log of activities undertaken by each member,
- Detailed list of participants and their functions,
- Records of any unusual events encountered.

The principal investigators routinely visited the test locations and observed the status of the data collection at the RST's to assure the smooth operation of the evaluation. In addition, the principal investigators were in contact with TRANSCOM to assure that the pertinent data was retrieved and stored properly.

Research associate and research assistants were responsible for maintaining computational equipment.

Real-time diagnostics were carried out at the roadside terminals to ensure that data were stored properly on the laptop computers.

Data collected from RST's were stored on laptop computers. Information obtained from the OIC was stored on DAT tapes. All the data was stored on the hard disk of a desktop PC at NJIT where it was further reduced and converted into a suitable format for analysis. All data were stored on optical disks for future access, review and security.

3.2.5 Data Collection and Reduction

Laptop computers were used to collect data by downloading it from the readers through a serial cable connected to the diagnostic port of the reader. Collected data from the RST's was in ASCII text format and formed the Raw Roadside Terminal Database. These text files contained information specific to the particular readers from which they were downloaded. Initially, Microsoft Excel® v.7.0 was used to import and analyze this data. However, MS Excel®'s limit of 16,384 lines per sheet was quickly found to be too confining for the purposes of this analysis. Text files recorded were in sizes of up to 30 MB. Subsequently, Microsoft Access® v.2.0 was used because it was capable of importing ASCII text files of this magnitude and format. MS Access v.2.0 was used to convert the text into a database format forming the *Roadside Terminal Database* for analysis.

Raw OIC Watch Data was stored at TRANSCOM on a DAT tape. These files were of the order of 100 MB or more in size and they contained information pertaining to the entire TRANSMIT system. The data stored in the DAT tape were downloaded to a HP workstation and transferred to a PC for further reduction to form the *OIC Watch Database.*

As a result of this evaluation test, the following databases were formed using the collected and reduced data:

- *Raw Roadside Terminal Database*

This database contains information collected at a specific roadside terminal is acquired by connecting a laptop computer to the diagnostic port. A sample of this database is presented below:

Time	Lane #	Function	Transaction #	Agency ID	Tag ID	Tag ID
>LANE<07:05:04>-A	Lane 2	PF	Txn:61756	Ag: 4	Sn: 156199	TA2RFxxxx
>LANE<07:05:24>-A	Lane 2	Pgm	Txn:61757	Ag: 4	Sn: 99390	TA2RSxxxx
>LANE<07:05:29>-A	Lane 4	Pgm	Txn:61758	Ag: 4	Sn: 97630	TA4RSxxxx
>LANE<07:05:45>-A	Lane 2	Pgm	Txn:61759	Ag: 4	Sn: 103596	TA2RSxxxx

- *Roadside Terminal Database*

This database is obtained through reduction of the *Raw Roadside Terminal Database* using the Access software. The sample shown below contains information specific to a fixed location.

Time	Tag ID
7:05:04 AM	156199
7:05:24 AM	99390
7:05:29 AM	97630
7:05:45 AM	103596

- *Raw OIC Watch Database*

Data received at the OIC from the RST's contain tag ID's in encrypted form as well as reader and antenna identification. The incident detection algorithm is based on this information and a sample of it is given below:

Tag ID	Time	Reader ID
E0C10803E9CA12000000	Tue Mar 26 16:21:22 1996	27
E0C108030E9C12000000	Tue Mar 26 16:21:23 1996	11
E0C10806672212000000	Tue Mar 26 16:21:23 1996	18
E0C10803A10812000000	Tue Mar 26 16:21:23 1996	27

- *Modified OIC Watch Database*

This modified database is obtained through reduction of Raw OIC Watch Database using the Access software. Sample shown below contains tag information received at OIC at a certain time interval.

Tag ID	Date	Time	Reader
3E9CA	Tue Mar 26	4:21:22 PM	27
30E9C	Tue Mar 26	4:21:23 PM	11
66722	Tue Mar 26	4:21:23 PM	18
3A108	Tue Mar 26	4:21:23 PM	27

3.3 Evaluation Results

The data collected during this evaluation is used to determine the performance of the TRANSMIT communication system. The measures of performance are expressed in terms of the following parameters:

- ***Transmission Rate (TR)*** is defined as the ratio of the received tag identification records in OIC data to the corresponding records collected at roadside terminals. By comparing the data collected at the OIC to the field data gathered at the individual roadside terminals subject to various traffic conditions at the NYST and GSP facilities, the communication links in the TRANSMIT system were tested.

- ***Detection Rate (DR)*** is defined as the ratio of the number of readings recorded at the roadside terminals to the corresponding number of known tag equipped vehicles crossing the capture zone. This detection rate was determined based on data collected utilizing only four probe vehicles driven along the test route and over a short period of time due to limited resources available in the evaluation. However, because it was not possible to equip all RSTs with data collecting computers, the detection rate referred to the ratio of the tags recorded at the OIC to the number of known tag equipped vehicles crossing the capture zone. Thus the transmission rate was inherent in the detection rate.

3.3.1 Transmission Rates and RST Messages

Out of the existing 22 locations in operation within the TRANSMIT system along the NYST and GSP, only 17 of them were subjected to testing. Location 18 was excluded from testing because the computer used in data collection could not be supplied with a reliable power source during the evaluation period. The remaining four RSTs were not included because they were located at exits where rather low volume traffic patterns were observed. These excluded roadside terminals are shown in Table 2 with their location identification.

Table 2. Excluded RST Locations

Location	Reason for Exclusion
5	Exit Reader
6	Exit Reader
17	Exit Reader
18	Lack of a reliable power
21	Exit Reader

In Table 3, a summary of the tested RSTs with their corresponding minimum and maximum read rates and transmission rates is presented.

The transmission rates versus the average read rates for the tested roadside terminals are shown in Figure 6. **All RSTs but one performed very satisfactorily, having transmission rates approaching 100%. The maximum hourly read rates for the locations that have exhibited almost perfect transmission rates varied between 444 tags/hour (location 7) and 4026 tags/hour (location 25)**.

The observed anomaly of transmission rate of 88% at location 27 corresponds to the only RF link in the TRANSMIT system. The observed maximum number of tag reads per hour of 5772 (Table 3) was between 7:00 and 8:00 AM at the RST 27. **The decrease in the transmission rate can be attributed primarily due to the presence of an RF link associated with this location**.

Transmission Capacity

The transmission capacity of the communication system is primarily constrained by the modem's baud rate along the dedicated leased telephone line between the multiplexer at RST location 9 and the OIC. This modem's 56 kbps baud rate can handle 56,000 (bps) x 3,600 (sec/hour) / 139 bytes (length of the tagged vehicle data) = 1.45 million tag equipped vehicles per hour. Since this multiplexer handles 13 FDDA circuits (locations 10-28, NYST) then

80,575 tag equipped vehicles per hour can be allocated per RST. The maximum capacity of 9.6 kbps modems installed at the remaining RSTs is 9,600 (bps) x 3,600 (sec/hour) / 139 bytes = 248,633 tag equipped vehicles per hour is much larger than the capacity of the multiplexer which is 80,575.

An estimate of the maximum traffic flow capacity for different freeway facilities, based on the 1994 Highway Capacity Manual is as follows (in passenger cars per hour per direction): four lanes - 8,800; six lanes - 13,800; eight lanes - 18,400; and ten lanes - 21,000. The maximum number of tag reads per hour that may be observed at Tappan Zee Bridge with a 100% market penetration rate, based on 7 lanes, is 16,100. The maximum hourly number of tag volumes observed on location 27 (Tappan Zee Bridge) during the evaluation period on March 1996 was found to be 5772 tag reads (two-way volume). This number is expected to increase significantly, as more travelers will install EZ Pass tags in their vehicles. However, even the maximum traffic flow capacity of 16,100 vehicles per hour is much less than TRANSMIT's communication system estimated capability of 80,575 vehicles per hour. With data compression, the capability of the TRANSMIT system can be enhanced to be able to accommodate more data flow than the above estimates. The above estimates were based on ideal detection, however, if error messages are generated and transmitted over the system these estimates could be decreased substantially. This decrease will not have any significant adverse effect on the successful operation of the system because of the available safety margin between the upper bound and operational transmission rates, 80,575 and 16,100 tag equipped vehicles per hour, respectively. **It can be concluded that the existing transmission capacity of the TRANSMIT system can handle the maximum possible traffic flow conditions without any constraints.**

RST Messages

Table 4 provides a description of the various types of communication messages recorded in the collected data. The distinction between a type 9 Duplicate Read and a type 12 Multiple Read should be noted. A type 9 Duplicate Read indicated a tag that was read twice at the same location and time. A type 12 Multiple Read indicated a tag that was read two or more times at the same location but within 1 to 60 seconds of each other. Table 5 summarizes the different messages that were found among the data recorded at the various RSTs.

Table 3. Minimum and Maximum Hourly Tag Read Rate and Average Transmission Rate at RSTs

RST Location	Data Collection Date - Time	Hourly Tag Read Rate (RST reads/hour)		Average Hourly Tag Transmission Rate (OIC reads/hour)
		Min	Max	rate @ RST)
1	2/27/96 - (7:00 - 20:00)	110	469	100%
2	2/27/96 - (7:00 - 20:00)	32	470	100%
3	2/27/96 - (12:00 - 24:00) 2/28/96 - (00:00 - 2:00)	29	582	100%
4	2/27/96 - (7:00 - 21:00)	13	522	100%
7	2/29/96 - (6:00 - 22:00)	52	444	100%
9	2/29/96 - (7:00 - 24:00) 3/1/96 - (00:00 - 21:00)	3	486	98.8%
10	2/29/96 - (6:00 - 23:00)	60	1139	100%
11	2/28/96 - (7:00 - 24:00)	4	1697	100%
13	3/1/96 - (00:00 - 21:00)	20	1637	100%
14	3/26/97 - (16:00 - 24:00) 3/27/96 - (00:00 - 24:00) 3/28/96 - (00:00 - 24:00) 3/29/96 - (00:00 - 17:00)	15	1715	99.96%[A]
16	2/28/96 - (8:00 - 24:00)	223	2691	100%
20	3/4/96 - (15:00 - 24:00) 3/5/96 - (00:00 - 15:00)	54	3757	99.99%
23	2/29/96 - (22:00 - 24:00) 3/1/996 - (00:00 - 22:00)	30	3838	99.99%
24	3/1/96 - (00:00 - 23:00)	1	2740	100%
25	2/29/96 - (6:00 - 23:00)	286	4026	99.99%[B]
27	3/27/96 - (13:00 - 24:00) 3/28/96 - (00:00 - 24:00) 3/29/96 - (00:00 - 15:00)	76	5772	88.03%
28	3/27/96 - (12:00 - 24:00) 3/28/96 - (00:00 - 24:00) 3/29/96 - (00:00 - 17:00)	32	3089	99.96%

[A] OIC data was not collected for the entire evaluation period. See the description of location 14 for further details.

[B] OIC data was not collected for the entire evaluation period. See the description of location 25 for further details.

Table 4. Message Types at the Roadcheck™ Reader

Message	Description	Notes
Type 1	RFC Error	Internal reader communication failure causing the reader to reboot. Typically takes 15 to 20 seconds to complete the cycle. Subsequently some data is lost.
Type 2	Timex	Occurs when the OIC does not respond to an Acknowledgment (Ack) or Not Acknowledgment (Nack) in 0.9 sec.
Type 3	Duplicate Ack	After Timex, the RST re-sends the tag. Subsequently, 2 Ack's are received by the RST from both transmissions.
Type 5	@@@@@	Defective communication between the data collecting computer and the RST.
Type 6	Wrong Sequence Number	Evidence of corrupted communication between the RST and the tag.
Type 7	READ ERROR	Corrupted communication between the RST and tag or RST and OIC.
Type 8	Blank	Defective communication between the data collecting computer and the RST.
Type 9	Duplicate Read	A tag is read twice at the same time, location and antenna.
Type 10	Cut and Shift	Defective communication between the data collecting computer and the RST.
Type 11	Continuation	Defective communication between the data collecting computer and the RST.
Type 12	Multiple Read	Corrupted communication between the RST and tag or RST and OIC.
Type 13	Exceeds Protocol	Corrupted communication between the RST and tag or RST and OIC.
Type 14	CRC__Err	Corrupted communication between the RST and tag or RST and OIC.
Type 15	BadTypErr	Corrupted communication between the RST and tag or RST and OIC.
Type 16	Invalid Frame	Corrupted communication between the RST and tag or RST and OIC.
Type 17	SeqNumErr	Corrupted communication between the RST and tag or RST and OIC.
Type 18	R1 IN	Corrupted communication between the RST and tag or RST and OIC.

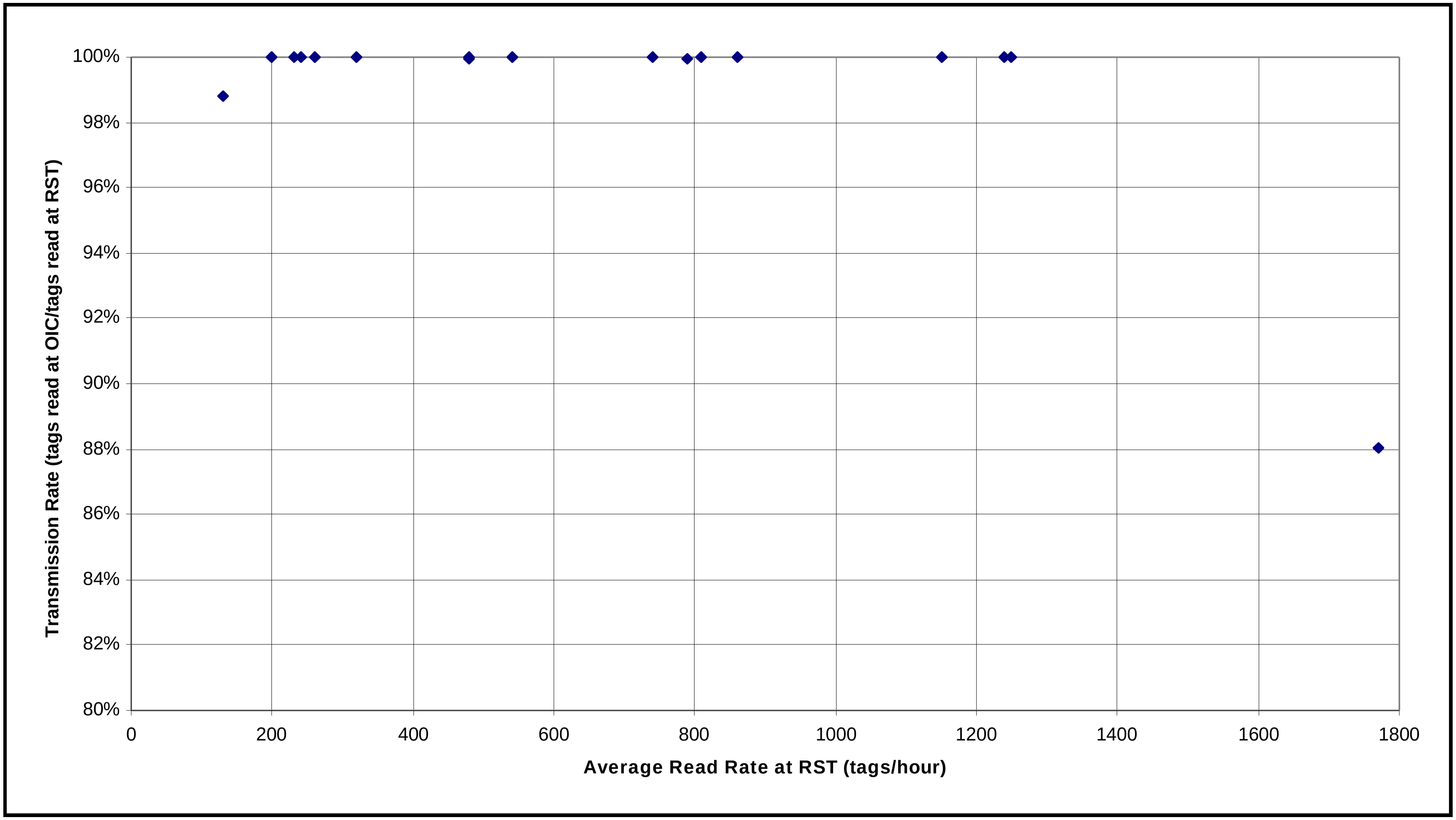

Figure 6. Transmission Rate versus Average Read Rate

Message Type	RST Location																
	1	2	3	4	7	9	10	11	13	14	16	20	23	24	25	27	28
1								X		X	X			X	X	X	
2						X		X		X	X	X		X	X	X	X
3							X	X	X		X	X	X	X	X	X	X
5							X										
6				X			X	X		X				X	XX	X	X
7															X	X	X
8			X									X			X		
9	X	X							X		X		X		X		X
10			X									X					X
11			X														
12	X						X		X				X		X		X
13																X	
14																X	
15																X	
16																X	
17								X		X				X	X	X	X
18				X			X	X		X			X	X	X	X	X

Table 5. Typical Message Types Observed at Various RST Locations

Total Number of Messages per RST

The following tables present various message types observed at each RST and their corresponding number of occurrences.

Table 6. Location 1, Tuesday, 2/27, 7:05 through 19:36

Message	Description	Number of Occurrences
9	Duplicate Read	3
12	Multiple Read	2

Average Read Rate: 260 reads per hour; Maximum Read Rate: 469 reads per hour; 100% transmission rate.

Table 7. Location 2, Tuesday, 2/27, 7:55 through 19:53

Message	Description	Number of Occurrences
9	Duplicate Read	2

Average Read Rate: 230 reads per hour; Maximum Read Rate: 470 reads per hour; 100% transmission rate.

Table 8. Location 3, Tuesday, 2/27, 7:20 through 20:04

Message	Description	Number of Occurrences
8	Blank	3
10	Cut and Shift	2
11	Continuation	7

Average Read Rate: 320 reads per hour; Maximum Read Rate: 382 reads per hour; 100% transmission rate.

Table 9. Location 4, Tuesday, 2/27, 7:24 through 20:04

Message	Description	Number of Occurrences
6	Wrong Sequence Number	8
7	READ ERROR	9

Average Read Rate: 240 reads per hour; Maximum Read Rate: 522 reads per hour; 99.97% transmission rate.

The sample downloaded from location 7 did not contain any messages. It was collected from Thursday, 2/29, 5:55 through 21:37. The average read rate was 200 reads/hour, the maximum read rate was 444 reads per hour, and the transmission rate was 100%.

Table 10. Location 9, Thursday, 2/29, 20:08 through Friday, 3/1, 20:39

Message	Description	Number of Occurrences
2	Timex	7

Average Read Rate: 130 reads per hour; Maximum Read Rate: 486 reads per hour; 98.8% transmission rate.

Note that all missed tags fell in the period between 22:13 and 23:03. If it weren't for these missed tags, the transmission rate would be 100%.

Table 11. Location 10, Thursday, 2/29, 6:29 through 22:23

Message	Description	Number of Occurrences
3	Duplicate Ack	14
5	@@@@@	1
6	Wrong Sequence Number	3
12	Multiple Read	2
18	R1 IN	1

Average Read Rate: 540 reads per hour; Maximum Read Rate: 1139 reads per hour; 100% transmission rate.

Table 12. Location 11, Wednesday, 2/28, 7:58 through 23:14

Message	Description	Number of Occurrences
1	RFC Error	4
2	Timex	50
3	Duplicate Ack	17
6	Wrong Sequence Number	6
17	SeqNumErr	6
18	R1 IN	8

Average Read Rate: 740 reads per hour; Maximum Read Rate: 1697 reads per hour; 100% transmission rate.

Table 13. Location 13, Thursday, 2/29, 22:23 through Friday, 3/1, 20:54

Message	Description	Number of Occurrences
3	Duplicate Ack	18
9	Duplicate Read	2
12	Multiple Read	1

Average Read Rate: 480 reads per hour; Maximum Read Rate: 1637 reads per hour; 100% transmission rate.

Table 14. Location 14, Tuesday, 3/26, 16:11 through Friday, 3/29, 16:35

Message	Description	Number of Occurrences
1	RFC Error	2
2	Timex	15
6	Wrong Sequence Number	3
17	SeqNumErr	3
18	R1 IN	4

Average Read Rate: 480 reads per hour; Maximum Read Rate: 1715 reads per hour; 99.96% transmission rate.

The transmission rate for location 14 was based only on a 44-hour time period because the data collection was interrupted for a few hours at the OIC between 19:11 on Tuesday, March 26 through 23:36 Wednesday, March 27,1996. Thus, the reported transmission rate included this interruption.

Table 15. Location 16, Wednesday, 2/28, 8:22 through 23:43

Message	Description	Number of Occurrences
1	RFC Error	4
2	Timex	28
3	Duplicate Ack	16
9	Duplicate Read	1

Average Read Rate: 1150 reads per hour; Maximum Read Rate: 2691 reads per hour; 100% transmission rate.

Table 16. Location 20, Monday, 3/4, 15:10 through Tuesday, 3/5, 14:50

Message	Description	Number of Occurrences
2	Timex	38
3	Duplicate Ack	44
8	Blank	2
10	Cut and Shift	24

Average Read Rate: 1250 reads per hour; Maximum Read Rate: 3757 reads per hour; 99.99% transmission rate.

Table 17. Location 23, Thursday, 2/29, 22:38 through Friday, 3/1, 21:41

Message	Description	Number of Occurrences
3	Duplicate Ack	67
9	Duplicate Read	5
12	Multiple Read	5
18	R1 IN	1

Average Read Rate: 860 reads per hour; Maximum Read Rate: 3838 reads per hour; 99.99% transmission rate.

Table 18. Location 24, Thursday, 2/29, 23:02 through Friday, 3/1, 21:58

Message	Description	Number of Occurrences
1	RFC Error	6
2	Timex	38
3	Duplicate Ack	21
6	Wrong Sequence Number	3
17	SeqNumErr	3
18	R1 IN	1

Average Read Rate: 810 reads per hour; Maximum Read Rate: 2740 reads per hour; 100% transmission rate.

Table 19. Location 25, Thursday, 2/29, 6:37 through 22:44

Message	Description	Number of Occurrences
1	RFC Error	30
2	Timex	67
3	Duplicate Ack	76
6	Wrong Sequence Number	6
7	READ ERROR	3
8	Blank	1
9	Duplicate Read	15
12	Multiple Read	273
17	SeqNumErr	6
18	R1 IN	6

Average Read Rate: 1240 reads per hour; Maximum Read Rate: 4026 reads per hour; 99.99% transmission rate.

The transmission rate for location 25 was based only on an 18-hour time period because the data gathering was interrupted for a few hours at the OIC. Thus, the reported transmission rate included this interruption.

Table 20. Location 27, Wednesday, 3/27, 12:37 through Friday, 3/29, 16:34

Message	Description	Number of Occurrences
1	RFC Error	126
2	Timex	39,585
3	Duplicate Ack	4,842
6	Wrong Sequence Number	883
7	READ ERROR	1
13	Exceeds Protocol	142
14	CRC__Err	6,661
15	BadTypErr	12
16	Invalid Frame	24
17	SeqNumErr	18
18	R1 IN	8,677

Average Read Rate: 1770 reads per hour; Maximum Read Rate: 5772 reads per hour; 88.03% transmission rate.

Location 27 at the Tappan Zee Bridge has unique features:

- the highest volume of tags read in the TRANSMIT system were observed here,
- the only radio link in the TRANSMIT system operates between the RSTs at location 27 and location 28,
- data collected at locations 27 and 28 have to be multiplexed here,
- it is the only link where vehicles have to reduce their speed significantly due to the toll plaza at the Tappan Zee Bridge.

The presence of the steel structure of the bridge may add negative effects due to interference of electromagnetic waves at the radio link frequencies. Furthermore, data collected at this location contained the largest number of error messages (see Table 20). In particular, there were an unusually large number of Type 2 messages (39,585) where the RST failed to establish communication to OIC. Other messages that were observed frequently were, Type 14 and Type 18, with 6,681 and 8,677 times, respectively, indicated the presence of corrupted communication between RST and OIC and/or RF tag. Multiple reads also associated with Type 3 messages have occurred 4,842 times. These tags were read at intervals ranging from 1 second to 6 minutes and beyond. Location 27 monitored traffic in both southbound and northbound directions on the Tappan Zee Bridge. Since it was possible for a vehicle to travel from one side of the bridge to the other in under 6 minutes, it was impossible to ascertain whether a Multiple Read was a result of a tagged vehicle actually making the circuitous trip (very unlikely) or corrupted communication between the RST and tag or RST and OIC. **However, despite the presence of high occurrence of various error messages, it can still be stated with confidence that the average transmission rate was 88.03%, showing hourly variations in the range from 68% to 98%.**

Table 21. Location 28, Wednesday, 3/27, 12:49 through Friday, 3/29, 16:34

Message	Description	Number of Occurrences
2	Timex	152
3	Duplicate Ack	14
6	Wrong Sequence Number	8
7	READ ERROR	2
9	Duplicate Read	43
10	Cut and Shift	16
12	Multiple Read	24
17	SeqNumErr	8
18	R1 IN	45

Average Read Rate: 790 reads/hour; Maximum Read Rate: 3089 reads per hour; 99.96% transmission rate.

Table 21 indicates that there were significantly less error messages observed at location 28 compared to location 27 (Table 20) within the same time period. The data shows that location 27 is the only location with transmission rate concerns. This provides added evidence that the radio link was the primary reason for having negative impacts on these transmission rates.

Appendix A contains examples of how the actual error messages appeared in the raw data.

3.3.2 Roadside Terminal (RST) Detection Rate

Estimates of the detection rate for each RST were determined through the probe vehicle experiment. By the end of the testing period, the four probes had passed each of the 28 RST readers 90 times. Four data records were not read at readers 104, 103, 102, and 101, which were considered to be flawed at the time of the testing. That resulted in only 89 records collected from each of these locations, versus 90 records for the remaining of the locations.

The data gathered from the test probes was compared to corresponding data collected simultaneously at the OIC. The comparison revealed missing records at the OIC for these probe vehicles. Possible explanations for the missing records are the following: presence of multiple tags in a capture zone, malfunctioning tags, and malfunctioning readers.

Each of these factors were analyzed and summarized in Figures 7 through 10. Each figure illustrated the percentage of missed records in a chosen category, based on time periods of the day in Figure 7, tag number in Figure 8, date in Figure 9, and corresponding reader numbers in Figure 10, respectively. Observations based on Figures 7 to 9 did not suggest any strong trends. However, Figure 10 exhibited location-related patterns. Some readers exhibited relatively high percentages of missed records while others showed very little or none at all. In particular, readers 1, 101, 9, 18, 118, 27, and 127 had missed records ranging from 47% to 72%. Locations 18, 118 low detection rate may be attributed to power failures during the evaluation period. Subsequently, TRANSCOM informed the evaluation team that the problem has been corrected and no additional power failures were experienced. The low detection rates observed at Locations 27 and 127 can be attributed to the communication problems discussed earlier. The lower detection rates observed at locations 1, 101 and 9 could be attributed to possible misalignments of the antennas at these locations.

One further anomaly was observed in the analysis was at location 16. Location 16 consisted of two different types of antennas. One monitored through traffic and the other an exit ramp. Although the antennas were supposed to read tags in their respective lanes, in fact 60% of the tags on the southbound side of the NYST were read by the exit antenna when they should have been read by the through traffic antenna. This problem did not occur at other locations with main line and exit antennas. It was recommended that the power of the antennas at this location be attenuated.

Since 14 out of the 18 tested locations exhibited near perfect detection rates, it can be concluded that the problems encountered at these RSTs were location specific rather than indicative of system wide problems.

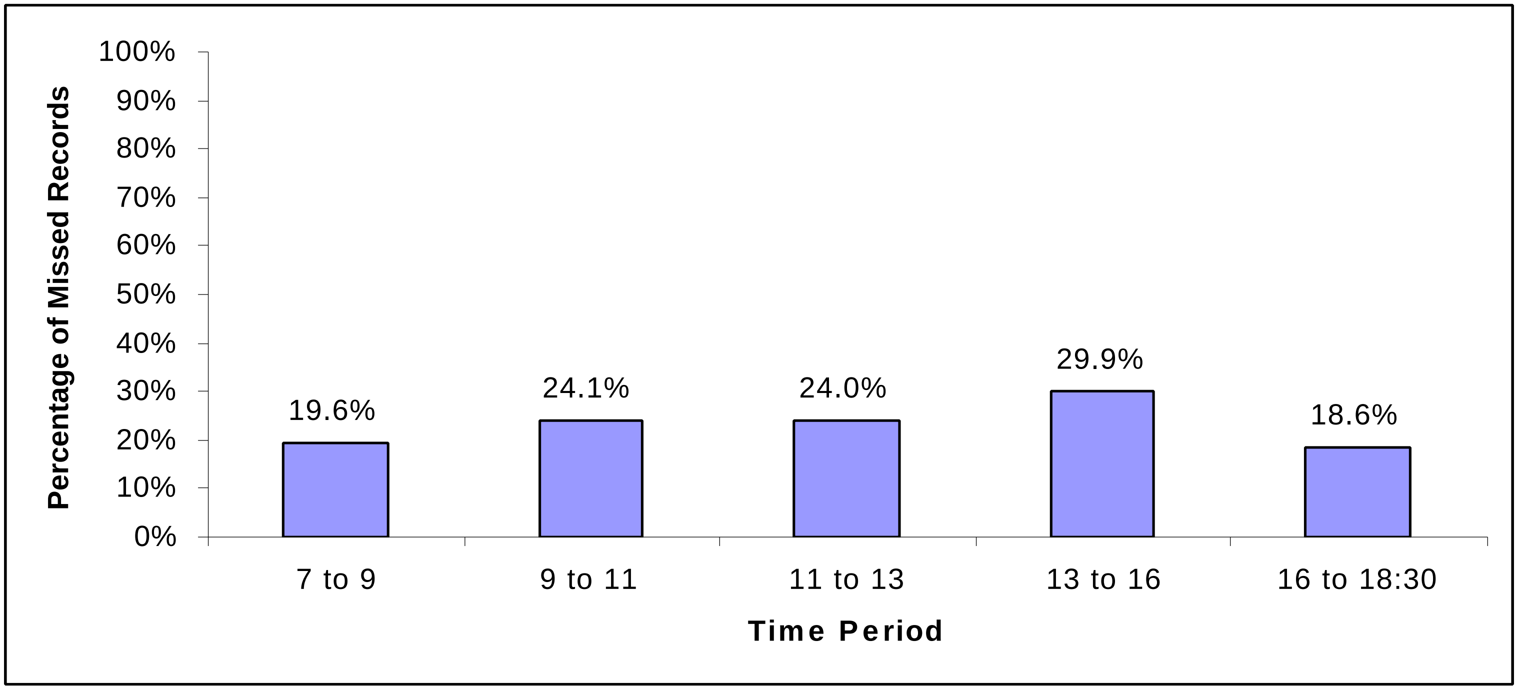

Figure 7. Missed Records by Time Period

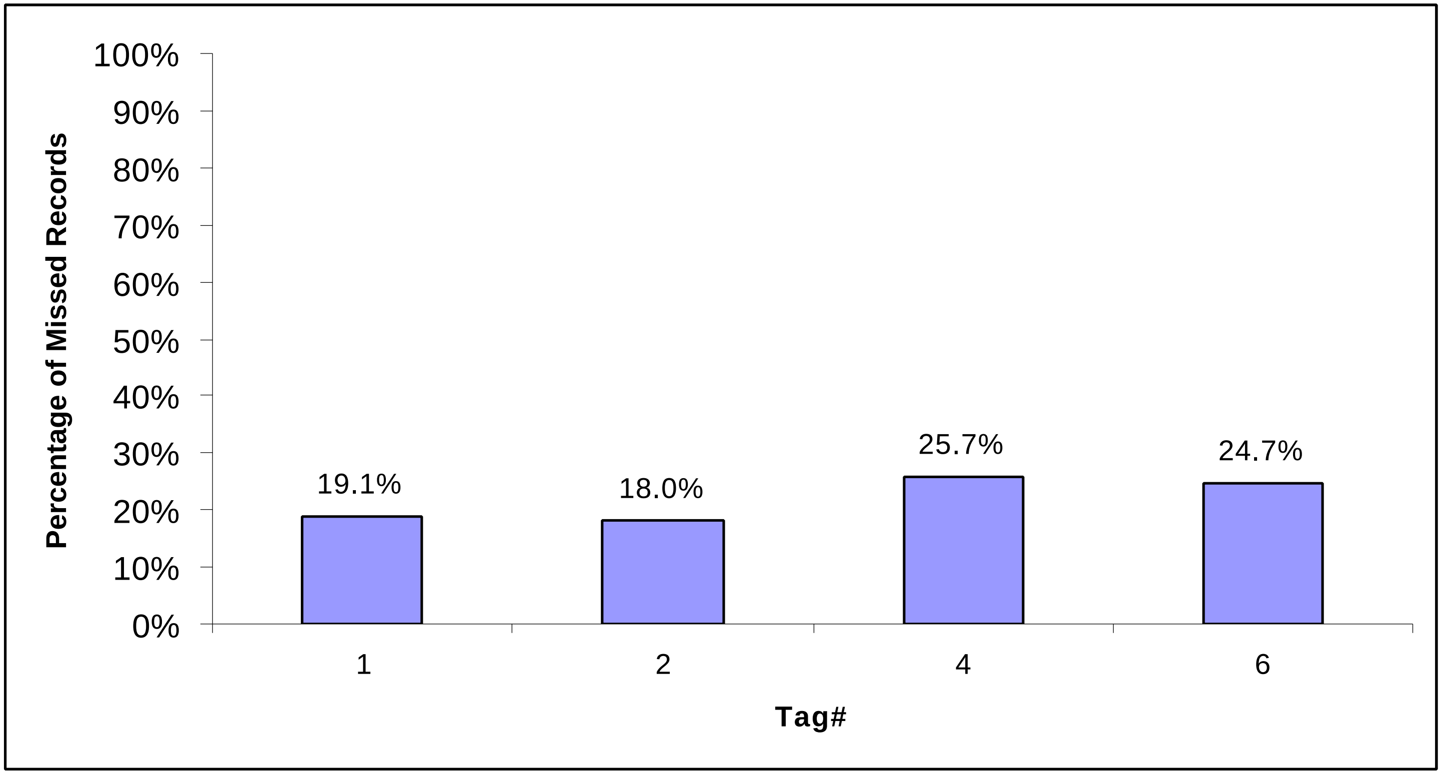

Figure 8. Missed Records by Tag Number

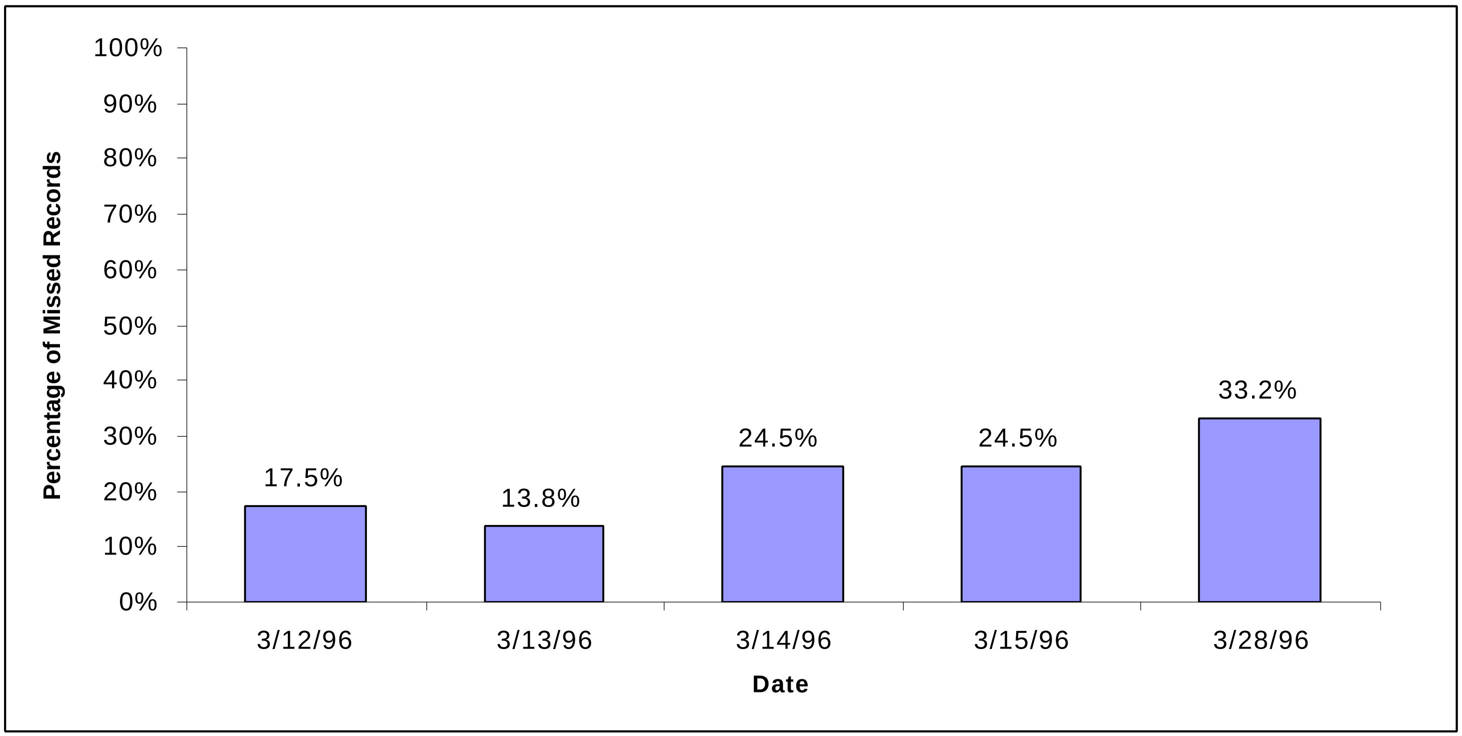

Figure 9. Missed Records by Date

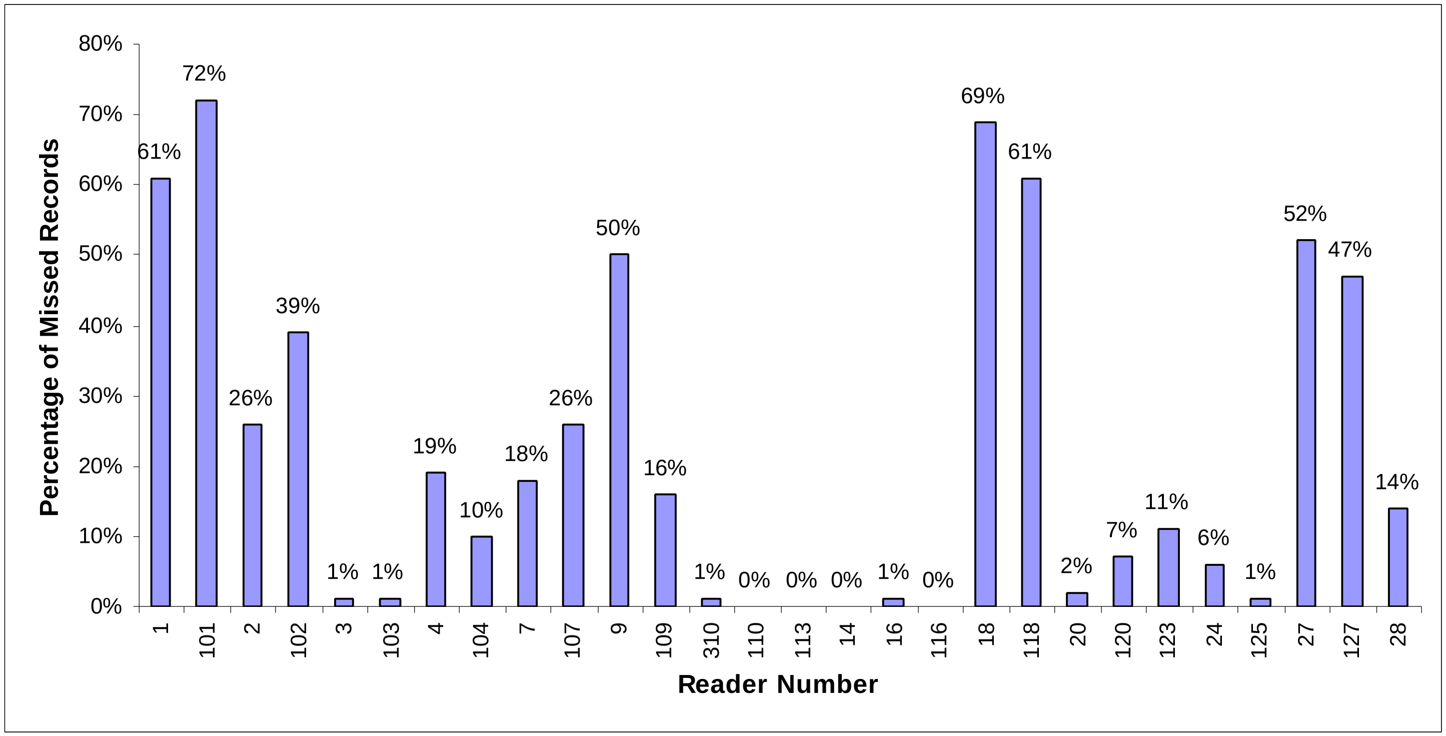

Figure 10. Missed Records by Reader Number

3.3.3 Analysis for RST Location 27

The occurrences of comparatively lower detection and transmission rates associated with Location 27 prompted a more detailed analysis of the collected data. There were two principal concerns why this particular link was chosen. The first issue that needed clarification was why tags mounted on vehicles were not detected properly by some of the antennas at location 27. As shown in Figure 10, the percentage of missed reads at this location was approximately 52%. The second concern was that the tags read were not being transmitted to the OIC reliably. As noted in Table 3, the average transmission rate at this particular location was 88%.

In order to assess the correlation between the average read rate and the transmission rate, a detailed analysis of location 27 was carried out, in terms of hourly time intervals covering the period beginning at 13:00 of Thursday, March 27 and ending at 16:00 of Friday March 29, 1996. The results are summarized in Table 22 and are shown graphically in Figure 11. A regression analysis was performed on the data of Table 22 using the method of least squares. The outcome is illustrated in Figure 12, indicating an insignificant correlation (R^2 = 0.26) between the transmission and the tag read rates. This hourly transmission rate showed variations between 66% and 98 %.

A more detailed analysis of location 27 in terms of shorter time intervals of 15 minutes was applied to the morning and evening peak periods of Thursday, March 28, 1996. Figure 13 presents the transmission rate versus the 15-minute tag read rate for Thursday morning peak period and the corresponding linear regression analysis. For the morning peak period (6:30 to 9:30 AM) and the evening peak period (16:00 to 19:00 PM) (see Figure 14), the R^2 value between tag read rates and transmission rates is found to be 0.39 and 0.48, respectively. The transmission rate for the morning and evening peaks displayed distinctly different patterns. In the morning peak period degradation in performance of the transmission rate was observed, especially between the hours of 8:00 to 9:00 AM and during the afternoon peak period from 15:00 to 18:00 PM.

Since the first set of tests conducted in March 1996 significant improvements were made in the TRANSMIT communication system, justified a follow up test. Two additional tests were conducted in the time periods extending from September 24 through October 1, and October 3 through October 4, 1996, for the purpose of clarifying the communication system performance at location 27.

During the period from 15:23:00 on Tuesday, September 24 through 12:19:00 on Tuesday, October 1, tag data was recorded from the RSTs at locations 23 and 27, simultaneously. Vehicles traveling from location 23 necessarily have to pass location 27 since the only means of exit was a service road that was used by the NYST. Thus tags collected at location 23 provided a basis for an alternative comparison to tags read at location 27. By comparing the samples collected from the RSTs 23 and 27, it was determined that 93% of the tags detected at location 23 were also detected at location 27. This second test is based on a much larger sample size of 118,579 tag reads versus only a sample of 90 tag reads of the first test. The second test is not a direct test of the detection rate, since it is based on tag data that are already read at location 23, not the entire population of the tags that pass through location 23. In the first test, the detection rate at location 23 was estimated to be 89%, however it is not known whether the performance of this particular location has either improved or declined during the conduct of the second test. **The detection rate at location 27 may be estimated as .89 x .93 = 0.83** if it is assumed that the detection rate of location 23 could still be applicable. This result is in contrast to the **48%** detection rate estimate from the first test using probe vehicles. **A much more substantial test would be required to provide true estimates of the detection rate, over a much longer time period. At best the new result provides an indication that the communication system at location 27 had improved significantly since March 1996 when the first test was conducted.**

The second issue was that tags read at location 27 were not consistently transmitted to the OIC. This was addressed by simultaneously collecting tag data at the RST at location 27, tapping into the radio link at location 28, and collecting data at the OIC. The purpose of tapping into the radio link was to collect a sample of tag data that was collected before it was transmitted to the OIC. One note should be made about the tapping procedure used to collect the data sample. It was possible that the tapping led to the attenuation of the signal generated at the RST reader that was fed into the OIC path. The resultant signal attenuation could have a detrimental effect on the transmission. In fact, when the tap connection was first made, communication between the RST at location 27 and the OIC was lost for a period of 20 minutes. Although the communication link was re-established, the integrity of the link remained in question.

Further analysis revealed a number of tags that were present in the data collected during tapping into the radio link at location 27 were absent in the data collected directly off the diagnostic port at location 28 using available MARK IV software. Hence, this could also be attributed to errors created by the above mentioned data collection technique or the MARK IV software itself. The second set of tests could not therefore provide a good estimate of the transmission rates at location 27.

Factors that may influenced the transmission and detection rates at location 27 are suggested below:

- The existence of the only radio link in the TRANSMIT system which connects the RSTs between locations 27 and 28. Data collected at location 27 is sent via radio frequency link to Location 28. The data collected at location 28 is multiplexed with data received through the RF link and forwarded to the OIC. Although the bit error rate test was performed on the radio link, it was found to be inconclusive.
- The configuration of antennas on the peak direction lanes and reversible lane on the Tappan Zee Bridge. On Tappan Zee Bridge, the peak direction utilizes 4 lanes and the opposing flow utilizes 3 lanes. In order to accommodate the reversal in the peak flows from morning to evening, the NYSTA employs the use of a movable barrier in the middle lane of the bridge. This requires that two antennas monitor the middle lane, one for each direction of traffic. Overall, there are 6 antennas installed for monitoring the tag equipped vehicles, at any instant of time, only 5 out of 6 antennas are in operation.

Table 22. Hourly Transmission Rate at Location 27

Hour Starting	Tags read @ OIC	Tags read @ RST	Hourly Transmission Rate (tags read @ OIC/ tags read @ RST)
13:00	817	901	91%
14:00	1314	1418	93%
15:00	1803	1981	91%
16:00	2581	3076	84%
17:00	3531	4214	84%
18:00	2772	3129	89%
19:00	1495	1656	90%
20:00	903	997	91%
21:00	853	933	91%
22:00	671	729	92%
23:00	448	494	91%
00:00	295	321	92%
1:00	115	117	98%
2:00	70	76	92%
3:00	100	104	96%
4:00	250	261	96%
5:00	1129	1179	96%
6:00	3617	3939	92%
7:00	4971	5772	86%
8:00	2706	3906	69%
9:00	1347	1987	68%
10:00	835	991	84%
11:00	654	761	86%
12:00	651	824	79%
13:00	786	949	83%
14:00	1174	1377	85%
15:00	1616	2269	71%

Table 22 (Continued) Hourly Transmission Rate at Location 27

Hour Starting	Tags read @ OIC	Tags read @ RST	Hourly Transmission Rate (tags read @ OIC/ tags read @ RST)
16:00	2302	3237	71%
17:00	2984	4494	66%
18:00	2408	3037	79%
19:00	1446	1576	92%
20:00	877	976	90%
21:00	710	795	89%
22:00	603	661	91%
23:00	401	425	94%
00:00	277	290	96%
1:00	114	123	93%
2:00	74	78	95%
3:00	105	111	95%
4:00	198	214	93%
5:00	932	980	95%
6:00	2831	2951	96%
7:00	3929	4200	94%
8:00	2714	3042	89%
9:00	1605	2070	78%
10:00	1017	1063	96%
11:00	763	834	91%
12:00	778	820	95%
13:00	945	987	96%
14:00	1344	1403	96%
15:00	1750	1944	90%

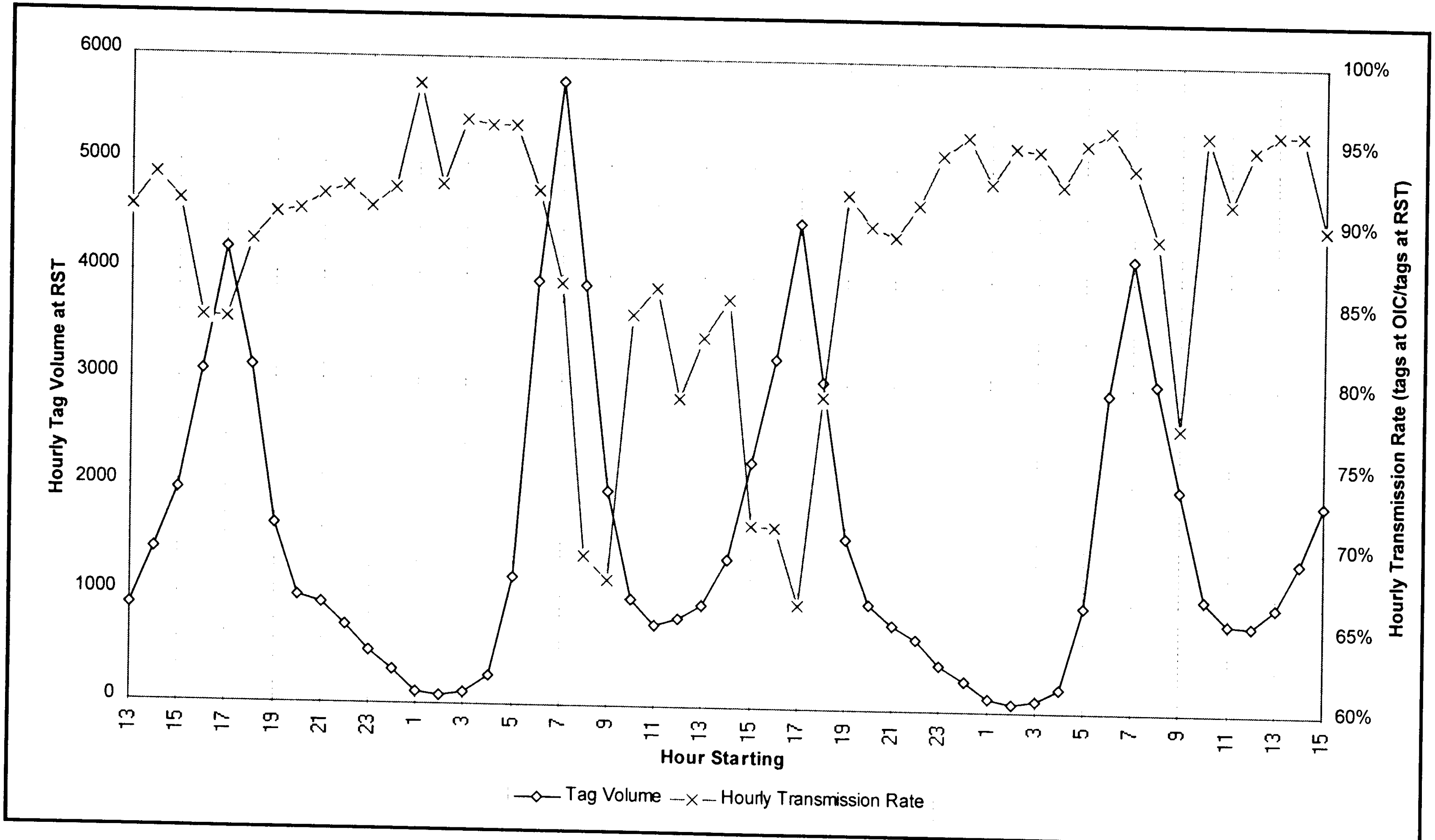

Figure 11. Hourly Tag Volume and Hourly Transmission Rate, Location 27

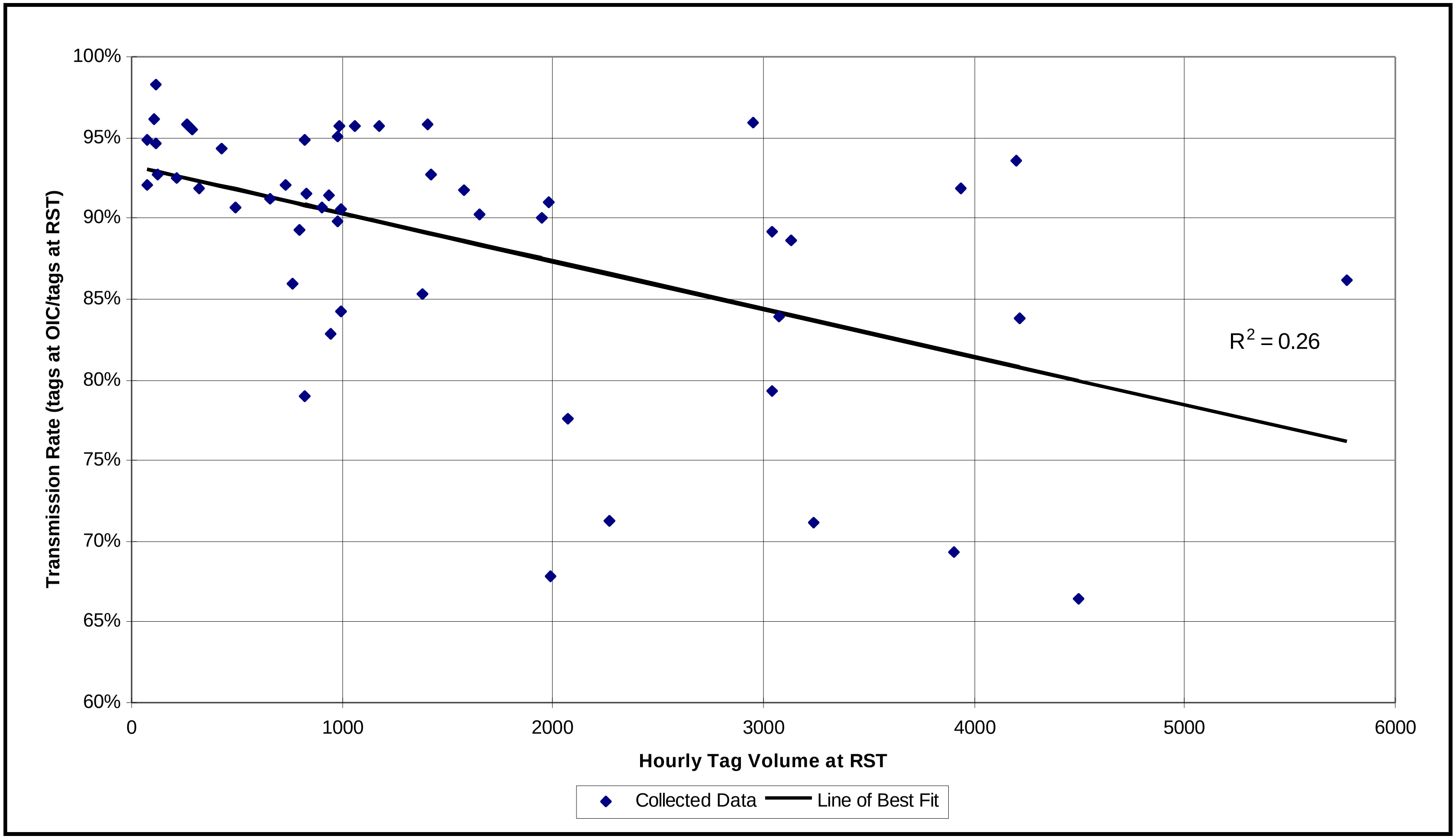

Figure 12. Transmission Rate versus Hourly Tag Volume at RST 27

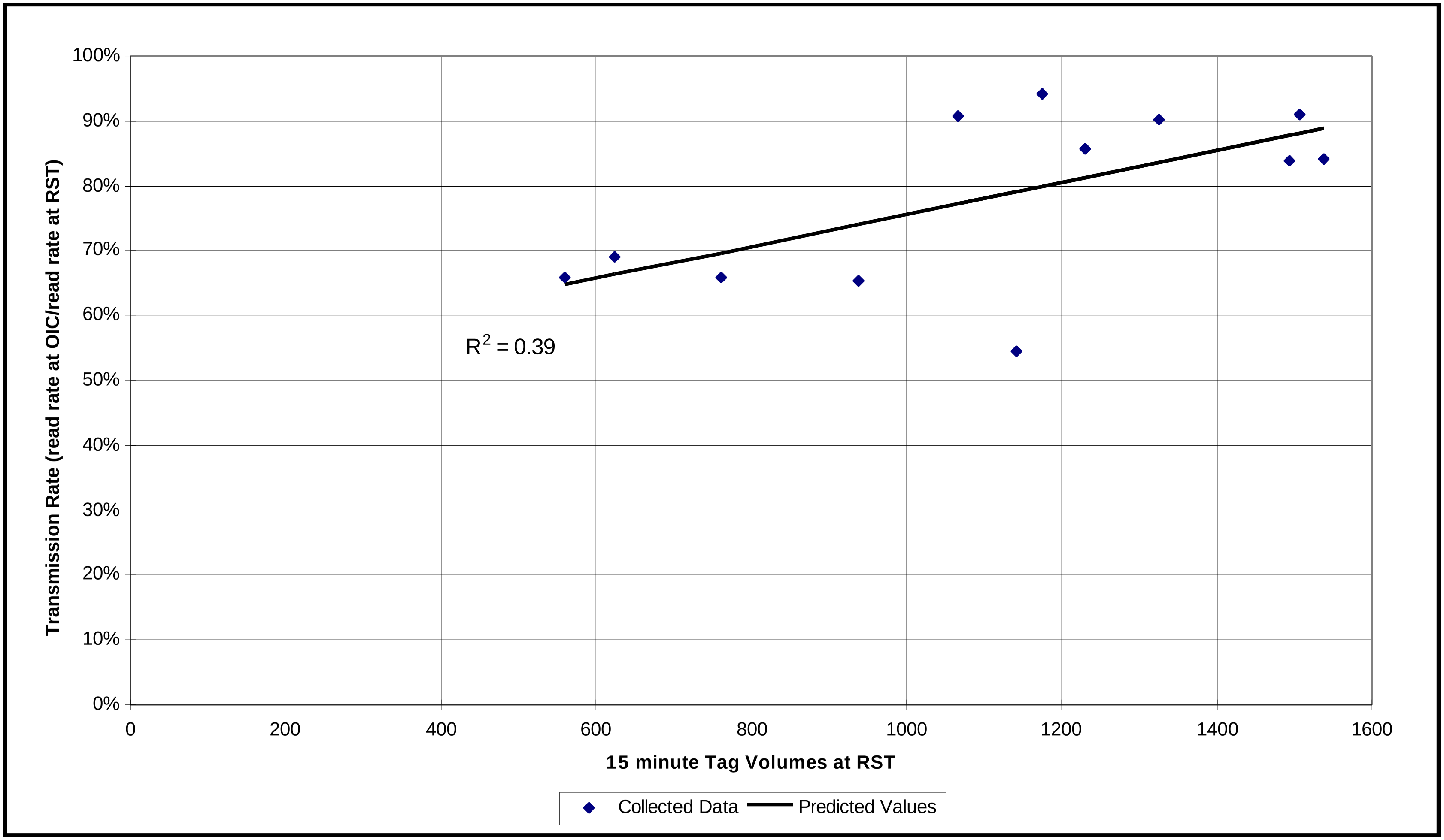

Figure 13. Transmission Rate versus 15-minute Tag volume at RST 27 for Thursday Morning Peak, 6:30 to 9:30, March 28, 1996

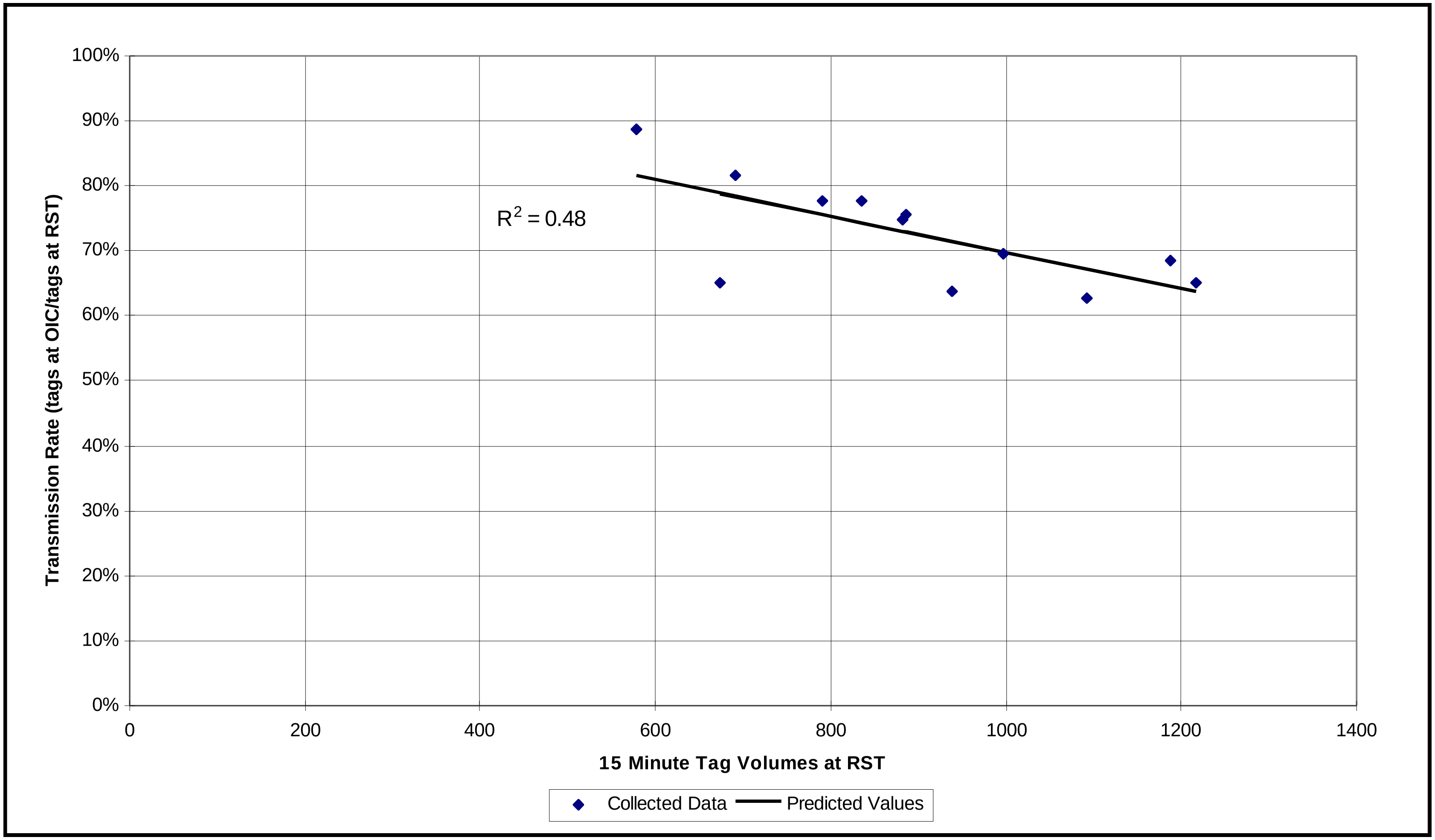

Figure 14. Transmission Rate versus 15 Minute Tag Volume at RST 27 for Thursday Evening Peak, 16:00 to 19:00, March 28, 1996

- Possible interference between the TRANSMIT radio link and other sources such cellular phone traffic. Especially at peak periods during higher volume traffic, more people slow down at the toll plaza and they may be using their cellular phones more often, which may cause an increase in interference with the radio link frequencies.
- Since the vehicles are interrogated continuously, the high volume of multiple responses within the relatively wide capture zone may lead to the overcrowding of the buffer set by the reader.
- Possible interference due to interaction of the bridge steel structure and the electromagnetic waves at the radio link frequencies.
- MARK IV software was undergoing changes during the first few months of the installation of the system.

The primary conclusions from the analysis of location 27 indicate that the transmission rate varied between 66% to 98% with an average of 88%. The detection rate improved from 48% to 83% between the initial and the second testing that were conducted in March and September of 1996, respectively. The radio link between locations 27 and 28 needs to be further investigated with an emphasis on each component of the system to identify the possible causes of the lower transmission rates more accurately.

3.4 Hardware and Software Problems

A measure of reliability of the TRANSMIT system is the down time at each individual RST or the OIC due to the hardware and/or software problems. However, during the evaluation period there was not any systematic method of identifying RST failures. The hardware and software failures identified in this report refer to incident logs maintained by operators at the OIC. Identification of problems in these records depended entirely on the operator's experience with the TRANSMIT system. A remote diagnostic system for the roadside terminals was under development, which once in operation, would allow the OIC to identify a reader failure as soon as it occurs. The hardware and software problems were cross-classified, per month and link, for the NYST and GSP roadside terminals, as shown in Tables 23 and 24, respectively. The hardware and software data were recorded in terms of links rather than RST locations. Only a few records included the specific location that was down. Therefore, the analysis was carried out in terms of links rather than locations, which would have been more appropriate. **The accurate characterization of the reliability of the TRANSMIT system could not be carried out during this phase of the evaluation, due to lack of detailed data related to the down times of the system as a whole or in terms of its specific components.**

3.4.1 New York State Thruway

During the evaluation period, the following hardware and software problems were observed along the NYST section of the TRANSMIT system: RST reader failures, OIC system crashes, firmware related problems, transformer problems, loss of communications with roadside readers, and one accident involving a tractor trailer and a roadside terminal. The hardware and software problems identified on the RSTs of the TRANSMIT system on NYST during the evaluation period are cross-classified per month and link in Table 23.

An average of 72 problems per month or 2.4 problems per day were encountered. During the month of January, hardware and firmware changes were introduced into the entire TRANSMIT system. Thus many of the hardware and software problems were probably associated with this introductory period. The frequency of the hardware and software problems remained constant during the following three months. On average, hardware and software problems occurred at a rate of 5 problems for every 2 days.

Hardware and software problems were further analyzed in terms of individual links to isolate the effects of problematic RSTs. As shown in Table 23, out of the 18 links comprising the NYST section, the six links with the highest frequency of problems, in descending order were 18, 24, 25, 17, 27, and 19. Each of these links experienced at least 20 equipment problems during the four-month period. In the absence of records indicating the duration when each RST or the OIC system was down during the evaluation period, more detailed analysis could not be carried out.

3.4.2 Garden State Parkway

The corresponding RST hardware and software problems reported in the TRANSMIT system along the GSP during the evaluation period are cross-classified per month and link in Table 24. Due to the relative infrequency of these problems (0.1-0.5 per day), it is concluded that the operation of the equipment associated with the GSP was very satisfactory.

Table 23. TRANSMIT Hardware and Software Problems Cross-Classified per Month and Link on NYST

Link	RST From - To	January 1996	February 1996	March 1996	April 1996	Total
13	**11-10**	0	0	3	0	3
14	**310-113**	3	3	0	4	10
15	**14-110**	6	0	0	1	7
16	**10-11**	2	4	0	1	7
17	**125-127**	4	2	14	7	27
18	**28-27**	4	9	13	14	40
19	**123-125**	7	10	1	2	20
20	**27-24**	2	0	3	0	5
21	**120-123**	7	3	0	4	14
22	**24-20**	6	1	2	3	12
23	**118-120**	6	1	0	1	8
24	**20-18**	8	8	10	9	35
25	**116-118**	5	8	10	5	28
26	**18-16**	7	4	4	1	16
27	**113-116**	12	7	5	2	26
28	**16-14**	8	2	3	2	15
29	**111-113**	0	1	0	6	7
30	**14-11**	2	3	0	1	6

Total		89 (2.9/day)	66 (2.3/day)	68 (2.2/day)	63 (2.1/day)	286 (2.4/day)

Table 24. Equipment Problems Cross-Classified per Month and Link on GSP

Link	RST From - To	January 1996	February 1996	March 1996	April 1996	Total
2	**1-2**	1	0	1	0	2
4	**2-3**	1	0	0	0	1
5	**104-103**	3	3	0	0	6
6	**3-4**	2	0	10	1	13
10	**7-9**	2	0	4	1	7
Total		**9 (0.3/day)**	**3 (0.1/day)**	**15 (0.5/day)**	**2 (0.1/day)**	**29 (0.24/day)**

3.5 Conclusions and Recommendations

3.5.1 Summary of Evaluation Results

The objective of this part of the evaluation was the performance and reliability of the TRANSMIT (**TRAN**SCOM's **S**ystem for **M**anaging **I**ncidents and **T**raffic) communication system. The performance of the communication system is quantified in terms of the data transmission rate of various communication links and the detection rate of its RSTs. The data transmission rate of the TRANSMIT system is primarily bounded by the system wide parameters such as the baud rate of modems, the data handling capacity of the leased telephone line in between individual Roadcheck™ readers, multiplexers installed at certain junctions and the radio link at Tappan Zee Bridge.

The assessment of the data transmission rate in the communication system was carried out by comparison of the collected daily data from the TRANSMIT system at the OIC to the corresponding field data gathered at selected RSTs along the test route. A total of 17 roadside terminals along the New York State Thruway and Garden State Parkway were each tested such that at least one morning and one evening peak was contained in the sample. This daily data collection was carried out during the months of February, March and September of 1996 for a total of 21 days.

The detection rate of the roadside terminals was tested using probe vehicles equipped with tags. These tests included 4 probe vehicles driven along the TRANSMIT route and were carried out for 5 days during March 1996. Tags associated with the probe vehicles were identified in the data collected at OIC, and hence this data was used to determine the detection rate of individual RSTs.

The transmission and detection rates of TRANSMIT system's RST readers is summarized in Table 25. The transmission rate is estimated based on two-way tag reads and the detection rate is estimated per direction.

The transmission capacity of the communication system is constrained primarily by the modem's baud rate along the dedicated leased telephone line between the multiplexer at RST location 9 and the OIC. The multiplexer handles 13 FDDA circuits (locations 10-28, NYST) with a resulting capacity of 80,575 tag equipped vehicles per hour per RST. Similarly, the maximum capacity of 9.6 kbps modems installed at the remaining RSTs are capable to handle 248,633 tag-equipped vehicles per hour per RST. An estimate of the maximum traffic flow capacity for different freeway facilities, based on the 1994 Highway Capacity Manual (1994 HCM) is as follows (in passenger cars per hour based on two-way volume): 4 lanes - 8,800; 6 lanes - 13,800; 8 lanes - 18,400; and 10 lanes - 21,000. The estimates for the maximum number of tag reads per hour that may be observed at Tappan Zee Bridge with a 100% market penetration rate, based on 7 lanes, is 16,100 (1994 HCM). The maximum hourly number of tag volumes observed on location 27 (Tappan Zee Bridge) during the evaluation period in March 1996 was found to be 5,772 tag reads (two-way volume).

The TRANSMIT system has a unique feature where error messages are explicitly embedded into the transmitted data if difficulties are encountered during detection or transmission. These error messages help significantly to identify possible causes which result in reduced transmission rates. The observed reduction in transmission rates at location 27 covering a two day test period can be attributed primarily due to the presence of corrupted communication (error type 14 and 18, 15,338 occurrences) between the RST and the OIC and/or tag and failure to establish communication to OIC (error type 2, 39,585 occurrences).

Table 25. Maximum Hourly Tag Read Rate, Transmission Rate and Detection Rate at each RST Reader

Reader Number(s)	**Max. Hourly Read Rate at RST (reads/hour)**	**Transmission Rate (read rate @ OIC/ read rate @ RST)**	**Detection Rate at RST reader**
1/101	469	100%	39% / 28%
2/102	470	100%	74% / 61%
3/103	582	100%	99% / 99%
4/104	522	100%	81% / 90%
7/107	444	100%	82% / 74%
9/109	486	98.8%	50% / 84%
310/110	1139	100%	99% / 100%
11/111	1697	100%	N/A / N/A
113	1637	100%	100%
14	1715	99.96%	100%
16/116	2691	100%	99% / 100%
18/118	N/A	N/A	N/A
20/120	3757	99.99%	98% / 93%
123	3838	99.99%	89%
24	2740	100%	94%
125	4061	99.99%	99%
27/127	5772	88.03%	48% / 53% (3/96) 93% (9-10/96)

Reader Number(s)	Max. Hourly Read Rate at RST (reads/hour)	Transmission Rate (read rate @ OIC/ read rate @ RST)	Detection Rate at RST reader
28	3089	99.96%	86%

The evaluation of the reliability of the TRANSMIT system led to the observation that during the evaluation period an average of 2.4 hardware and software problems per day were encountered on RST terminals located along NYST and an average of 0.31 along GSP, repsectively. Locations 17, 18, 19, 24, 25, and 27 exhibited the highest number of problems, from 20 to 40, with location 18 presenting the most (40). Location 18 experienced a considerable number of power failures during the evaluation period. Subsequently, TRANSCOM informed the evaluation team that this problem had been fixed. Along GSP, the existing five RSTs experienced very few hardware and software problems. Out of the total 29 problems occurred during the four month evaluation period, 13 of them were observed at location 6.

3.5.2 Conclusions

The communication system performance in the TRANSMIT system has been assessed satisfactorily in terms of the chosen test parameters, the transmission rate of various communication links and the detection rate of the roadside terminals. Data collection techniques employed were sufficient to determine accurately these parameters for the specific periods during the evaluation.

One of the measures of performance of the TRANSMIT communication system is the transmission rate, which has been determined by comparison of the data collected in the RST Database to the corresponding data in the OIC Database. **The transmission rates for all locations, except one, were found to be near perfect, ranging from 98.8% to 100%, regardless of the observed hourly read rates (maximum = 4,026 tags/hour - Location 25). A site-specific anomaly of the transmission rate of 88% was observed at location 27 (maximum hourly read rate = 5,772 tags/hour)**. At this site the hourly transmission rate variations ranged from 66% to 98%, and are attributed primarily due to the presence of a radio link. Location 27, located on the Tappan Zee Bridge, has the only radio link within the system while the remaining locations are connected through telephone lines. Other possible causes for such low transmission rates may be attributed to the wide capture zone of the antenna configuration at the bridge and the presence of a high traffic volume traveling at very low speeds, especially during the peak periods of the day.

The detection rate of individual RSTs subjected to testing using 4 probe vehicles led to a compilation of a limited database. Out of 18 RST locations tested 14 of them showed detection rates higher than 74%, in most of them this rate was approaching 100%. However, locations 1, 101, 102, 9, 18, 118, 27 and 127 showed a detection rate variation between 28% and 61%. Locations 18, 118 experienced power failures during the evaluation, which explains the lower detection rates. **The detection rate of locations 27 and 127 showed significant**

improvement, from 48% to 83%, during a second test that was conducted six months after the first test . This significant improvement may be attributed to better fine-tuning of the communication hardware and software. **It can be concluded that lower detection rates are not problematic to the entire system but specific to a few individual locations.**

The upper bound for the transmission capacity estimate of the communication system is 80,575 tag reads per hour per RST. This estimate was based on ideal detection, however, if error messages are generated and transmitted over the system these estimates could be decreased substantially. This decrease will not have any significant adverse effect on the successful operation of the system because of the available safety margin between the upper bound and operational transmission rates, 80,575 and 16,100 (Tappan Zee Bridge maximum two-way volume, 7-lanes) tag equipped vehicles per hour, respectively. **It can be concluded that the transmission capacity of the TRANSMIT system is capable to handle the maximum possible traffic flow conditions without any constraints.**

NYST RST locations 17, 18, 19, 24, 25, and 27, exhibited 20 or more hardware and software problems during the four-month evaluation period. For the GSP, only location 6 exhibited more than 10 hardware and software problems. **The frequency of hardware problems for these locations could degrade the performance of the TRANSMIT system significantly either for the specific link or the entire system as it is unable to detect possible incidents during the down time period. The severity of these problems could not be determined during this evaluation due to the lack of available data, such as the down time of each RST or the OIC.** It should be noted that the MARK IV RST failures and transformer problems have been rectified since the initial data collection during this evaluation.

3.5.3 Recommendations

It was observed that there was a significant improvement in the performance of the communication system between two different phases of the system, which were 6 months apart due to overall improvements in the system. Since the TRANSMIT system undergoes continuous fine-tuning of its elements, additional periodic testing becomes essential to establish the current state of the system. Although it was concluded that the transmission capacity of the TRANSMIT system is capable to handle the maximum possible traffic flow conditions without any constraints and the detection rates were found to be at a satisfactory level for most of the RSTs, the following recommendations are made to further improve the performance of the system.

It is recommended to establish a periodic monitoring of individual roadside detectors be included as a part of the operation and maintenance. Since some RSTs were observed to possess 100% detection rate, it should be set as a goal to achieve such a performance throughout the entire system. Some minor changes can be introduced into the system, such as periodic counting of the detected tags at the roadside terminal, and transmission of this information where a corresponding tag counter could be set for the same time interval resulting in periodic evaluation of the transmission rate. Similar mechanism can be established at the toll plazas to automatically determine and record the detection rates for the locations that are located before or after the toll plazas with no exits or entrances in between.

A more detailed experiment should be conducted for RSTs, which exhibited low detection rates, such as location 9. This may be accomplished through a controlled experiment to investigate the antenna position and orientation, as well as the location of the EZ Pass tags on the individual vehicles. Other tests may be conducted to establish the functionality of each antenna and the strength of the signal that is transmitted to the vehicle to activate the tag.

Due to the limited scope defined within the evaluation test, it was very difficult to pinpoint the exact nature of the problems observed related to the radio link at location 27. It is recommended to carry out an extensive evaluation of the radio link, including detailed analysis of possible interference effects in a realistic environment. If a provision is made such that Tappan Zee Bridge toll plaza data is automatically transmitted to the OIC, then its comparison with TRANSMIT data will help to diagnose any potential problems with the problematic radio link.

Further firmware enhancements such as remote activation features built into the system may help to maintain the system more efficiently in case of possible malfunctions. It is further recommended that this type of evaluation become a routine feature within the TRANSMIT system to continuously diagnose the current status of the individual components and the system as a whole.

There are no built-in features in the TRANSMIT system to detect and record the down times of the RSTs and the OIC. Measures have to be taken to identify the nature of hardware or software malfunctions and provisions have to be included into the system software to record the nature and duration of such failures.

4 EVALUATION OF TRAFFIC PARAMETERS

Executive Summary

TRANSCOM's **S**ystem for **M**anaging **I**ncidents and **T**raffic (**TRANSMIT)** capability to estimate traffic flow parameters is quantified in terms of:

- link mean travel time and variance,
- link space mean speed and variance.

Each time an E-ZPass tag equipped vehicle passes a RoadSide Terminal (RST) location, its tag identification number (tag ID) and the detection time are recorded. Data containing tag ID, detection time, location and lane position are forwarded to the Operations Information Center (OIC) at Jersey City, NJ. The travel time estimation for a particular link of a specific time interval of the day is based on the records of individual tag equipped vehicle data at consecutive roadside readers. Currently, these link travel time estimates are being used in the incident detection algorithm. The link mean travel time and space mean speed are estimated in 15-minute time intervals for weekdays, Saturdays, Sundays and holidays which are specified by the operator.

In order to determine the accuracy of the link travel time estimates of the TRANSMIT system, a traffic probe test consisting of four vehicles was conducted in March 1996. During the test period, which took place between March 12 and 28, 1996, link travel time data were collected for a total of five weekdays. Each probe vehicle was equipped with a unique tag ID allowing it to be identified among the corresponding TRANSMIT system data stored at the Operation Information Center (OIC). During the probe test drivers were instructed to follow the "average car technique". The assisting members in the probe vehicles were instructed to record the time on a log sheet when the front end of the vehicle passed below the location of a RST. The analysis of the collected data was carried out through a pairwise comparative test of the link travel time data collected by the vehicle probes and the corresponding TRANSMIT system data collected at the OIC. In addition, the probe link travel time data were compared to the TRANSMIT historical link travel time estimates.

The E-ZPass market penetration rate at Hillsdale toll plaza (GSP) varied from 1.59% to 16.50% and at Spring Valley and Tappan Zee Bridge toll plazas (NYST) varied from 5.29% to 73.84%, based on data provided by TRANSCOM for the week of November 17, 1996. In general, the GSP showed a much lower E-ZPass market penetration rate than NYST, which is expected since only NYST had installed the E-ZPass toll collection system.

The importance of the E-ZPass volume lies in the minimum sample size required to provide good estimates of the link travel time for each link of the TRANSMIT system and for each 15-minute time period of the day. **Using the historical link mean travel time and standard deviation, and a 95% confidence interval, it was determined that 90% of the links require**

a sample size of less than 15 vehicles per 15-minute time interval to provide accurate link travel time estimates.

Based on a comparison of the required sample size for a 95% confidence interval and a tolerance of 10% of the historical link mean travel time, 85.5% (2,111 out of 2,470 intervals) of the link travel time intervals exhibited adequate E-ZPass volumes. Correspondingly, for a tolerance of 20% of the historical link mean travel time, 97.4% (2,406 out of 2,470 intervals) resulted in adequate E-ZPass volumes in providing accurate estimates. The lack of adequate sample size for these few 15-minute time intervals will be considerably lessened as the E-ZPass market penetration rate is expected to increase in the near future.

A comparison of the OIC and the corresponding probe vehicle link travel time data indicated that 92% of the link travel time data were within 3 seconds from each other. Since about 8% of the link travel time data at OIC and the corresponding probe vehicle data have differences in excess of 3 seconds it may be concluded that for these records the time stamps at various RST locations may have been recorded incorrectly by the reader due to either hardware or software problems or data collection errors. **The results of the pairwise t-test indicated that only 3 time intervals out of a total of 130 for all the links and time intervals failed the test, link 17 in time periods 11:30 AM - 13:00 PM and 16:30 PM - 18:30 PM, and link 18 in time period 6:30 AM - 9:00 PM. These three links are associated with location 27 (radio link at Tappan Zee bridge which exhibited the highest number of communication problems). Therefore it may be concluded that the tag equipped vehicle link travel times are recorded properly at OIC**.

The results presented in this evaluation were based on a limited scope probe vehicle test. It is recommended that a more comprehensive test be conducted that will provide a much larger sample size for each 15-minute period of the day, including weekends, and special holidays. The primary reason for this test will be to provide an indication of the current status of the TRANSMIT's roadside reader locations. This test will establish the current detection rate at each location, as well as the reliability of the link travel times. It is suggested that during this test the synchronization of the clocks at each roadside reader be tested and corrected. Specifically, the roadside reader locations, which exhibited lower detection rates and high frequency of communication problems, should be revisited to identify whether the problems are still present or have been corrected.

It is also recommended that TRANSMIT becomes a national test bed for providing link travel time probe vehicle data, traffic volume, and Origin-Destination data. A procedure should be established to collect and store data on tapes or other storage devices that would be accessible to transportation researchers across the nation. The traffic parameters data determined by the TRANSMIT system has a unique character and it would provide a valuable resource for researchers. Similar types of data were not available before or were extremely costly and time consuming to compile. In particular this data would be useful to the Traffic Flow Theory and Characteristics Committee of the Transportation Research Board (TRB), as well as other TRB committees and the Federal Highway Administration.

It may be concluded that link travel time and space mean speed estimation can be done successfully by the TRANSMIT system for incident detection, transportation planning and traveler information. Path travel time and O-D estimates as well as vehicle tracking should also be considered to be part of the output of the TRANSMIT system since these parameters are readily available once the software is modified. Traffic volume estimates are not currently available by the TRANSMIT system. A study should be undertaken to establish the feasibility of providing such an estimate for the traffic volume based on the market penetration rate which can be continuously estimated in real time at each toll plaza. It is noted that originally the TRANSMIT system was developed to provide incident detection information, however, it is realized that it can provide these additional parameters which would make it a more complete traffic management and information system for the metropolitan area.

4.1 Purpose and Scope

The purpose of this part of the evaluation was to assess the capability of the **TRANSMIT** system to estimate the following traffic flow parameters:

- link mean travel time and variance,
- link space mean speed and variance.

The accuracy of these estimates was determined through a traffic probe test that was conducted along the TRANSMIT route during March 1996. The analysis of the collected data is carried out through a pairwise comparative test of the link travel time data gathered by the vehicle probes to the corresponding data collected at the OIC.

This chapter also includes one week period of traffic flow data collected at the Spring Valley and Tappan Zee Bridge toll plazas on New York State Thruway, and Hillsdale toll plaza on Garden State Parkway. The total traffic volume observed at these toll plazas and the corresponding E-ZPass traffic volume per hour of the day and day of the week were collected. The collected field data could be used for the estimation of the total traffic volume at each Roadside Terminal Reader (RST) location of the TRANSMIT system, based on the total number of tag reads at these locations.

This chapter includes an executive summary, purpose and scope, the evaluation data collection procedures, a summary of pertinent data collected and its analysis, and a summary of the results and recommendations.

4.1.1 Hypothesis for Link Travel Time.

The link travel time difference m_D, between the OIC link travel times estimates and the corresponding probe vehicle link travel time estimates is within a time difference Δ_0, per link and per time period of the day, with a 95% confidence interval.

Null Hypothesis: Ho: $m_D \leq |\Delta_0|$ versus Alternative Hypothesis: Ha: $m_D \rangle |\Delta_0|$

Test statistic value: $t_{paired} = \frac{\bar{d} - \Delta_0}{s_d / \sqrt{n}}$, with (n - 1) degrees of freedom,

where:

$m_D = m_1 - m_2$

m_1 : the population mean of the OIC link travel time data, for each time interval,

m_2 : the population mean of the probe vehicle link travel time data for each time interval,

Δ_0 : paired link time difference tolerance ($\pm$ 3 seconds),

$\bar{d} = \frac{1}{n}\sum_{i=1}^{n}(t_{1i} - t_{2i})$; sample mean link travel time difference, for each time interval,

t_1 : OIC link travel time data point,

t_2 : probe vehicle travel time data point,

s_D : sample standard deviation of link travel time difference, for each time interval,

n : sample size per time interval.

4.2 Data Collection

The objective of the traffic parameter evaluation was to test the TRANSMIT system's ability to accurately estimate travel times, space mean speed for each 15-minute time periods along its 30 links. The principal objective was to identify any significant differences in the link travel time estimates acquired through probe vehicles and the corresponding values determined through the TRANSMIT system. The probe vehicle test utilized four probes and concentrated primarily on the morning peak (6:30 - 9:00), the noon peak (11:00 - 13:00), and the evening peak (16:30 - 18:30) periods of the day. However, smaller samples of data were collected during the morning and afternoon off-peak periods as well.

During the test period, between March 12 and 28, 1996, link travel time data were collected for a total of five weekdays. Each probe vehicle was equipped with a unique tag ID allowing it to be identified among the data collected at the Operation Information Center (OIC). Drivers were instructed to follow the "average car technique" while driving. The assisting members in the probe vehicles were instructed to record the time on a log sheet when the front end of the vehicle passed below the location of an antenna reader. All participants were trained in the data collection procedure prior to the actual test in order to reduce errors in data collection. The participants were driven twice along the test route prior to the actual testing to familiarize themselves with the locations of antenna readers and the proper data collection techniques.

A total of 2,516 data records were collected during the probe vehicle test covering these five days, out of which only 38 records were confirmed by the data collectors that they were not recorded properly. In each "record" collected by the vehicle probes, the RST location number, time, date, and tag ID number were included. Simultaneously, the corresponding tag ID records were obtained at the OIC, which contained the detection time of the probe vehicles at each RST.

In addition, hourly traffic volume data were acquired by TRANSCOM at the Tappan Zee Bridge and Spring Valley toll plazas on NYST and Hillsdale toll plaza on GSP for the week of November 17 to 23, 1996 for this evaluation. This data sorted in hourly traffic flow rates for the weekday, Saturday and Sunday is presented in Appendix B and served as the basis to determine the current market penetration rate of the E-ZPass toll collection system.

4.3 Evaluation Results

The evaluation for the estimation of traffic parameters of the TRANSMIT system was carried out simultaneously with the evaluation of its communication system. The undertaken probe vehicle test addressed the following issues:

- the detection of the tag equipped vehicles at each individual RST reader,
- the estimation of the difference between the link travel times determined by the TRANSMIT system at OIC versus the corresponding values collected by the probe vehicles.

The analysis of the data on the detection rate of the roadside readers was presented in the evaluation of the communication system [see Chapter 3]. This section includes a summary of the traffic volume data collected by TRANSCOM at the Tappan Zee Bridge and the Spring Valley toll plazas on NYST, and the Hillsdale toll plaza on GSP during a one week period, followed by the analysis of the data collected during the probe vehicle test.

4.3.1 Traffic Volumes and E-ZPass Market Penetration at the Toll Plazas

A week of traffic volume data at the Tappan Zee Bridge Toll Plaza southbound on the NYST, at the Spring Valley toll plaza northbound and southbound on the NYST, and at the Hillsdale toll plaza northbound and southbound on the GSP, were collected. The analyzed data included the hourly total traffic volume and the E-ZPass volume at each toll plaza between November 17 and 23, 1996. The hourly variations of the traffic volumes are given in Tables B1 to B9 and in Figures B1 to B9 in Appendix B, correspondingly.

The minimum and maximum hourly traffic volumes and E-ZPass market penetration rate estimates are listed in Table 26. In general, the GSP showed a much lower E-ZPass market penetration rate than NYST which it is expected since the GSP has not installed the E-ZPass toll collection system currently.

In Table 27, the required sample size for a sample of links and time intervals of the day is presented. Based on a comparison of the required sample size for a 95% confidence interval and a tolerance of 10% of the historical link mean travel time, 85.5% (2,111 out of 2,470 intervals) of the link travel time intervals exhibited adequate E-ZPass volumes.

Correspondingly, for a tolerance of 20% of the historical link mean travel time, 97.4% (2,406 out of 2,470 intervals) resulted in adequate E-ZPass volumes in providing accurate estimates. This is also illustrated in the frequency distribution diagram in Figure 15, where for a 95% confidence interval, 96% of the links require a sample size of less than of 20 vehicles and 90% require less than 15 vehicles, per 15-minute time interval. The sample size *n* **is determined via**

$$n = \left(\frac{s\,V}{e} \right)^2$$

where: n = sample size, s = historical SD, V = 1.96 for 95% CI, e = tolerance around the mean

Table 26. Market Penetration of the E-ZPass System Based on the E-ZPass Hourly Volumes Collected at Toll Plazas on 11/17-23/96

	% Vehs w/ EZ pass NB	**% Vehs w/ EZ pass SB**	**Reference Table**
min	1.59%	1.97%	Table B1. Hillsdale Toll Plaza
max	10.30%	13.47%	Sunday Total and EZ Pass H. Vol. - 11/17/96
min	2.65%	1.90%	Table B2. Hillsdale Toll Plaza
max	13.69%	12.10%	Weekday Total and EZ Pass H. Vol. - 11/18-22/96
min	1.76%	2.05%	Table B3. Hillsdale Toll Plaza
max	13.20%	16.50%	Saturday Total and EZ Pass H. Vol. - 11/23/96
min	N/A	13.00%	Table B4. Tappan Zee Bridge
max	N/A	60.38%	Sunday Total and EZ Pass H. Vol. - 11/17/96
min	N/A	14.10%	Table B5. Tappan Zee Bridge
max	N/A	73.84%	Weekday Total and EZ Pass H. Vol. - 11/18-22/96
min	N/A	14.48%	Table B6. Tappan Zee Bridge
max	N/A	67.37%	Saturday Total and EZ Pass H. Vol. - 11/23/96
min	7.59%	8.86%	Table B7. Spring Valley Toll Plaza
max	21.02%	29.30%	Sunday Total and EZ Pass H. Vol. - 11/17/96
min	5.88%	5.29%	Table B8. Spring Valley Toll Plaza
max	37.99%	44.53%	Weekday Total and EZ Pass H. Vol. - 11/18-22/96
min	8.71%	5.78%	Table B9. Spring Valley Toll Plaza
max	21.96%	28.71%	Saturday Total and EZ Pass H. Vol. - 11/23/96

It may be concluded that for the majority of the links and 15-minute time intervals of the day, there already exists a sufficient E-ZPass market penetration to provide an adequate sample size for the accurate determination of the average link travel time. The lack of an adequate sample size for a few 15-minute time intervals will be lessened as the E-ZPass market penetration rate is expected to increase in the near future. It is noted that at the time that this evaluation was undertaken, only NYST had installed the E-ZPass system.

4.3.2 Summary of Pairwise Link Travel Time Results

Out of a total of 2,516 records collected by the probe vehicles, 1,968 (78%) corresponding entries were also found to be recorded at the OIC. Of the 548 records that were "missed," 59.3% were associated with locations 27, 18, and 1. Locations 2, 4, 7 and 9 were associated with an additional 33.2% of missed records. These locations exhibited communication problems. Without these locations the corresponding detection rates would have been near 100%. The results for the detection test are presented in the evaluation of the communication test in Chapter 3.

The 1,968 records which were matched between the OIC data and the probe vehicle data, resulted in a total of 1,755 individual probe vehicle link travel time entries which were used for the pairwise analysis. These link travel times were compared to the corresponding probe vehicle link travel times recorded in the OIC database. A comparative analysis of the collected data from the probe vehicle database and the OIC database yielded several discrepancies, which can be attributed to:

- errors made by the individual data collectors in the probe vehicles (32, 1.8%),
- possible errors within the TRANSMIT system (11, 0.6%).

The process of identifying the error source involved examination of link travel times that looked unreasonably low or high, such that tag equipped vehicles could not have experienced during the probe vehicle test. Unfortunately, many of the discrepancies between the two database records were difficult to clarify because the sources of errors were not that obvious to decipher. The 11 entries for the link travel times that were attributed to possible errors in the TRANSMIT system, exhibited discrepancies in the range between 25 to 68 seconds. These 11 possible errors and the additional 32 records that were identified as errors by the data collection personnel were excluded from the analysis, resulting in a total of 1,712 records.

A pairwise analysis was conducted to determine the differences between the probe vehicle data and the corresponding data collected at OIC. Among the 138 errors that could not be attributed to any source, the observed discrepancies ranged from 4 to 54 seconds. **The OIC and the corresponding probe vehicle link travel time data indicate that 1,527 (89%), 1,573 (92%) and 1,599 (93.4%) were within 2, 3 and 4 seconds from each other, respectively.**

Table 28 presents the mean, standard deviation and the number of observations of the link travel time difference of the pair data (the OIC data and the probe data), per link and time period of the day. Table 29 presents the t-paired statistic with a 95 % confidence interval and the null hypothesis that the mean link travel time difference of the OIC and the corresponding probe vehicle data are within a tolerance of ± 3 seconds from each other. Time periods with less than 3 sample sizes were excluded from the t-test. The ± 3 seconds tolerance is justified under the assumption that the data collection personnel could not know a priori when the

Table 27. Required Sample Size for a Sample of Links and 15-min Time Intervals; 95% C.I.

Link #	15-minute Time Interval	Historical Average Travel Time (s)	Historical Standard Deviation (s)	Required Sample Size for a Tolerance (# of vehicles)		15-min E-ZPass Volume (# of vehicles)	% Diff. (15-min E-ZPass volume and Req'd Sample Size at 10% of Mean
				10% of Mean	20% of Mean		
13	6:30	45.5	5.0	18.6	4.6	13.3	-39.5%
16	7:45	103.6	5.1	3.7	0.9	7.7	51.6%
18	8:00	83	5.9	7.8	1.9	207.8	96.3%
17	8:15	203.5	15.9	9.4	2.3	345.3	97.3%
11	8:30	85.8	5.0	5.2	1.3	72.2	92.8%
16	9:15	103.9	5.0	3.6	0.9	4	11.0%
20	9:30	140	11.0	9.5	2.4	63	84.9%
1	10:00	63.1	5.0	9.6	2.4	16.6	41.9%
13	10:45	43	5.0	20.8	5.2	4.1	-406.7%
15	11:30	90	5.5	5.7	1.4	15.4	62.7%
17	12:15	124	10.5	11.0	2.8	99.1	88.9%
18	12:30	85	6.0	7.7	1.9	90.4	91.5%
19	12:45	28.1	5.0	48.7	12.2	102.7	52.6%
19	13:00	28.1	4.1	32.7	8.2	98.2	66.7%
26	13:00	104.9	6.8	6.5	1.6	48.8	86.8%
16	12:15	106.4	5.0	3.4	0.8	3.6	5.7%
13	12:30	45.9	5.0	18.2	4.6	4	-355.9%
14	12:30	62.2	5.0	9.9	2.5	18	44.8%
11	12:45	85.9	5.0	5.2	1.3	9.1	42.8%
12	12:45	86.2	5.0	5.2	1.3	5.1	-1.4%
18	16:00	74.9	5.2	7.4	1.9	382.6	98.1%
18	16:15	75.6	5.1	7.0	1.7	434.6	98.4%
22	16:30	78.9	6.1	9.2	2.3	334.3	97.3%
18	16:45	72.8	5.1	7.5	1.9	449.8	98.3%
20	17:00	139.3	9.3	6.8	1.7	391.1	98.2%
13	17:30	43.3	5.0	20.5	5.1	7.9	-159.4%
1	19:15	66	5	8.8	2.2	24.8	64.4%
9	20:00	70.3	4.1	5.2	1.3	8	34.7%
5	21:00	95.8	5.1	4.4	1.1	8.1	46.2%

Figure 15. Frequency Distribution of the Required Sample Size for the Estimation of 15-minute Link Mean Travel Times based on a 95% C.I. and Interval Size 10% of the Mean

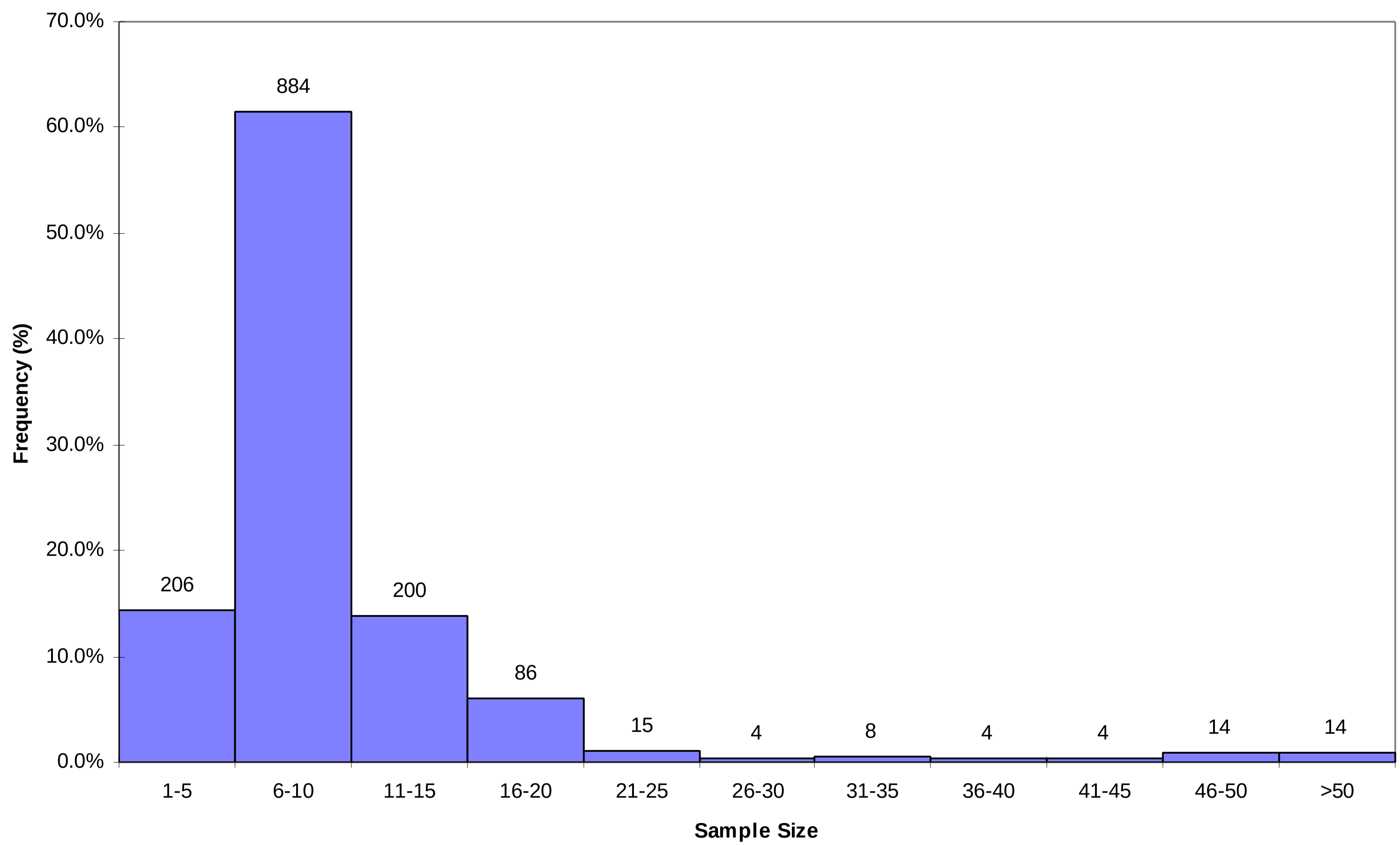

Table 28. Mean, Standard Deviation and Sample Size of Link Travel Time Differences between Vehicle Probes and OIC Data

Link Number	6:30 - 9:00			9:00 - 11:00			11:00 - 13:00			13:00 - 16:30			16:30 - 18:30		
	Mean (sec)	**Std. Dev. (sec)**	**Sample Size**	**Mean (sec)**	**Std. Dev. (sec)**	**Sample Size**	**Mean (sec)**	**Std. Dev. (sec)**	**Sample Size**	**Mean (sec)**	**Std. Dev. (sec)**	**Sample Size**	**Mean (sec)**	**Std. Dev. (sec)**	**Sample Size**
1	4.50	5.50	2	0.75	0.83	4	1.00	0.89	5	0.00	1.55	5	0.89	0.99	9
2	2.00	3.70	6	0.00	0.00	1	0.17	0.37	6	0.75	0.43	4	1.00	0.94	9
3	-0.50	2.50	14	0.00	1.00	2	0.09	0.90	11	0.00	0.00	3	0.25	0.62	20
4	-0.65	1.71	17	-0.33	0.94	3	-0.22	2.62	18	0.00	0.60	11	-0.32	0.92	19
5	0.94	0.78	18	0.83	0.69	6	0.67	0.84	21	0.62	0.62	13	0.37	1.19	27
6	1.50	4.90	16	0.00	0.00	2	0.00	2.25	23	-0.67	0.94	9	-0.63	1.66	19
7	-1.31	2.31	16	-0.57	0.49	7	-0.65	0.68	17	-0.60	0.80	10	-0.28	1.34	25
8	-1.06	5.01	16	-0.50	0.87	4	0.25	0.92	24	-0.13	0.78	8	0.10	1.37	20
9	1.07	2.34	14	-0.25	0.83	4	0.47	0.72	15	0.13	0.33	8	0.58	1.04	24
10	0.28	1.28	18	0.00	0.82	3	0.00	0.63	10	0.50	0.50	4	0.60	1.28	10
11	-0.71	0.82	17	-0.20	0.75	5	-0.39	0.59	18	-0.44	0.83	9	-0.96	1.16	26
12	-0.45	1.50	20	-0.20	0.75	5	-0.32	0.80	28	0.73	2.99	11	1.21	7.10	24
14	-0.30	3.95	20	0.20	0.75	5	-0.15	1.53	27	-0.73	2.99	11	0.00	1.10	23
15	0.18	0.92	17	0.83	1.21	6	0.14	0.77	21	0.85	1.61	13	-0.38	3.10	29
17	-0.50	18.60	10	6.83	6.64	6	6.08	10.46	12	2.80	2.79	5	6.67	5.76	15
18	5.33	1.80	6	22.00	0.00	1	5.20	7.67	10	0.17	4.74	6	2.94	5.38	17
19	1.55	5.84	20	-0.25	0.83	4	0.83	1.25	24	-0.22	1.55	9	0.19	1.06	27
20	-2.13	2.93	16	-5.50	8.64	6	-4.40	8.48	20	0.13	2.03	8	-2.62	4.66	21
21	-4.44	7.90	18	0.00	0.00	2	-1.19	1.84	21	-1.00	0.00	3	-0.77	1.01	26
22	0.69	1.61	16	-0.17	1.86	6	0.09	0.79	22	0.00	3.49	11	-0.88	4.80	26
23	0.95	0.83	19	1.25	0.83	4	0.91	1.73	22	0.00	0.50	8	0.67	0.78	21
24	-3.00	3.00	2	-0.67	0.94	3	-0.25	0.66	8	0.00	1.00	2	0.40	0.80	10
25	-2.29	3.81	7	0.00	0.00	1	-0.18	0.94	11	0.00	0.00	1	0.20	0.75	15
26	0.67	1.49	18	0.29	0.70	7	0.50	0.67	20	-0.38	3.13	13	1.34	3.04	29
27	0.48	4.22	21	-0.50	1.12	4	0.07	0.96	28	0.22	5.01	9	0.04	1.02	24
28	-0.33	1.05	18	-0.43	0.90	7	-0.50	0.92	20	-1.00	1.57	13	0.00	3.03	29

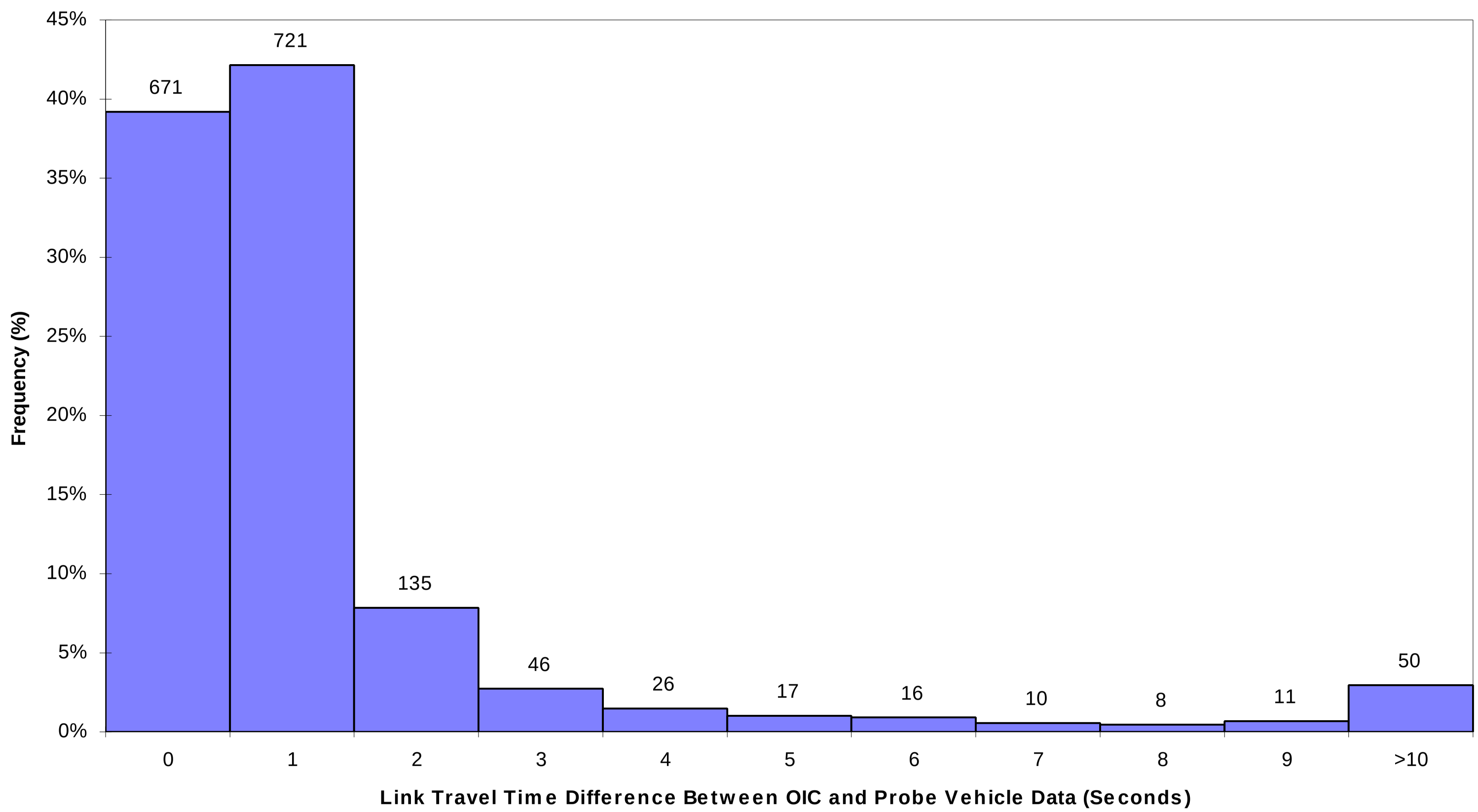

Figure 16. Frequency Distribution of the Link Travel Time Differences Between the OIC and the Probe Vehicle Data

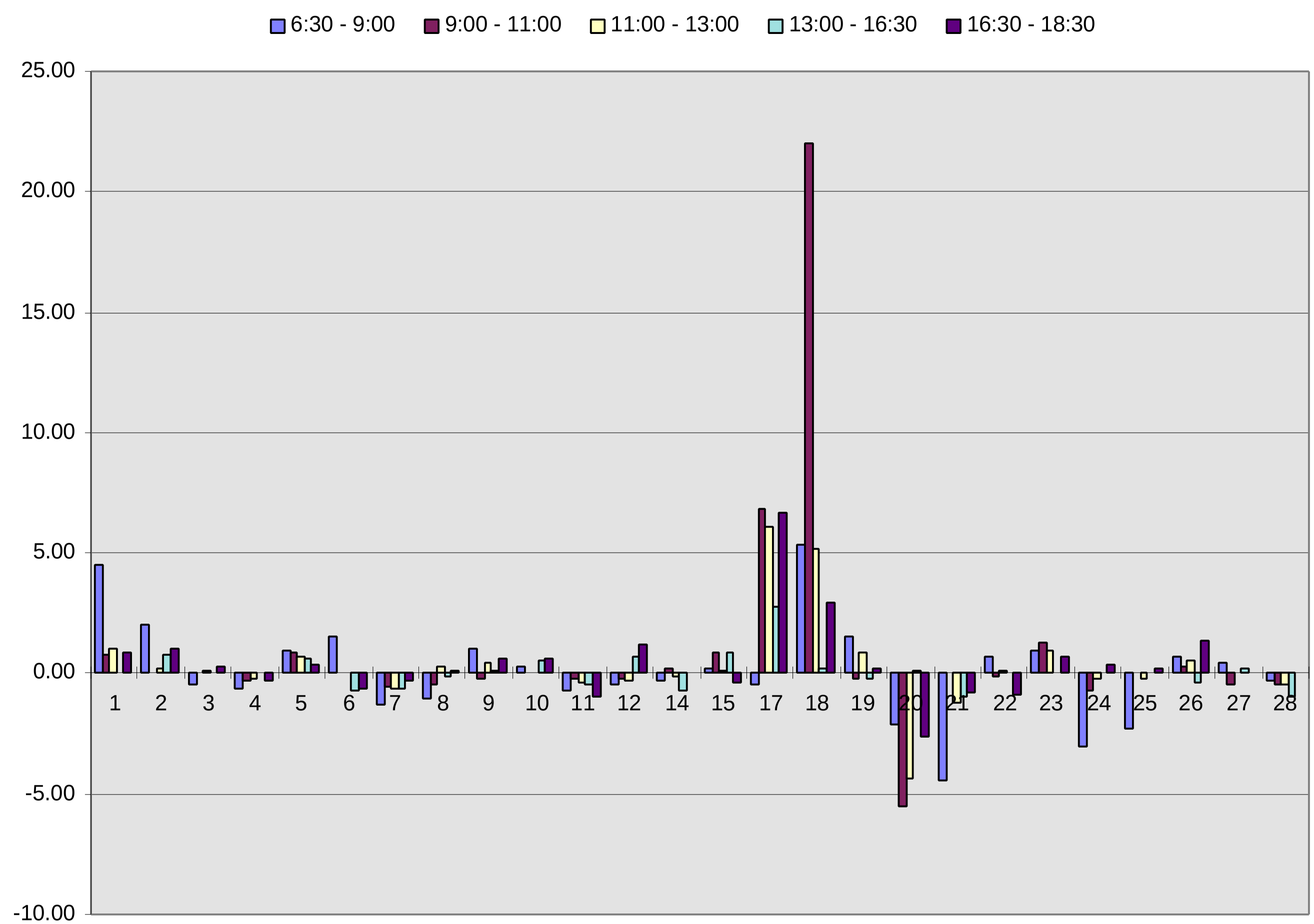

Figure 17. Mean of Link Travel Time Differences versus Link Number and Time Period of the Day

roadside reader detects the vehicle. The detection zone of each RST is about 60 ft, therefore a vehicle may be detected at any point within the capture zone. Therefore, discrepancies between two corresponding records in the order of 1 to 3 seconds should be expected.

The results in Table 29 indicate that only 3 time intervals failed the t-pairwise test, link 17 and time periods 11:30 AM to 13:00 PM and 16:30 PM to 18:30 PM, and link 18 and time period 6:30 AM to 9:00 PM. Therefore it may be concluded that the tag equipped vehicle link travel times are recorded properly at OIC. Both links 17 and 18 are associated with location 27 (radio link at Tappan Zee bridge) which exhibited the highest number of communication problems during the evaluation (see Chapter 3).

Although no considerable link travel time differences have been observed for the majority of the links and time periods of the day, the following is noted as a caution to be taken under consideration. The accuracy of each individual link travel time that is estimated at OIC depends on the time stamps at two consecutive RST readers. **If a tag record at a RST reader is timed incorrectly then the travel time of the upstream and the downstream links would be estimated incorrectly.** Since about 8% of the link travel time data at OIC and the corresponding probe vehicle data have differences in excess of 3 seconds it may be assumed that the time stamps at different RST locations may have been recorded incorrectly by the RST reader due to either hardware or software problems or due to data collection errors. Efforts should be undertaken to examine the possibility that the time stamp placed on the tag IDs may sometimes be recorded incorrectly. **The clocks at each RST must be synchronized and should be checked for errors periodically.**

This study concentrated only on the data recording procedure of the RSTs and the OIC. It did not examine the link travel time estimation algorithm used by the TRANSMIT system in updating the historical link travel time estimation. Therefore, additional studies should be undertaken to examine the accuracy of the historical link travel time estimation algorithm.

Table 29. t-paired test of Link Travel Time Differences between Vehicle Probes and OIC Data;
95 % Confidence Interval; $m_D \leq |3$ seconds$|$

Link	6:30 - 9:00				9:00 - 11:00				11:00 - 13:00				13:00 - 16:30				16:30 - 18:30			
Number	t sample	t a=.025	m_D C.I 95%	Test	t sample	t a=.025	m_D C.I 95%	Test	t sample	t a=.025	m_D C.I 95%	Test	t sample	t a=.025	m_D C.I 95%	Test	t sample	t a=.025	m_D C.I 95%	Test
1	N/A	N/A	N/A	N/A	1.81	3.18	± 4.32	T	2.50	2.78	± 4.92	T	0.00	2.78	± 3.92	T	2.68	2.31	± 3.76	T
2	1.33	2.57	± 6.88	T	N/A	N/A	N/A	N/A	1.10	2.57	± 3.56	T	3.46	3.18	± 4.00	T	3.18	2.31	± 3.72	T
3	-0.75	2.16	± 4.44	T	0.00	12.71	± 11.98	T	0.34	2.23	± 3.00	T	0.00	3.00	± 3.00	T	1.80	2.09	± 3.29	T
4	-1.56	2.12	± 3.88	T	-0.61	4.30	± 5.34	T	-0.36	2.11	± 3.38	T	0.00	2.23	± 3.47	T	-1.50	2.10	± 3.44	T
5	5.14	2.11	± 3.39	T	2.97	2.57	± 3.72	T	3.66	2.09	± 3.36	T	3.55	2.18	± 3.50	T	1.62	2.06	± 3.47	T
6	1.22	2.13	± 5.61	T	N/A	N/A	N/A	N/A	0.00	2.07	± 3.65	T	-2.12	2.31	± 3.88	T	-1.66	2.10	± 3.80	T
7	-2.27	2.13	± 4.23	T	-3.06	2.45	± 3.46	T	-3.92	2.12	± 3.54	T	-2.37	2.26	± 3.61	T	-1.04	2.06	± 3.55	T
8	-0.85	2.13	± 5.67	T	-1.15	3.18	± 4.38	T	1.33	2.07	± 3.57	T	-0.45	2.37	± 3.73	T	0.33	2.09	± 3.64	T
9	1.71	2.16	± 4.35	T	-0.60	3.18	± 4.32	T	2.52	2.15	± 3.25	T	1.07	2.37	± 3.50	T	2.75	2.07	± 3.44	T
10	0.92	2.11	± 3.64	T	0.00	4.30	± 5.03	T	0.00	2.26	± 3.57	T	2.00	3.18	± 4.29	T	1.48	2.26	± 3.92	T
11	-3.53	2.12	± 3.42	T	-0.60	2.78	± 3.93	T	-2.79	2.11	± 3.58	T	-1.60	2.31	± 3.52	T	-4.23	2.06	± 3.47	T
12	-1.34	2.09	± 3.70	T	-0.60	2.78	± 3.93	T	-2.12	2.05	± 4.85	T	0.81	2.23	± 6.23	T	0.83	2.07	± 6.00	T
14	-0.34	2.09	± 4.85	T	0.60	2.78	± 3.93	T	-0.50	2.06	± 4.85	T	-0.81	2.23	± 3.51	T	0.00	2.07	± 3.48	T
15	0.79	2.12	± 3.47	T	1.68	2.57	± 4.27	T	0.85	2.09	± 3.93	T	1.90	2.18	± 4.25	T	-0.66	2.05	± 4.18	T
17	-0.08	2.26	± 16.31	T	2.52	2.57	± 9.97	T	**2.01**	**2.20**	**± 5.74**	**F**	2.25	2.78	± 7.13	T	**4.48**	**2.15**	**± 6.19**	**F**
18	**7.28**	**2.57**	**± 4.88**	**F**	N/A	N/A	N/A	N/A	2.15	2.26	± 7.38	T	0.09	2.57	± 6.36	T	2.25	2.12	± 5.77	T
19	1.19	2.09	± 5.73	T	-0.60	3.18	± 4.32	T	3.27	2.07	± 4.07	T	-0.43	2.31	± 3.47	T	0.91	2.06	± 3.42	T
20	-2.90	2.13	± 4.56	T	-1.56	2.57	± 12.06	T	-2.32	2.09	± 4.50	T	0.17	2.37	± 5.41	T	-2.57	2.09	± 5.12	T
21	-2.39	2.11	± 6.93	T	N/A	N/A	N/A	N/A	-2.96	2.09	± 3.00	T	N/A	N/A	N/A	N/A	-3.88	2.06	± 3.41	T
22	1.71	2.13	± 3.86	T	-0.22	2.57	± 4.96	T	0.54	2.08	± 5.19	T	0.00	2.23	± 5.10	T	-0.94	2.06	± 4.94	T
23	5.00	2.10	± 3.40	T	3.02	3.18	± 4.32	T	2.47	2.08	± 3.37	T	0.00	2.37	± 3.40	T	3.93	2.09	± 3.35	T
24	-1.41	12.71	± 29.95	T	-1.22	4.30	± 5.34	T	-1.07	2.37	± 4.67	T	N/A	N/A	N/A	N/A	1.58	2.26	± 3.57	T
25	-1.59	2.45	± 6.52	T	N/A	N/A	N/A	N/A	-0.64	2.23	± 3.00	T	N/A	N/A	N/A	N/A	1.04	2.15	± 3.41	T
26	1.90	2.11	± 3.74	T	1.08	2.45	± 3.65	T	3.33	2.09	± 4.81	T	-0.44	2.18	± 4.23	T	2.38	2.05	± 4.16	T
27	0.52	2.09	± 4.92	T	-0.89	3.18	± 4.78	T	0.39	2.05	± 6.42	T	0.13	2.31	± 3.48	T	0.20	2.07	± 3.43	T
28	-1.34	2.11	± 3.52	T	-1.25	2.45	± 3.84	T	-2.43	2.09	± 3.91	T	-2.30	2.18	± 4.23	T	0.00	2.05	± 4.15	T

4.4 Conclusions and Recommendations

4.4.1 Summary and Conclusions

The purpose of this aspect of the evaluation was to assess the accuracy of the TRANSMIT system's link travel time estimation of vehicles equipped with E-ZPass tags. This test was carried out through a comparison of probe vehicle travel times with the corresponding tag ID travel time estimates recorded at the OIC during a five-day test in March 1996. In addition, a week long hourly traffic volume data were collected at the Hillsdale (GSP), Tappan Zee Bridge (NYST) and Spring Valley (NYST) toll plazas, which were used to provide an indication of the current E-ZPass market penetration rates and their impact on link travel time estimation.

The E-ZPass market penetration rate at Hillsdale toll plaza (GSP) varied from 1.59% to 16.50% and at Spring Valley and Tappan Zee Bridge toll plazas (NYST) varied from 5.29% to 73.84% (11/1996). In general, the GSP showed a much lower E-ZPass market penetration rate than NYST, which is expected since only NYST has installed the E-ZPass toll collection system.

The importance of the E-ZPass volume lies in the minimum sample size required to provide good estimates of the link travel time for each link of the TRANSMIT system and for each 15-minute time period of the day. **Based on a comparison of the required sample size for a 95% confidence interval, only 14.5% of the specific time intervals do not have an adequate E-ZPass tag volume to provide accurate estimates of the link travel time with a tolerance of 10% of the mean. With a tolerance of 20% of the mean, only 2.6% of the time intervals don't have the adequate E-ZPass tag volume.** The lack of adequate sample size for these few 15-minute time intervals will be considerably lessened as the E-ZPass market penetration rate is expected to increase in the near future.

A comparison of the OIC and the corresponding probe vehicle link travel time data indicated that 92% were within 3 seconds from each other. Since about 8% of the link travel time data at OIC and the corresponding probe vehicle data have differences in excess of 3 seconds, it may be concluded that for these records the time stamps at various RST locations may have been recorded incorrectly by the reader due to either hardware or software problems or due to data collection errors. The results of the pairwise t-test indicated that only 3 time intervals out of a total of 130 failed the test, link 17 in time periods 11:30 AM - 13:00 PM and 16:30 PM - 18:30 PM, and link 18 in time period 6:30 AM - 9:00 PM. These links are associated with location 27, which exhibited the highest number of communication problems during the evaluation. Therefore it may be concluded that the tag equipped vehicle link travel times are recorded properly at OIC.

4.4.2 Recommendations

The results presented in this evaluation were based on a limited scope probe vehicle test. It is recommended that a more comprehensive test be conducted that will provide a much larger sample size for each 15 minute period of the day, including weekends, and special holidays. The primary reason for this test will be to provide an indication of the current status of the TRANSMIT system's roadside reader locations. This test will establish the current detection rate at each location, as well as the reliability of the link travel times. It is suggested that during this test the synchronization of the clocks at each roadside reader be tested.

An automated procedure should be developed which can provide a diagnostic of the number of vehicles that are missed at roadside readers. This can be implemented at locations just before or after the toll plazas where the total number of tag equipped vehicles is known through the toll records of the corresponding highway authority (NYSTA or NJHA).

A test that was not undertaken during this evaluation is the capability of the system to provide accurate estimates of the link traffic volume. It is recommended that such a test to be undertaken in the future, given the higher penetration rate of tag equipped vehicles that are expected to be detected by the TRANSMIT system. The estimation of the traffic volume at various sections of the roadway is a valuable tool for traffic management and transportation planning and such a test will address the capability of the TRANSMIT system in providing accurate estimate at all roadside locations.

Furthermore, the TRANSMIT system may provide Origin-Destination data although the system currently does not have any procedure for providing these estimates. Such estimates would be extremely useful for traffic management, traveler information, and transportation planning. It is suggested that such a procedure be developed and built into the system in the future. This may require installation of additional RSTs at some entrances and exits of the roadway to capture as many tag-equipped vehicles as possible.

The estimation procedure of new historical link travel times was not addressed during this phase of the evaluation. It should be addressed in a follow up evaluation since it is one of the most important parameters used for the incident detection algorithm as well as the 15-minute historical link mean travel time estimate. This evaluation could be conducted by storing the daily link travel time parameters used by the TRANSMIT system for incident detection, and the daily records of the OIC tag data. Initially, one month of data should be collected and analyzed, and then follow up evaluations should be conducted on a regular basis with weekly data per month. Furthermore, data should be collected and analyzed for special holidays, as well as days with abnormal traffic and environmental conditions. This procedure may be automated through special software designed specifically for this purpose, and become an integral part of the operation of the TRANSMIT system.

It is also recommended that the TRANSMIT system becomes a national test bed for providing link travel time probe vehicle data, traffic volume, and O-D data. A procedure should be established to collect and store data that would be accessible to transportation researchers across the nation. The traffic parameters data determined by the TRANSMIT system has a unique character and it would provide a valuable resource for researchers.

5 EVALUATION OF THE INCIDENT DETECTION SYSTEM

Executive Summary

One of the major functions of TRANSCOM's System for Managing Incidents and Traffic (TRANSMIT) is to detect incidents. TRANSMIT's incident detection algorithm, developed by PB Farradyne Inc. is based on the processing of real time TRANSMIT system data. The information containing the detection times of a tag-equipped vehicle at consecutive RoadSide Terminals is used to estimate the vehicle's link travel time. The expected link travel times of vehicles detected by the TRANSMIT system are estimated using the link travel time distribution for specific time intervals of the day. Under free flowing, non-incident traffic conditions, vehicle link travel times tend to be normally distributed. When a number of vehicles fail to arrive at the downstream detector at the expected travel times, the probability of an incident within the link increases. As more and more vehicles fail to arrive at the downstream detector, the probability of a false alarm decreases. These frequent late arrivals causes the confidence level of an incident to increase to it's user set threshold triggering an alarm at the OIC.

The evaluation of the TRANSMIT incident detection system is based on incident related data covering the time period extending from January 1, to April 30, 1996. The evaluation is based on comparative analysis of incidents recorded by the TRANSMIT system versus incident data recorded by New York State Thruway (NYST) and Garden State Parkway (GSP). The incident records were compiled in the following databases for the four-month evaluation period:

TRANSMIT NYST Incident Database - this database is compiled by TRANSCOM operators and contained a total of 2552 records for the four month evaluation period. After a preliminary analysis this database was reduced to 608 records by excluding duplicate entries, to include true incidents, false alarms, and alarms which could not be classified as either true incidents or false alarms.

TRANSMIT GSP Incident Database - A total of 244 entries were recorded in the TRANSMIT database. These records were reduced to 56 by excluding duplicate entries, to include true incidents, false alarms, and alarms, which could not be classified as either true incidents or false alarms.

NYST Incident Database - The NYST daily logs consisted of a total of 443 records, related to the section equipped with TRANSMIT RSTs. A reduction of these records in order to eliminate duplicate records of the same incident and minor events that were unlikely to have any noticeable effect on traffic flow operations (e.g. street lights out, bridge closed to all commercial, motorcycle traffic, etc.), resulted in a modified database containing 218 entries. Furthermore, the remaining 218 records were divided into two groups, minor (82 records) and major (136 records) incidents. Only the 136 major incidents were used in this study.

GSP Incident Database - The GSP daily logs consisted of 18 incident records for the four-month evaluation period.

The incident detection performance of the TRANSMIT system is quantified in terms of the following parameters:

- **Probability of Detecting Incidents**

  The probability of detecting an incident is the ratio of the incidents that were detected by the TRANSMIT system versus the total number of incidents observed on each facility.

  Based on the evaluation results, the TRANSMIT's incident detection algorithm performed very well along the NYST for the months of February to April 1996 with a range of 92% to 95% detection rate based on the best case scenario (non-classified alarms were treated as true incidents). Similarly, under the worst case scenario (non-classified alarms were treated as false alarms) its performance ranged from 91% to 95% during the months between February and April 1996**.** Under both scenarios, January exhibited lower detection rates of 78% (best case) and 72% (worst case). It is noted that January was the first month that the MARK IV system was in operation, which may have contributed to the lower performance, as the system required adjustments and fine-tuning.

  A similar analysis conducted for the GSP, resulted in a probability of detection ranging from 67% to 79% per month and averaging to 75% for the entire evaluation period, during which a total of 62 true incidents were recorded.

- **Probability of False Alarms and False Alarm Rates**

  The probability of false alarms is the number of false alarms divided by the total number of alarms for the specified period of time. The false alarm rate is determined as the ratio of the number of false alarms to the number of cycle time intervals, for the period of interest.

  Following the analysis of the probability of incident detection, best and worst case scenarios were applied to study the false alarm rates and the probability of false alarms. Under the best case, all 67 non-classified alarms along the NYST were considered as true incidents yielding an average probability of false alarms of 10%, showing monthly variations between 6% and 14%. The corresponding false alarm rates varied between 0.0022% and 0.0080%. For the worst case scenario, if all 67 non-classified alarms were treated as false alarms, then the average probability of false alarms would have been increased to 22%, showing monthly variations between 17% and 33%. Similarly the corresponding false alarm rates under the worst case scenario varied between 0.0111% and 0.0127%.

The corresponding false alarm rates for the GSP for the best and worst case scenarios were found to be between 0.0% and 0.0012% per month, and 0.0004% and 0.0034%, respectively. The probability of false alarms ranged from 0.0% to 50.0%, with an average of 16.0% for the best case scenario and from 5% to 67% for the worst case scenario, respectively.

A high percentage of false alarms was observed during the morning off-peak period (30%) from 9:00 to 11:00 AM and the evening off-peak from 18:30 PM to 6:30 AM at 22%. These are rather high values and efforts should be undertaken to reduce the false alarm rate to a minimum.

The mean time to detect an incident could not be estimated for the TRANSMIT system due to the unavailability of the accurate time of occurrence of an incident from either the NYST or the GSP incident records. This is an important parameter in any incident detection algorithm and should be incorporated in a future more comprehensive evaluation.

It is further recommended that the incident recording procedure be modified to include a more detailed and accurate description of the incident.

The TRAMSIT system compares very favorably among various incident detection algorithms reported in the literature. The detection rates reported in the literature varied between 67% to 100% and TRANSMIT reported a detection rate of 72% to 95% on the NYST and 67% to 79% on the GSP. The TRANSMIT false alarm rates were found to be better than the best reported rates of 0.043% for an algorithm which is based on the catastrophe theory utilizing loop detector technology.

5.1 Purpose and Scope

This chapter presents the results of the evaluation on the incident detection accuracy and reliability of the TRANSMIT system. The methodology followed was developed in the evaluation test plan [1] to assess the capability of the TRANSMIT system to detect incidents reliably and accurately. Incidents are detected through the utilization of the real time data collected by the TRANSMIT system via the algorithm [3, 4, 5] developed by PB Farradyne, Inc. This evaluation is based on comparison of the incident data generated by the TRANSMIT system to the corresponding incident databases made available from the New York State Thruway Authority (NYSTA), and the New Jersey Highway Authority (NJHA).

The incident detection performance in the TRANSMIT system is quantified in terms of the following parameters:

- probability of detecting true incidents,
- probability of triggering false alarms,
- rate of false alarms,
- mean time difference in incident detection.

The probability of triggering false alarms is determined through analysis of the false alarms occurred in the TRANSMIT incident database. The probability of detecting true incidents is determined via comparison of the TRANSMIT incident data to the corresponding records of the respective agencies monitoring the NYST and the GSP. An attempt was made to determine the mean time difference in incident detection through a pair-wise comparison of the average of the difference in detection times of corresponding true incidents identified by TRANSMIT and New York State Thruway Authority (NYSTA), and TRANSMIT and New Jersey Highway Authority (NJHA), respectively.

This chapter includes an executive summary, purpose and scope, the evaluation data collection procedure, a summary of pertinent data collected and its analysis, and a summary of results and recommendations.

5.2 Data Collection

The evaluation of TRANSCOM's incident detection system is based on a comparative analysis of various incident databases. Incident records of the TRANSMIT system are compared to the corresponding records in the incident databases formed out of the daily NYST and the GSP logs. The TRANSMIT database is maintained by operators employed by TRANSCOM. These trained employees observe the day to day operations of the system, respond to alarms, and comment on the nature of the alarms. The NYST and NJHA daily logs consisted of records of the daily operations of the New York State Thruway and Garden State Parkway, respectively. In addition, historical logs maintained by TRANSCOM and the experiences of TRANSCOM personnel were drawn upon in preparation of this report. A typical sample of records as extracted from the TRANSMIT and NYST incident databases are presented below:

- TRANSMIT Incident Database

link	Inc Type	Start Date	Start Time	Inc State	COMMENTS
19	unknown	3/15/96	3:43:00 PM	ALARM	
19	"AC1-Accident, lane	3/15/96	3:50:00 PM	CONFIRMED	nysta -- called - accident - right lane blocked
19	"AC1-Accident, lane closed"	3/15/96	4:21:00 PM	TERMINATED	Delays gone

- NYST Incident Database

The NYST incident records database covers the period between January 1 to April 30, 1996. A sample of these records which were provided by NYSTA in mid-July, 1996 are shown below.

MP	Start Date	Start Time	Comments
15.1	1/2/96	1:00:00 PM	A/A PD
19.3	1/2/96	3:05:00 PM	A/A PI
16.3	1/2/96	7:18:00 PM	A/A PD
14.5	1/3/96	6:45:00 AM	A/A PD ONE LANE CLOSED

As seen from these samples, both incident databases have common entries such as date, time and location. However, the nature of incidents in NYST database is defined as: A/A - Auto Accident, PD - Property Damage, PI - Personal Injury, Lane Closed, etc. In the TRANSMIT database, incidents defined in the NYST database are included as well as other events such as weather (WTR), unknown, etc., and comments may contain more additional information. Location has also been expressed in terms of a milepost in a NYST record whereas TRANSMIT record is expressed in terms of the link number.

5.2.1 Incident Detection on New York State Thruway

The section on the NYST subjected to analysis in this evaluation consists of an 11-mile stretch of road extending east from the Spring Valley Toll Plaza to the Tarrytown Toll Plaza (Tappan Zee Bridge) on the west. Historical logs of incidents were obtained from both TRANSCOM and the NYSTA. Analysis of these databases revealed a number of factors that made them rather difficult to compare on a one-to-one basis in their original forms. Both the NYST and TRANSCOM databases had to be edited before they could be analyzed. In order to facilitate the analysis, records in these two databases were reduced so that one incident was represented by a single record. The data records in the NYST database were divided into the following two categories:

- *Road Work/Construction Related Alarms*- alarms triggered by roadway repairs, construction activities, or rock blasting. Rock blasting took place on a daily basis during weekdays of March and April, 1996,
- *Major Incident Alarms*- any alarm due to an incident that was detected by the system and confirmed by the evaluators that it had occurred (this does not include road work and other types on construction which are in a separate category).

The TRANSMIT database included the above two categories, including two additional categories as follows:

- *False Alarm* - any alarm that could not be attributed to a known equipment problem, road work, or true incident,
- *Non-classified alarm*- is the triggered alarm which includes:

– **elapsed time period of 10 minutes or more between an "alarm" status and a "confirm" or "terminate" status, with no reference in TRANSMIT records, NYST logs, or in any other source of information as to the nature of the alarm,**
– **a "confirm" status with no associated "alarm" or "terminate" status,**
– **an "alarm" status with no associated "confirm" or "terminate" status.**
–

The analysis process and assumptions made for each database are outlined below:

New York State Thruway Database

The reduction process to obtain the final database where each incident is represented by a single record generated intermediate databases as follows:

- <u>NYST1</u> (443 records) - This database included all the original information that was received from the NYSTA. It covered the four-month period from January 2, 1996 through April 28, 1996.
- <u>NYST2</u> (258 records) - Many of the entries in the NYST1 database included multiple records of the same events. For example, if a lane had been closed and then reopened at a later time, there were two corresponding entries for this same event. Since the analysis did not involve the duration of incidents, such events were reduced to a single record.

- NYST3 (218 records) - Minor events that were unlikely to have caused a noticeable reduction in capacity or speed were also logged. An example of such events was "Street lights out." The exclusion of these types of records resulted in a new database with 218 entries.
- NYST major (136 records) - Only capacity or speed reducing incidents in "NYST3" database were included in this final database.
- NYST minor (82 records) - Only the events that did not cause capacity or speed reducing conditions on traffic flow in the "NYST3" database were included in this final database.

In the records noteworthy comments were used to classify some entries as major or minor incidents. The following comments included in the original records helped to classify entries as "major" incidents:

- Lane closures,
- Ambulance calls,
- Reports of objects being struck in the roadway,
- Vehicle fires,
- Construction activities involving the holding of normal traffic flow,
- Patrons falling from vehicles.

Among those events that did not result in capacity reducing conditions were auto accidents resulting in either property damage or personal injuries but not requiring additional comments into the database by the NYST personnel. Subsequent conversations with NYST personnel confirmed that the lack of further comments in such entries indicated that these were minor incidents that most likely did not result in capacity reducing conditions. Incidents of this nature were not likely to be detected by the TRANSMIT system.

TRANSCOM Database

TRANSCOM's records were also reduced in steps to yield a final database where an incident is represented by a single entry. Each step in this reduction process produced modified databases as shown below:

- NYST-TRANSMIT1 (2552 records) - This database included all the original records that was received from TRANSCOM. It included all the entries from January 2, 1996 through April 28, 1996 regarding the NYST.
- NYST-TRANSMIT2 (894 records) - TRANSCOM's practice in recording incidents involved three steps. Initially, either the personnel or the system initiated an alarm. Then, operators determined whether the alarm was false or confirmed to be true by checking with the NYSTA or any other available means. Finally, the alarm was terminated and appropriate actions were taken if necessary. The NYST-TRANSMIT1 database was reduced so that each incident was represented by only one record that resulted in the NYST-TRANSMIT2 database, which contained 894 records.
- Equipment Related Alarms (286 records) – Entries corresponding to alarms associated to the problems in communication system, power system, or in hardware/software in the TRANSMIT system were records were excluded from the analysis.

- NYST-TRANSMIT3 (608 records) - Excluding alarms that were associated with equipment problems resulted in 608 records. These records were used in the analysis of false alarms.
- NYST-TRANSMIT Minor (25 records) - This database contained incidents in NYST-TRANSMIT3 which correlated to the incidents of the original "NYST minor" database. Since these 25 incident records were found in the TRANSMIT database, they were considered as major incidents. The "NYST minor" was then updated to 82 records by excluding these 25 records which were then included in the "NYST major," resulting in 136 records. Table 30 presents the breakdown of the NYST-TRANSMIT3 incident database, including the equipment related alarms database.

Table 30. Classification of Alarms Recorded by the TRANSMIT System on NYST

1996	Road Work	Major Incidents	Minor Incidents	Non-classified Alarms	False Alarms	Total Alarms	Equipment Problems
January	8	54	6	28	6	102	89
February	33	76	7	11	20	147	66
March	48	104	6	18	14	190	68
April	38	96	6	10	19	169	63
Total	**127**	**330**	**25**	**67**	**59**	**608**	**286**

One final comment is about the nature of these databases. There were indications that the archival data from both the NYSTA and TRANSMIT were incomplete. For example, during March 1996, there was a significant amount of construction activity on the NYST. Although both TRANSMIT and NYST records contained references to this, both sets of records appeared to have missing entries of construction activity on NYST. Since construction activity was consistently communicated between the agencies in practice, as shown in the TRANSCOM's logs it was reasonable to assume that logs were incomplete. Consequently, it was reasoned that the true number of incidents could possibly exceed the union of the two databases. However, since it was not feasible to collect such a comprehensive database of incidents, it was assumed that the available information was sufficient to conduct the analysis in this evaluation.

Combining the NYSTA and TRANSMIT Databases

Comparison of "NYST major" (136 records) and "NYST-TRANSMIT3" (608 records) incident databases revealed the presence of 77 correlated records. Incidents were considered to be correlated when two corresponding records were matched in these databases when the following conditions were satisfied:

- incident occurrence in approximately the same location (±1 mile),
- incident occurrence in approximately the same time interval (±60 minutes).

Whenever possible, other sources were also used to confirm this correlation including the personal knowledge and recollection of operators and other records of the events that took place at TRANSCOM and the NYSTA. The two databases were then combined to form a comprehensive major incident database, the NYST-TRANSMIT Major Alarms Incident Database, which resulted in a total of 608 major incidents. This new database excluded 59 false alarms, as shown in Table 30, which are contained in the NYST-TRANSMIT3 database.

NYST-TRANSMIT Major Alarms Incident Database (608 records) - 77 records were contained in both the NYST major database and the TRANSMIT database; 472 records were contained in NYST-TRANSMIT3 database only; 59 records were contained in NYST major database only.

5.2.2 Incident Detection on Garden State Parkway

The section of the TRANSMIT route subjected to incident detection along the GSP consists of a 9 mile roadway that extends north from the Hillsdale Toll Plaza to the intersection with the NYST. Incident records were obtained from both TRANSCOM and the NJHA for the evaluation period extending from January 1, to April 30, 1996. GSP records contained only 18 incidents in the four month period, in comparison of the TRANSMIT logs which contained 244 records. Because of the significantly lower volume of activity occurring along the GSP, the analysis process was much simpler than that for the NYST.

Garden State Parkway Database

GSP-Major Incident Database (18 records) - This database, obtained from the NJHA contained 18 records. Since each record corresponded to a separate incident, it was not necessary to reduce the database.

GSP-TRANSCOM Database

The original database obtained from TRANSCOM related to the GSP for the four-month evaluation period contained a total of 244 records. To facilitate the analysis this database was reduced. Each step in this reduction process produced modified databases as shown below:

- GSP-TRANSMIT1 (244 records) - It contained all the records pertaining to the GSP for the period from January 1, 1996 through April 30, 1996 obtained from TRANSCOM.
- GSP-TRANSMIT2 (85 records) - Some of the records in TRANSMIT1 contained test messages pertaining to system tests conducted by operators. Since these messages had no relation to incidents, they were taken out of the analysis. Many incidents were represented by more than one record in GSP-TRANSMIT1. As explained earlier, the analysis process was facilitated by a one to one relation between records and incidents. GSP-TRANSMIT1 was reduced to GSP-TRANSMIT2 for this purpose as well.
- GSP-TRANSMIT3 (56 records) - Excluding alarms that were associated with equipment problems resulted in the GSP-TRANSMIT3 incident database with a total of 56 records. These records were used for the analysis of false alarms.

Combining the GSP and TRANSMIT Databases

Comparison of GSP-Major and GSP-TRANSMIT3 incident databases revealed a correlation between three incidents. Taking this into consideration, the two tables were combined to form a new database labeled "GSP-TRANSMIT Major Incident Database". This new database excluded 9 false alarms, as shown in Table 31, which are contained in the GSP-TRANSMIT3 database.

GSP-TRANSMIT Major Incident Database (62 records) - 3 records were contained in both the GSP major database and the TRANSMIT database; 44 records were contained in GSP-TRANSMIT3 database only; 15 records were contained in GSP major database only.

Table 31. Classification of Alarms Recorded by the TRANSMIT System on GSP

1996	Road Work	Major Incidents	False Alarms	Non-classified Alarms	Total Alarms	Equipment Related Alarms
January	1	9	3	6	19	9
February	4	14	0	1	19	3
March	0	8	3	1	12	15
April	0	2	3	1	6	2
Total	**5**	**33**	**9**	**9**	**56**	**29**

5.3 Evaluation Results

Results of the evaluation for the incident detection capability of the TRANSMIT system are presented below. Although the three databases compiled out of the available data provided extensive information, a number of inherent factors embedded in the databases made it otherwise difficult to reach precise conclusions. However, common analysis both for the NYST and the GSP sections was applied to quantify the probability of false alarms, the false alarm rate, the probability of detecting true incidents and the mean time differences in incident detection.

The incident detection analysis in the TRANSMIT system is carried out separately for the GSP and NYST. The reasons of analyzing both sections independent of each other are:

- The section of the GSP monitored by the TRANSMIT system had a relatively small percentage of vehicles which were equipped with E-ZPass tags traveling on this road compared to NYST. The E-ZPASS system was operational only on the NYST when this evaluation was undertaken,
- The NJHA and the NYSTA have different incident recording procedures,
- Lower occurrences of incidents on the GSP; GSP records contained only 18 incidents in the four-month period from January through April 1996, in comparison to the 136 incidents

contained in the NYST logs. In addition, TRANSMIT logs contained 56 incidents associated with the GSP compared to the 608 incidents associated with the NYST.

5.3.1 Hypotheses Tested in the Evaluation Test

The incident detection capability of the TRANSMIT system in this evaluation has been analyzed quantitatively in terms of the parameters which have been described in the following hypotheses.

Mean Time Difference in Incident Detection

Hypothesis 1: The mean time difference, $\overline{\Delta} t_d$, in incident detection between the TRANSMIT system and records based on logs from NYST and GSP, is less than or equal to zero with a 95% confidence interval.

$$\overline{\Delta} t_d = \frac{1}{n} \sum_{n=1}^{n} \Delta t_n$$

where:

$\Delta t = t_T - t_R$,

Δt : time difference between an incident detected by TRANSMIT and it being detected by either of the two agencies,

t_T : time incident is detected by the TRANSMIT system,

t_R : time incident is detected by either of the two agencies,

Δt_n : difference in records for each incident,

n : number of incidents detected by both systems.

Test statistic: paired t-statistic (one sided) with a 95% confidence interval.

Null Hypothesis H_O : $\overline{\Delta} t_d \le 0$ versus *Alternative Hypothesis* H_a : $\overline{\Delta} t_d > 0$.

Probability of Triggering a False Alarm in Incident Detection

A false alarm is defined as an occurrence where the incident detection system indicates the presence of an incident which actually did not take place. The false alarm probability is a measure of the incident detection system in a specified time period and can be described as:

$$p_f = \frac{n_f}{N_\Sigma}$$

where:

p_f : Probability that a detected incident is a false alarm,

N_Σ : Number of true incidents N_T plus the number of false alarms n_f,

n_f : Number of false alarms detected by the TRANSMIT system.

Hypothesis: Test if the probability of a detected incident being a false alarm is zero within a 90 % confidence interval.

Test Statistic: Binomial distribution with 90 % confidence interval.

Null Hypothesis H_O *:* $p_f = 0$ vs. *Alternative Hypothesis* H_a*:* $p_f > 0$.

Probability of Detecting a True Incident

An incident is defined as an occurrence where the incident detection system indicates the presence of an incident that actually did take place. True incidents include road work and other types of construction. The incident detection probability is a measure of the incident detection system effectiveness and performance in a specified time interval and can be described as:

$$p_{id} = \frac{n}{N_T}$$

where:

p_{id} : Probability that an alarm triggered by the system is confirmed as an incident,
N_T : Number of all incidents detected by other means,
n : Number of incidents detected by the system.

Hypothesis: Test if the proportion of true incidents detected by the TRANSMIT system is greater or equal to 0.95, with a 95 % confidence interval.

Test Statistic: Binomial distribution with 95 % confidence interval.

Null Hypothesis $H_O : p_M \geq 0.95$ versus Alternative Hypothesis $H_a : p_M < 0.95$

5.3.2 Analysis of Results for the New York Sate Thruway

Analysis of False Alarms on NYST

TRANSMIT System's Probability of a False Alarm Based on the Total Number of Alarms on NYST

The probability of a false alarm is a measure of the reliability in incident detection. In essence, it quantifies the performance of the system from the operators' perspective and is based on the percentage of alarms that can be classified as false. Here, this measure was estimated based on the "NYST-TRANSMIT3" database, which contained individual records for each incident and included shockwave as well as "rubbernecking" effects. The probability of a false alarm is determined by examining all the alarms in the "NYST-TRANSMIT3" database, which are subsequently compared to the data in the NYSTA records and other available sources.

Equipment problem related alarms were identified and excluded from the performance analysis of the incident detection algorithm. These alarms were analyzed separately and discussed in Chapter 3 and their contributions were taken into consideration in the overall performance of the system. Road work delays and valid incidents are considered to be true incidents that the system was designed to detect. False alarms were classified as the alarms that could not be verified as true incidents.

Table 32 presents the classification of alarms for the TRANSMIT records associated with the NYST as well as the probability of a false alarm covering the four month period extending from January 1, 1996 to April 30, 1996.

Table 32. TRANSMIT System's Probability of a False Alarm Based on the Total Number of Alarms on NYST

1996	Major Incidents	Minor Incidents	False Alarms	Non-classified Alarms	Total Alarms	Probability of a False Alarm	
						Best	Worst
January	62	6	6	28	102	6%	33%
February	109	7	20	11	147	14%	21%
March	152	6	14	18	190	7%	17%
April	134	6	19	10	169	11%	17%
Total	**457**	**25**	**59**	**67**	**608**	**10%**	**22%**

The presence of the 67 non-classified alarms prompted the analysis to include the best and the worst case scenarios. Under the best case, all 67 non-classified alarms were considered as true incidents which resulted in an average probability of a false alarm of 10%, ranging from 6% to 14%. If all 67 non-classified alarms were considered as false alarms then the average probability of a false alarm would be 22%, ranging from 17% to 33%.

TRANSMIT System's False Alarm Rates Based on the Total Number of Polling Periods on NYST

The false alarm rate is the most commonly used measure of performance in incident detection. The false alarm rate is based on defining the cycle time interval of performance which is usually considered to be between 5 to 15 seconds; then the period of the evaluation (e.g. one month, season or year, etc.) is chosen; the period of evaluation is divided by the cycle time interval to obtain the corresponding number of intervals; hence the false alarm rate is determined as the ratio of the number of false alarms to the number of cycle time intervals. The false alarm rate in the TRANSMIT system is determined for the period of the evaluation covering the time period of four months extending from January 1 to April 30, 1996. The incident detection algorithm used in the TRANSMIT system is based on a cycle time interval of 10 seconds. Using the method described above, the false alarm rates per month are determined as shown in Table 33.

Similarly, as with the probability of false alarms, the best and worst case scenarios were considered, based on the 67 non-classified alarms. Under the best case scenario (all 67 non-classified alarms were treated as true incidents) the false alarm rates range from 0.0022% to 0.0080%, averaging to 0.0057%, where the highest rate was observed in February 1996.

Under the worst case scenario (all 67 non-classified alarms were treated as false alarms) the false alarm rates range from 0.0111% to 0.0127%, averaging to 0.0120%, where the highest rate was observed in January 1996. In order to provide a more detailed presentation of the occurrence of incidents during the evaluation period, the false alarms were further cross-classified in terms of links and month. A summary of the monthly breakdown and per link of the TRANSMIT system is presented in Appendix C. The results did not reveal any apparent patterns of the false alarms by either per link or per month.

Table 33. TRANSMIT System's False Alarm Rates Based on the Total Number of Poll Periods on NYST

1996	False Alarms	Non-classified Alarms	Cycle Time Intervals (10 sec)	False Alarm Rate	
				Best Case	Worst Case
January	6	28	267,840	0.0022%	0.0127%
February	20	11	250,560	0.0080%	0.0124%
March	14	18	267,840	0.0052%	0.0119%
April	19	10	259,200	0.0073%	0.0111%
Total	**59**	**67**	**1,045,440**	**0.0057%**	**0.0120%**

Analysis of Probability of Detecting an Incident by the TRANSMIT System on NYST

Another measure of reliability used in incident detection is the probability of detecting an incident. In essence, this is a ratio of incidents that were detected by the system versus the total number of incidents for a specified time period. Here, this probability was determined by analyzing the databases in "NYST major" and the "NYST-TRANSMIT3" containing incidents that caused a noticeable reduction in speed. The classification of these incidents is shown in Table 34. Similarly as before, the 67 non-classified alarms were first considered as incidents (best case) and then as false alarms (worst case). A summary of the incidents observed on NYST per month and per link is presented in Table C3 (Appendix C).

Table 34. TRANSMIT System's Probability of Detecting an Incident on NYST

1996	Incidents in NYST database	Incidents in TRANSMIT database	Incidents in both databases			Non-classified Alarms	TOTAL Incidents	Probability of Inc. Detection	
			Roadway works	Major Incidents	Minor Incidents			(best)	(worst)
Jan.	27	53	0	9	6	28	123	78%	72%
Feb.	11	100	1	8	7	11	138	92%	91%
Mar.	13	137	9	6	6	18	189	93%	92%
Apr.	8	115	11	8	6	10	158	95%	95%

Total	59	405	21	31	25	67	608	90%	89%

Results in Table 34 indicate that the **TRANSMIT's incident detection algorithm performed very well for the months of February to April with a range of 92% to 95% detection rate based on the best case scenario. Similarly, under the worst case scenario its performance ranged from 91% to 95% during the months between February and April 1997.** Under both scenarios, January exhibited lower detection rates of 78% (best case) and 72% (worst case). It is noted that January was the first month that the MARK IV system was in operation, which may have contributed to the lower performance, as the system required adjustment and fine tuning.

It may be concluded that the performance of the TRANSMIT system's incident detection algorithm in terms of its ability to detect capacity reducing incidents was very satisfactory for the evaluation period, with the exception of the month of January.

5.3.2.1 Analysis of Incidents and False Alarms on NYST per Time Period of the Day and Day of the Week

The detected incidents and the recorded false alarms on the NYST were further studied in detail in terms of the day of the week and time interval of the day. The day is divided into the following time intervals:

* the morning peak from 6:30 AM to 9:00 AM,
* the morning off-peak from 9:00 to 11:00 AM,
* the noon peak from 11:00 to 13:00 PM,
* the afternoon off-peak from 13:00 to 16:30 PM,
* the evening peak from 16:30 to 18:30 PM,
* the evening off-peak from 18:30 to 6:30 AM.

The collected incident data classified in terms of these time intervals due to recorded incidents and false alarms are summarized in Figures C1 - C5 (Appendix C). Figures C1, C2, and C3 present the weekday frequency distribution of valid incidents, incidents due to roadwork, and false alarms, respectively. Figures C4, C5 and C6 present the frequency distribution of valid incidents, incidents due to roadwork, and false alarms on Saturdays and Sundays.

Table 35. Major and Roadwork Related Incidents, False Alarms and % of False Alarms for Weekdays; Per Time Period of the Day on NYST

Time Interval	**6:30 - 9:00**	**9:00 - 11:00**	**11:00 - 13:00**	**13:00 - 16:30**	**16:30 - 18:30**	**18:30 - 6:30**
Major Incidents	128	18	41	94	53	21
Roadwork	12	3	87	8	10	7
TOTAL INCIDENTS	140 (29.0%)	21 (4.4%)	128 (26.5%)	102 (21.2%)	63 (13.1%)	28 (5.8%)
False Alarms	10	9	5	19	8	8
False Alarms/ (Incidents + Alarms) *100	6.7 %	30.0 %	3.8 %	15.7 %	11.3 %	22.2 %

These results indicate that most of the incidents occurred during the weekdays rather than weekends. Incidents occurring on Saturdays and Sundays constitute 11% of the total. The highest percentage of incidents recorded by the TRANSMIT system occurred during the morning peak period from 6:30 to 9:00 was 29.0% versus 26.5% for the noon peak period from 11:00 to 13:00 (see Table 35). The lowest percentage of incidents was observed during the morning and the evening off-peak periods, with 4.4% and 5.8%, respectively.

The highest percentage of false alarms to the total number of alarms per time interval of the day was observed during the morning off-peak period (9:00 - 11:00) at 30%, and during the evening off-peak period from 18:30 PM to 6:30 AM at 22.2%. These morning off-peak and the evening off-peak periods recorded the lowest total number of incidents at 4.4% and 5.8%, respectively. In contrast, the lowest percentage of false alarms is observed during the noon peak period, at 3.8%. The high percent of false alarms during the morning and evening off-peak periods indicates that a study should be undertaken to identify the possible source(s) that yield such high false alarm percentages which contrast the rather good performance of the algorithm during the other time periods of the day. The low percentage of false alarms during the noon peak period underscores the success of the algorithm in cases of roadway capacity reducing incidents. The NYST roadway capacity was reduced by one lane on some of the TRANSMIT links due to rock blasting which took place during the noon peak period (11:00 AM - 13:00 PM) for the months of March and April, 1996.

Analysis of Mean Time Difference in Incident Detection for NYST

The TRANSMIT and the NYSTA incident records were based on clocks which are not synchronized to a common reference time. The best estimate of the differences between the two clocks was found to be ± 5 minutes. In addition, the NYSTA incident records appeared to be logged to the nearest 5 minutes. Thus the margin of error could extend into the ± 10 minutes range. It was therefore concluded that this measure of performance could not be evaluated based on the current NYST and the TRANSMIT system's incident databases. It is however a very important measure of performance and it should be included at a future evaluation when the means of recording the incident occurrence time are available.

5.3.3 Analysis of Results for the Garden State Parkway

Analysis of False Alarms for GSP

TRANSMIT System's Probability of a False Alarm Based on the Total Number of Alarms on GSP

Alarms in the TRANSMIT logs associated with the GSP were classified in the same manner as those associated with the NYST. The classification of alarms recorded during the evaluation period is shown in Table 31.

As with the NYST, equipment related alarms were analyzed separately. The remaining alarms were used to determine the probability of false alarms, which are shown in Table 36. This data were further cross-classified per link and month in Table C2 (Appendix C).

The probability of false alarms under the best case scenario ranged from 0% to 50%, averaging to 16% for the four-month evaluation period. The probability of false alarms under the worst case scenario, showed variations between 5% and 67%, averaging to 32%. Under the best and worst case scenarios, the highest probability of false alarms were observed in April 1996. These values were found to be rather high in comparison to the NYST, which can be attributed to the low number of incidents, occurred along the GSP. It should be noted that the small sample size recorded during the month of April contained only two major incidents and three false alarms. In contrast, the month of February that exhibited the highest occurrence of incidents yielded no false alarms.

Table 36. TRANSMIT System's Probability of a False Alarm Based on the Total Number of Alarms on GSP

1996	Major Incidents	False Alarms	Non-classified Alarms	Total Alarms	Probability of False Alarms (%)	
					Best Case	Worst Case
January	10	3	6	19	16	47
February	18	0	1	19	0	5
March	8	3	1	12	25	33
April	2	3	1	6	50	67
Total	**38**	**9**	**9**	**56**	**16**	**32**

TRANSMIT System's False Alarm Rates Based on the Total Number of Poll Periods on GSP

The best and worst case scenarios in the TRANSMIT system for the GSP were based on 9 non-classified alarms that were recorded during the four month period. Under the best case scenario (all 9 non-classified alarms were treated as true incidents) yielded false alarm rates ranging from 0.0% to 0.0012%, averaging to 0.0009%. Under the worst case scenario (all 9 non-classified alarms were treated as false alarms) the false alarm rates ranged from 0.0004% to 0.0034%, averaging to 0.0017% (Table 37). In order to provide a more detailed representation of the occurrence of incidents during the evaluation period, the false alarms were further cross-classified in terms of links and month. A summary of the monthly breakdown and per link of the TRANSMIT system is presented in Table C2 (Appendix C). The results did not reveal any apparent patterns of the false alarms either per link or per month.

Table 37. TRANSMIT System's False Alarm Rates Based on the Total Number of Poll Periods on GSP

1996	False Alarms	Non- classified Alarms	Periods	False Alarm Rate (%)	
				Best Case	Worst Case
January	3	6	267,840	0.0011	0.0034
February	0	1	250,560	0.0000	0.0004

March	3	1	267,840	0.0011	0.0015
April	3	1	259,200	0.0012	0.0015
Total	**9**	**9**	**1,045,440**	**0.0009**	**0.0017**

TRANSMIT System's Probability of Detecting an Incident on GSP

Out of the total 62 incidents included in "GSP All", the best case scenario in the probability of incident detection yielded variations between 69% and 79%, averaging to 75%. However, considering the small number of non-classified alarms encountered during the evaluation period, the worst case scenario did not show significant changes; the variation was observed to be between 67% and 78%, and the average was 70% as shown in Table 38. Here, the non-classified alarms (9) were included in determination of the best case scenario and were treated as true incidents, whereas they were excluded under the worst case scenario.

It may be concluded that the incident detection algorithm yielded lower incident detection rates on the Garden State Parkway during the four-month period in comparison to the results on the NYST. This is attributed to the fact that tag equipped vehicle volumes on GSP were rather low since the E-ZPass system has not been implemented on this facility.

Analysis of Mean Time Difference in Incident Detection on GSP

There were only three incidents between the two databases showed any correspondence, hence, it was not possible to determine mean time difference in incident detection with any significance. Given the circumstances, any measure of the mean time difference in incident detection from the current data would have been unreliable. As a result, it was concluded that this measure is not applicable at the present time.

Table 38. TRANSMIT System's Probability of Detecting an Incident on GSP

1996	Incidents in GSP only	Incidents in TRANSMIT Records only	Incidents in both		Non-classified Alarms	TOTAL	Probability of Incident Detection (%)	
			Roadway works	Valid Incidents			Best	Worst
Jan.	5	10	0	0	6	21	76	67
Feb.	5	17	0	1	1	24	79	78
Mar.	4	7	0	1	1	13	69	67
Apr.	1	1	0	1	1	4	75	67
Total	**15**	**35**	**0**	**3**	**9**	**62**	**75**	**70**

5.3.4 Comparison of Incident Detection Algorithms

The algorithm implemented in the TRANSMIT system compares favorably among the various algorithms used in contemporary systems for incident detection. Table 39 presents the performance of various incident detection algorithms in terms of the detection rate, the false alarm rate and the mean detection time.

The NYST section of the TRANSMIT system exhibited detection rates varying between 72% to 95%. The lowest detection rates of 72% was observed during the month of January which was the first month that the MARK IV system was operational and was undergoing major adjustments and tuning. Excluding the result for January, the worst case for the detection rate becomes 91% for February and kept improving to 95% for the month of April. The corresponding false alarm rates varied between 0.0022 to 0.0127% are among the best rates of all applied algorithms. The corresponding detection rates for the GSP section of the TRANSMIT system varied between 67% to 79% which were attributed to the small sample size of the incidents occurred during the evaluation and the low volume of tag equipped vehicles. The associated false alarm rates that varied between 0.0 and 0.0034% are also better than most of the reported rates of Table 39. **In conclusion, considering the number of tag equipped vehicles and the number of incidents detected along the NYST section of the TRANSMIT system, the TRANSMIT incident detection algorithm performed exceptionally well in comparison to other algorithms.**

Table 39. Comparison of Various Incident Detection Algorithms [6]

Algorithm	Detection Rate	False Alarm Rate	Mean Detection Time
Pattern Recognition Type			
California Algorithm	67%	0.134%	2.91 min.
All Purposes Incident Detection (APID)	66%	0.05% per stn.	2.55 min.
STATISTICAL TYPE			
Standard Normal Deviate Model	92%	13%	1.1 min
Bayesian Algorithm	100%	100% - 0%	3.9 min
Time Series Type			
Box Jenkins ARIMA Model	100%	1.4% 2.6%	0.58 min 0.39 min
Smoothing Model	92%	1.87%	0.74 min
Double Exp. Smoothing Model	82%	0.28%	5.05 min
High Occupancy (HIOCC) Algorithm	96%		
Filtering Model	95%	1.5%	40 sec
Dynamic Model		Prob. < 0.0002	small
CATASTROPHE THEORY TYPE	100%	0.043%	1.5 min
NEURAL NETWORK	97%	0.213%	170 sec
VIDEO IMAGE PROCESSING			
INVAID - TRISTAR System	> 90%	1 every 3 h (avg.)	20 sec
TRANSMIT - NYST	**72 - 95%**	**(0.0022%: 1in124 h)** **(0.0127%: 1in22 h)**	**N/A**

TRANSMIT - GSP	**67 - 79%**	**(0.0%: ¥)** **(0.0034%: 1in83 h)**	**N/A**

5.4 Conclusions and Recommendations

5.4.1 Summary and Conclusions

This part of the evaluation report covered the performance of the TRANSMIT incident detection system for the period extending from January 1 to April 30, 1996. The performance of the TRANSMIT incident detection system was evaluated based on the following parameters applied to the NYST and GSP sections, respectively:

- the probability of detecting an incident is determined via comparison of the TRANSMIT incident data to the corresponding records of the respective agencies monitoring the NYST and the GSP,

- the probability of triggering a false alarm is determined through analysis of the false alarms recorded in the TRANSMIT incident database and compared to the corresponding incident databases of the NYSTA and NJHA,

- the false alarm rate was determined for the whole evaluation period as well as for each individual month separately,

- the mean time difference in incident detection could not be estimated due to the lack of reliable data therefore it was excluded from this phase of the evaluation;

The principal parameters of the TRANSMIT incident detection system for the NYST and the GSP are summarized in Table 40.

The evaluation results in Table 40 indicate that the probability of detecting incidents in the TRANSMIT system has reached the peak of 95% along the NYST in the month of April, 1996. The worst case has been observed to be 67% along the GSP which can be attributed to the low number of tag equipped vehicles. **The average incident detection probability of 90% which was observed along the NYST is a confirmation that the TRANSMIT system is performing well when adequate number of tag equipped vehicles are present.** Under both scenarios, January exhibited lower detection rates of 78% (best case) and 72% (worst case) on the NYST. It is noted that January was the first month that the MARK IV system was in operation, which may have contributed to the lower performance, as the system required adjustments and fine tuning.

The probability of false alarms on the NYST were found to be between 6% and 33% and the corresponding false alarm rate between 0.0022% and 0.0127%, respectively. Similarly the GSP experienced a probability of false alarms that varied between 0% and 67%. This extremely high percentage is due to very low number of incidents occurred during the month of April 1996. The corresponding monthly false alarm rates which are independent of the total number of incidents, varied between 0.0% and 0.0034%. Furthermore, a high probability of a false alarm was observed for the morning off-peak period between 9:00 and 11:00 AM at 30%, and the evening off-peak period between 18:30 PM and 6:30 AM at 22%. These are rather high values and efforts should be undertaken to reduce such a false alarm rate to a minimum.

Table 40. Performance of the TRANSMIT Incident Detection System

1996	Probability of Incident Detection (%)				False Alarm Rate (%)				Probability of a False Alarm (%)			
	GSP		NYST		GSP		NYST		GSP		NYST	
	Best	Worst	Best	Worst	Best	Worst	Best	Worst	Best	Worst	Best	Worst
January	76	67	78	72	0.0011	0.0034	0.0022	0.0127	16	47	6	33
February	79	78	92	91	0.0000	0.0004	0.0080	0.0124	0	5	14	21
March	69	67	93	92	0.0011	0.0015	0.0052	0.0119	25	33	7	17
April	75	67	95	95	0.0012	0.0015	0.0073	0.0111	50	67	11	17
Total	**75**	**70**	**90**	**89**	**0.0009**	**0.0017**	**0.0057**	**0.0120**	**16**	**32**	**10**	**22**

A comparison of the TRANSMIT incident detection algorithm to various algorithms reported for contemporary incident detection systems revealed that it performed exceptionally well both in terms of incident detection and false alarm rates.

5.4.2 Recommendations

Based on the evaluation of the TRANSMIT incident detection system the following recommendations are made in an effort to improve its performance:

- A more detailed description of a recorded incident is needed. A common reporting procedure should be established between various agencies involved in detecting and responding to incidents. In particular, the notifying source and as much information as possible to describe a particular incident should be included in the incident record. A detailed incident detection data sheet form should be developed which could be used in the future by the state police as well as other incident recording entities. The development of this form as well as training to fill out such log will require an additional study. In addition, an incident data reporting procedure should be devised which will enable TRANSCOM to obtain police incident records within a few days (or even in real time) and maintain a global incident record database for all the agencies. These incident records databases will serve as a means in disseminating information to various agencies and educational institutions around the country who are interested in the analysis of incident data. TRANSCOM can fulfill the function serving as an incident data bank for the NY/NJ/CT metropolitan area.
- Accurate records of the detected incidents in TRANSMIT, NYST and GSP databases should be maintained. In addition, cameras could be placed at high incident locations in order to determine the exact nature and the time of occurrence of an incident; this will

provide an independent verification of an incident and will serve as a reference for establishing the accuracy of the TRANSMIT system and other remaining databases.

- In case of an incident alarm, individual values of the parameters associated with the incident detection, at least fifteen minutes prior to the incident and one hour after the incident, should be stored for validation and further improvement of the incident detection algorithm.
- The analysis for this report included only four months, from January to April, 1996, which was the period just after the MARK IV equipment was installed for the TRANSMIT system. The system underwent considerable improvements since then, especially with regard to the MARK IV software, therefore a bias may be included in the results. Furthermore, the analysis could only test the system under limited environmental conditions. A more unbiased study should be followed which will cover at least one year in order to quantify the performance of the system under various environmental conditions, as well as the reliability of the system under a longer period of time. The latter includes the percentage of time that the system components were down, which is addressed under the communications system evaluation test.
- A follow-up study should be conducted to examine the possible causes for the reported higher false alarm rates during the morning off-peak (9:00 - 11:00 AM) and the evening off-peak (18:30 PM - 6:00 AM) periods.
- The probability to detect an incident should be further improved from a current level of 67% (GSP) to above 90% for capacity reducing incidents. Since this higher rate (up to 95%) has been observed in three consecutive months on NYST, it is expected that similar and better performance can be achieved on the GSP as the volume of tag equipped vehicles is increased to higher values.

6 EVALUATION OF THE COST, BENEFITS AND INSTITUTIONAL ISSUES

Executive Summary

The evaluation of the TRANSCOM's System for Managing Incidents and Traffic (TRANSMIT) included of a comparative assessment of its costs to three other traffic surveillance systems. A review of the benefits that each of these systems can provide in terms of traffic management, traveler information and transportation planning is presented. The institutional issues related to the TRANSMIT system's implementation are also addressed. This part of the evaluation focused on:

- **TRANSMIT costs** for the capital field equipment per Road Site Terminal (RST), central equipment, system installation, maintenance and operation,
- **TRANSMIT benefits** in terms of traffic management, traveler information and transportation planning,
- **TRANSMIT related institutional issues** between the involved agencies, the private sector and the general public,
- **Comparison of the TRANSMIT system to Inductive Loop Detection System (ILDS), Video Image Detection System (VIDS) and Microwave Radar Detection System (MRDS)**.

Comparative Costs of Traffic Surveillance Systems

The comparison of the TRANSMIT system to ILDS, VIDS and MRDS systems, is based on the cost of a typical detection site on a six-lane highway. The hardware capital costs include field components of a typical detection site installed along the system as well as the ancillary equipment. The system installation cost covers the field installation of hardware, cabinet/foundation, cables, etc. The maintenance costs for a detection site include on-site hardware and software support and personnel expenses. Operations costs involve costs due to leased telephone lines and utilities expenses. These costs associated with the various traffic surveillance systems are summarized in Table 41.

Table 41. Comparative Costs per Detection Site (Six-Lane Highway)

Description	TRANSMIT	ILDS	VIDS	MRDS
Capital Cost:				
• Hardware	$14,700	$4,100	$24,500	$26,500
• Installation	$21,700	$50,560	$45,100	$25,200
Total Capital Costs	**$36,400**	**$54,660**	**$69,600**	**$51,700**
Maintenance Costs/Year	$2,900	$7,950	$3,300	$2,900
Operations Costs/Year	$2,040	$2,040	$2,040	$2,040
Total Annual Costs	**$4,940**	**$9,990**	**$5,340**	**$4,940**
Total Cost for One Year	**$41,340**	**$64,650**	**$74,940**	**$56,640**

The total cost for one year of operation including the capital costs of hardware and installation of a TRANSMIT system RST site represents 64%, 55%, and 73% of the corresponding costs for ILDS, VIDS and MRDS systems, respectively.

TRANSMIT System Benefits

The current and potential benefits of the TRANSMIT system offer unique opportunities in traffic management, and traveler information systems and provide the basis for more accurate transportation planning studies. Furthermore, the TRANSMIT system could be used for transit and fleet management.

The principal benefits of the currently implemented TRANSMIT system are**:**

- **Automated incident detection,**
- **Traffic flow parameter estimation (link travel time and space mean speed).**

The potential benefits of TRANSMIT that can be obtained without any substantial hardware/software modifications and costs, include the estimation of the following traffic flow characteristics**:**

- **Vehicle position estimation and tracking,**
- **Path travel time estimation,**
- **Origin - Destination (O-D) matrix direct estimation,**
- **Traffic volume estimation.**

The TRANSMIT system provides a number of advantages over other traffic surveillance techniques for traffic management, traveler information and transportation planning. Its principal advantage lies in its ability to identify and monitor vehicles in consecutive roadway segments. This capability provides the basis for the TRANSMIT system to determine real time estimates of the space mean speed, link and path travel time, as well as O-D data.

In order to operate TRANSMIT type systems successfully it is required that a sufficient number of probe vehicles be detected at the individual RSTs within the corresponding time interval of the day. **As more and more of the toll facilities of the metropolitan area are equipped with the E-ZPass system, the full benefits of the TRANSMIT system will materialize. The TRANSMIT system will be able to utilize the largest pool of probe vehicles in the country.**

Institutional Issues associated with the TRANSMIT system

The TRANSMIT system is an example of a multi-jurisdictional cooperation between different public agencies and the private sector. An alternative contracting approach utilizing a consultant for handling multi-jurisdictional projects has been developed where the member agencies have control over the review of the bid packages and the contractor selection procedure. The consultant resolves technical incompatibilities between the systems of the different agencies in a unified way that results in a simpler system. **This approach provided**

flexibility to TRANSCOM through PB Farradyne Inc. to resolve administrative and technical difficulties between the agencies and to reduce the system implementation time.

The privacy of the identity of the vehicles equipped with the E-ZPass tags was set as a requirement by TRANSCOM and the member agencies prior to the implementation of the project. The vehicle ID is encoded immediately upon reception at the OIC. This policy avoided any potential negative public reactions towards the system and lead to a smooth implementation of the TRANSMIT system.

Recommendations

The TRANSMIT system has a potential to provide extensive data for traveler information systems. Its current capabilities in terms of real time link and path travel time estimates should be exploited.

An effort should be made to use the TRANSMIT system data to provide estimates for the incident duration and to predict its effects on the roadway as well as adjacent roadways.

The rapid high volume data acquisition capability of the TRANSMIT system can enhance research in advanced traffic flow theory. It could provide unmatched opportunity to verify various proposed models with real time traffic flow data.

The TRANSMIT system should become a case study for multi-jurisdictional type of projects. Various metropolitan areas in the US could benefit from the experiences gained through the implementation of the TRANSMIT system.

TRANSMIT has been primarily sponsored with federal resources. **Various innovative alternative-funding mechanisms should be sought for establishing public/private partnerships for future expansion and operation**. For example, many of TRANSCOM's member agencies are contributing their own local and federal funds to finance the expansion of the TRANSMIT system.

6.1 Purpose and Scope

The cost, benefits, and institutional issues associated with the TRANSMIT system are presented in this chapter. This analysis includes the hardware capital costs for the RST, the communication system components, installation, operation and maintenance for a typical six-lane highway installation. These costs are compared with those of alternative traffic surveillance technologies including ILDS, VIDS and MRDS systems. Other vehicle positioning systems such as Global Positioning Systems (GPS) and cellular telephony were not considered. GPS base probes do not have sufficient market penetration and each vehicle would require additional hardware, while cellular telephony systems have limited accuracy (within 500 feet) which may be sufficient in emergency situations but not particularly useful in traffic management.

The overall benefits of the TRANSMIT system and the three alternative technologies mentioned above, in terms of traffic management, traveler information and transportation planning are assessed. This report also includes an assessment of the potential benefits of an expanded TRANSMIT system. Furthermore, the benefits of the TRANSMIT system were also assessed based on the qualitative survey responses by the TRANSMIT system's affiliated agencies.

This chapter includes brief descriptions of the TRANSMIT system, ILDS, VIDS, and MRDS systems. The costs of the TRANSMIT system, ILDS, VIDS and MRDS systems, and their potential benefits are presented. In addition, the institutional issues related to the TRANSMIT system's implementation are also addressed. This chapter concludes with a summary of conclusions and recommendations. The qualitative survey and corresponding responses on the benefits are included in Appendix D.

6.2 Description of Traffic Surveillance Systems

A brief description of the TRANSMIT system, the ILDS, VIDS and MRDS systems is presented next.

6.2.1 TRANSMIT System (RF Probe Based)

Each time a RF probe (E-ZPass tag) equipped vehicle passes a RST location, its tag identification number (ID) and the detection time are recorded. Data containing tag ID, detection time, location and lane position is forwarded to the Operations Information Center (OIC). Then, the tag ID is encoded at the OIC into a random number to ensure the anonymity of the motorist.

The vehicle travel times between successive readers are then determined from the stored data at the OIC. The incident detection algorithm is based on statistical comparison of measured travel times with normal travel times for the same time period of the day and type of the day (weekday, Saturday, Sunday, or holiday). When the algorithm detects multiple successive vehicles arriving at a downstream reader of a specific link of the system experiencing unusually long travel times, an alarm is triggered to indicate the occurrence of a possible incident.

The following traffic data is collected and/or estimated by the TRANSMIT system:

- *Vehicle Identification/Location/Classification and Time*: The encoded vehicle ID, location, classification and time are recorded in real time and can be stored in a historical database,
- *Link Travel Time*: A pair of an upstream and a consecutive downstream RSTs defines a link. The travel time of an individual vehicle is determined once the system identifies the recorded time stamps of the same tag ID at both the upstream and downstream RSTs,
- *Average Link Travel Time and Speeds*: Based on the number of tag equipped vehicles passing a TRANSMIT link during a specific time interval, the average link travel and speeds are estimated,

- *Path Travel Time and Speed Estimation*: Currently the path travel time is estimated manually by adding the average link travel time of individual links that form a particular path. In the future these estimations can be obtained with an automated procedure which can record the path travel times of individual vehicles for specific time interval.
- *Incident detection*: Incident detection is based on the historical link travel time, the standard deviation and the arrival times of tag-equipped vehicles at the RST.

A schematic of a typical RST location of a TRANSMIT based system on a six-lane highway is depicted in Figure 18. The principal components of the RST site are: reader antenna(s), coaxial RF-cabling, equipment cabinet (modem and controller) and the corresponding conduit and communication cabling.

6.2.2 Inductive Loop Detection System (ILDS)

A detector consists of insulated electrical wire wraps placed up to 18" or more into the pavement. Operation is based on the principle of a change in the inductance due to the change of electromagnetic fields when a vehicle (vehicle axle) passes over the detection zone. Usually the detection zones have a square loop configuration of six by six feet.

The following traffic data can be collected:

- *Traffic Flow Rate:* Single loop detectors count each axle passing over the detection zone. Based on historical survey data of the composition of traffic, the axle counts are converted to number of vehicles per time interval of the day. The traffic flow rate in vehicles per hour is then estimated,
- *Vehicle Speed*: Paired detectors usually spaced six to ten feet apart provide estimates of vehicle speed,
- *Vehicle Classification:* Paired loop detectors provide estimates of vehicle length which could then be converted to different vehicle classes,
- *Space Occupancy*: Percentage of time the detection zone is occupied,
- *Incident detection*: Incident detection is based on the traffic flow rate, vehicle speed and space occupancy.

A schematic of a typical ILDS location on a six-lane highway is depicted in Figure 19. The principal components of the ILDS site are loop detectors embedded in the pavement, equipment cabinet (modem, controller(s) and amplifier(s)) and the corresponding conduit and communication cabling.

6.2.3 Video Image Detection Systems (VIDS)

These systems utilize video outputs from cameras located roadside or overhead to identify vehicles using video image algorithms. This is accomplished by placing virtual detection zones on the screen image, digitizing and analyzing video images. Through the use of these virtual detectors the following traffic data can be collected:

- *Traffic Flow Rate:* The change of digitized data in the virtual detection zone signifies a passing of a vehicle. As such the traffic flow rate is estimated per time interval of the day,
- *Vehicle Speed*: Paired virtual detectors provide estimates of vehicle speeds,
- *Vehicle Classification:* Paired virtual detectors provide estimates of vehicle lengths which could then be converted to different vehicle classes,

Space Occupancy: Percentage of time the detection zone is occupied,

- *Incident detection*: Incident detection could be based on the traffic flow rate, vehicle speed and space occupancy. Some VIDS provide direct incident detection based on the change of consecutive video images.

A schematic of a typical VIDS location for a six-lane highway is depicted in Figure 20. The principal components of the VIDS site are: video camera assembly, equipment cabinet (modem, controller(s) and video image processor) and the corresponding conduit and communication cabling.

6.2.4 Microwave Radar Detection Systems (MRDS)

These systems detect the presence of a vehicle by continuously emitting microwave energy towards the roadway. Operation is based on the Doppler effect of the frequency shift of a back scattered signal from an approaching vehicle towards the radar detector.

The following traffic flow parameters can be estimated:

- *Traffic Flow Rate:* The flow rate can be estimated based on the beam activations per time interval of the day,
- *Vehicle Speed*: Vehicle speed can be estimated from two bursts of reflected energy with a vehicle class assumption,
- *Space Occupancy*: Some of these detectors can provide vehicle presence by measuring the range between the detector and the vehicle,
- *Incident detection*: Incident detection is based on the traffic flow rate, vehicle speed and space occupancy.

A schematic of a typical MRDS location for a six-lane highway is depicted in Figure 21. The principal components of the MRDS site are: radar detector unit, equipment cabinet (modem, controller(s)) and the corresponding conduit and communication cabling.

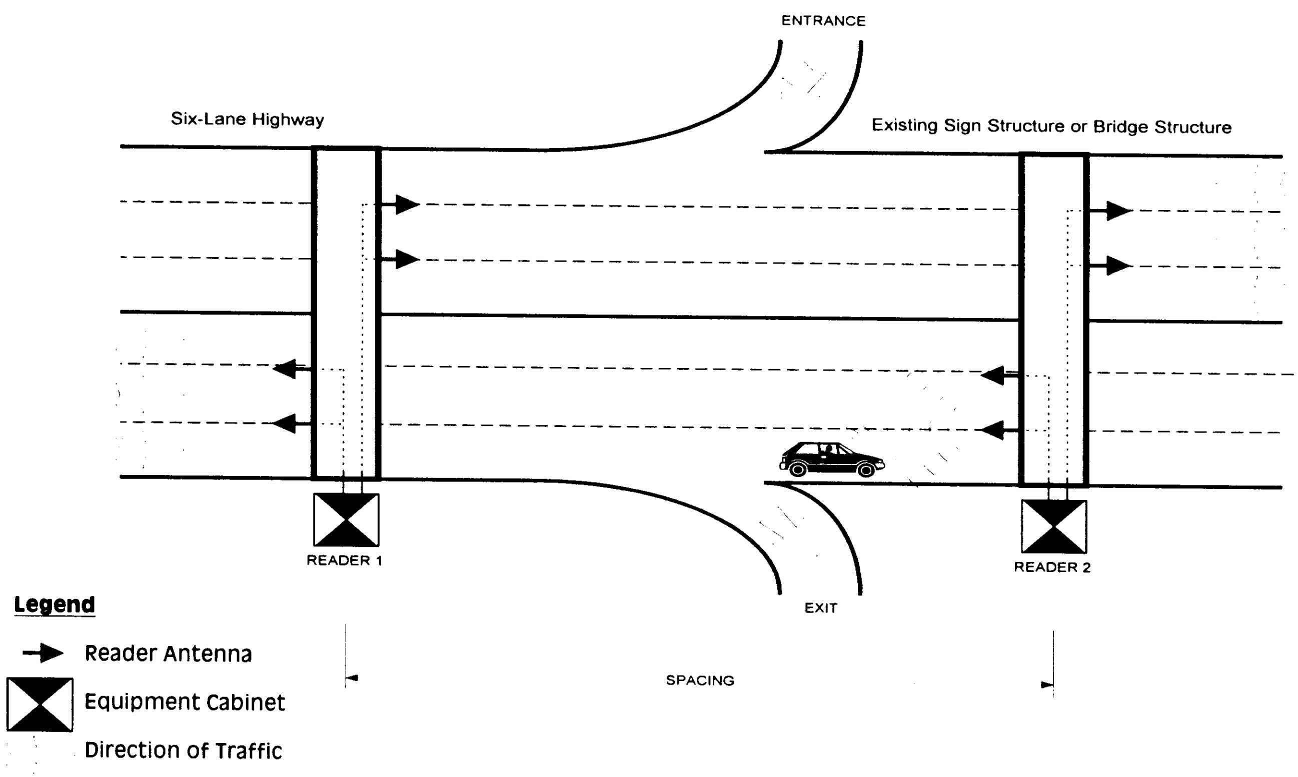

Figure 18. Two Typical TRANSMIT System Road Site Terminal (RST) Locations on a Six-Lane Highway

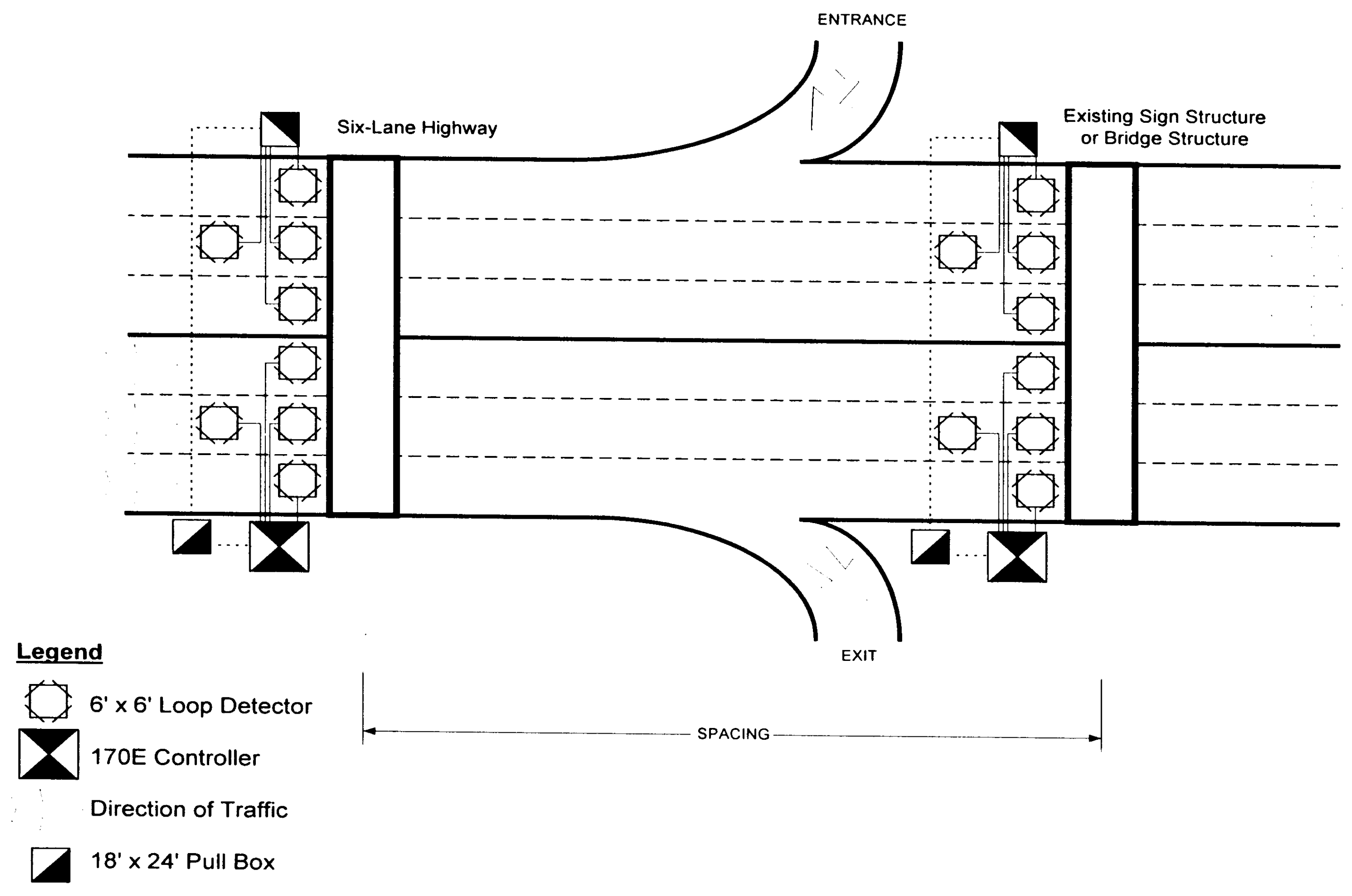

Figure 19. Two Typical Inductive Loop Detector System (ILDS) Locations on a Six-Lane Highway

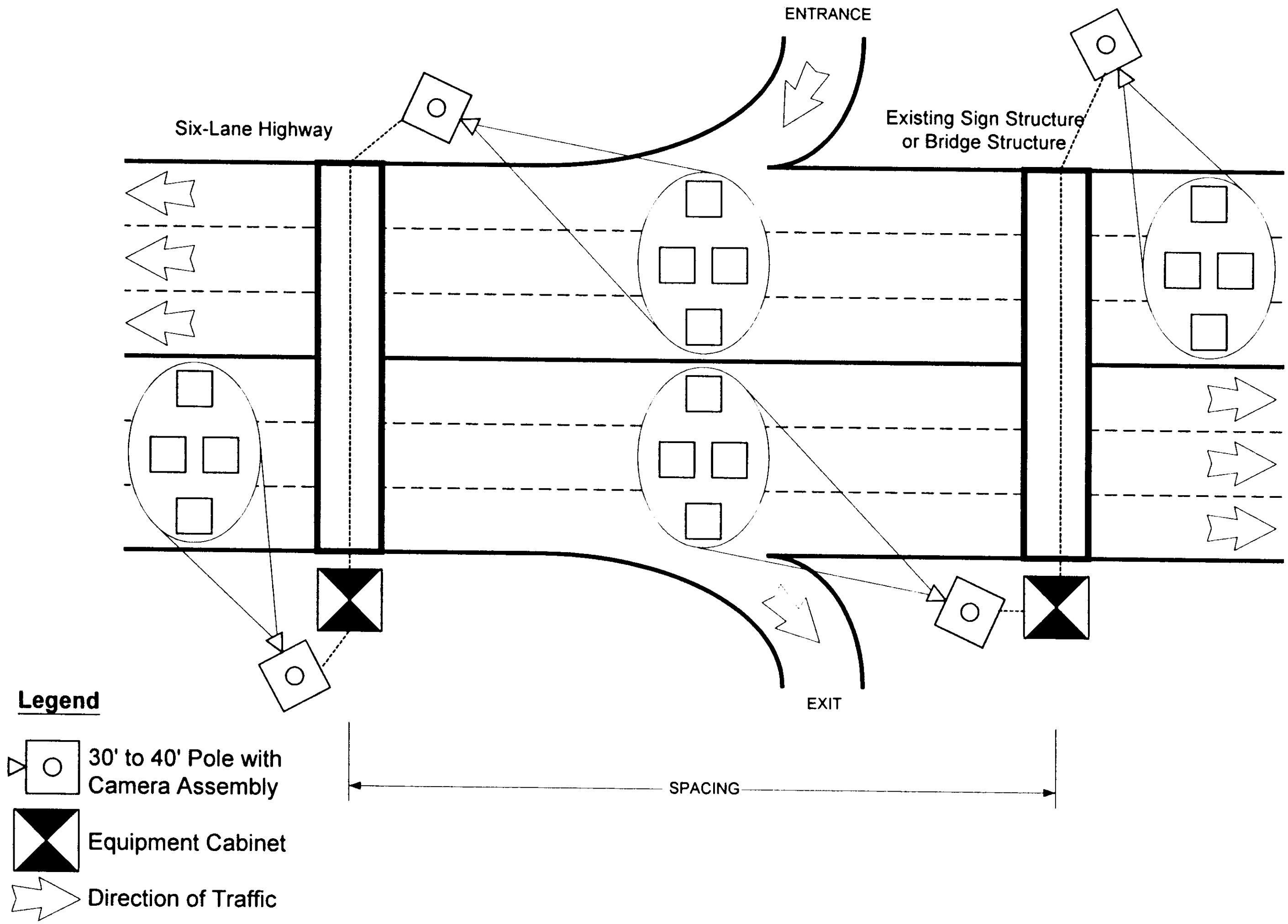

Figure 20. Two Typical Video Image Detection System (VIDS) Locations on a Six-Lane Highway

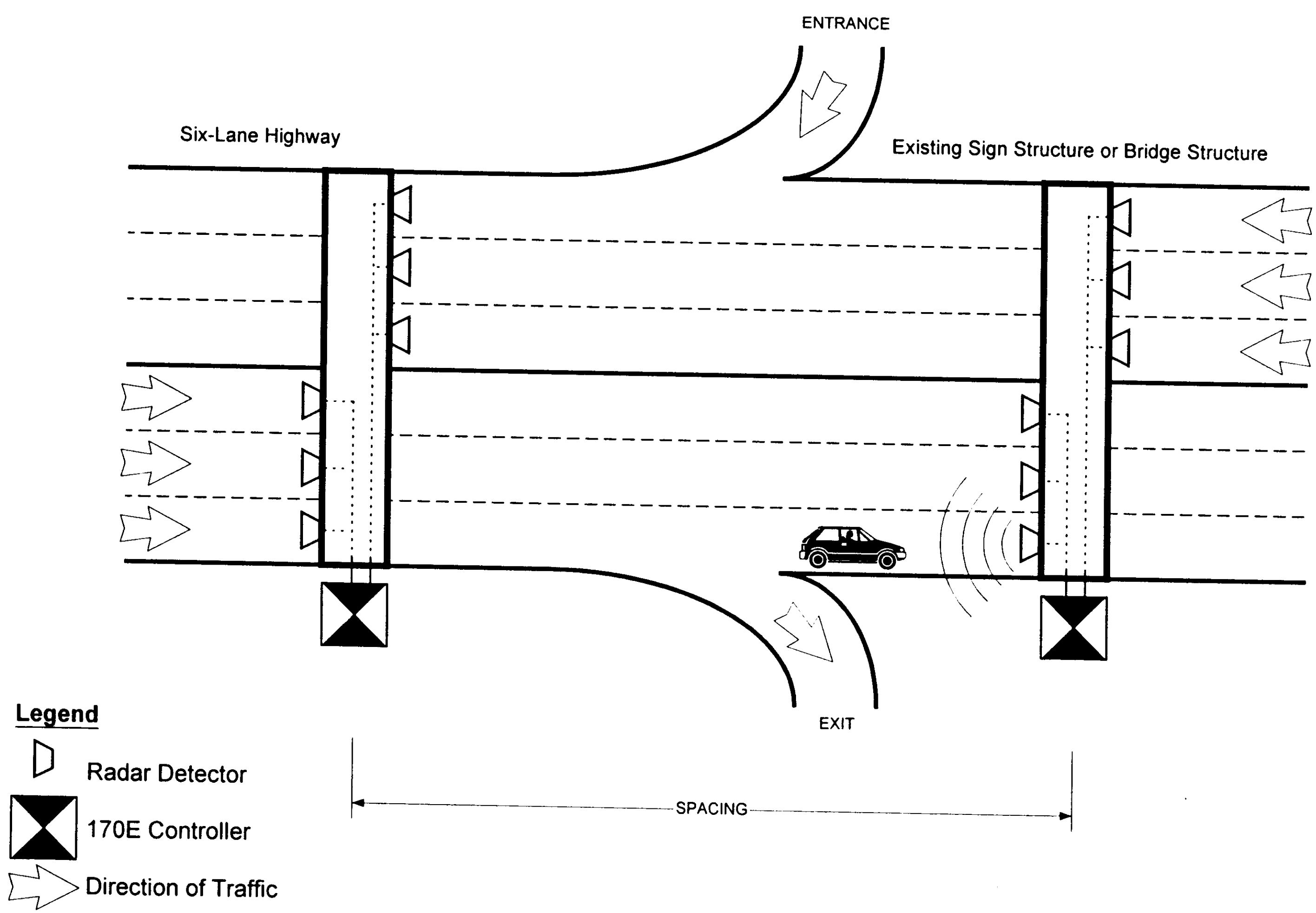

Figure 21. Two Typical Microwave Radar Detection System (MRDS) Locations on a Six-Lane Highway

6.3 Costs of Traffic Surveillance Systems

The costs for the TRANSMIT system were obtained by TRANSCOM. The cost estimates for the ILDS, VIDS and MRDS were obtained by PB Farradyne, Inc. and were based on manufacturer prices and engineering estimates based on various projects. The cost comparison was based on a per site basis for a six-lane highway.

It is noted however that a cost per mile basis should take into consideration the necessary spacing for each technology to produce the required traffic flow parameters. This task however was beyond the scope of this evaluation. Such an evaluation however, should be undertaken in the future in order to provide a comprehensive cost comparison of various traffic surveillance systems. Such a study should include the life cost of each technology, capital cost, maintenance and operation cost as well as its accuracy per traffic flow parameter, reliability (e.g. percentage of time that is in operation). Such a task will be non-trivial based on the rapid advances in traffic surveillance, communications and relevant software technologies.

6.3.1 TRANSMIT System Costs

The costs listed in this section were provided by TRANSCOM, based on their current estimates. The actual cost of a TRANSMIT based system depends on the frequency of RST spacing on the specific system. The costs listed below are the approximate installation, maintenance and operation costs of the TRANSMIT system for a six-lane highway. The costs for the RF tags (transponders) are not included in this analysis since they are treated as a part of the electronic toll collection system, the E-ZPass™ system which is currently in operation in the metropolitan area. The current RST spacing for the TRANSMIT system varies between 0.5 to 2.1 miles.

Hardware TRANSMIT Costs

The major hardware components of the TRANSMIT system in the field and their corresponding costs as shown in Table 42 are:

- Roadcheck™ [A] Basic Reader System (at the RST),
- Modems for leased telephone lines.

Table 42. TRANSMIT RST Hardware Costs for a Six-Lane Highway Location

Quantity	Unit	Description	Unit cost	Total
1	Each	Standard Reader	$6,000	$6,000
4	Each	Lane Kits (RF Module and Antennas)	$2,050	$8,200
1	Each	Modem	$500	$500
			Total	**$14,700**

[A] Roadcheck™ is a registered trademark of MARK IV Industries, Inc.

Computer/Communication Hardware Costs

In addition to the RST hardware, there is hardware at the OIC, NYSTA's and the NJHA's Traffic Operations Center (TOC) for processing the information and operating the system. This hardware includes the following:

- Communications concentrator,
- Communications server,
- Database server,
- Remote workstations,
- Leased line modems,
- CSU/DSU's.

The corresponding costs of their components are listed in Table 43.

Table 43. Central Computer/Communications Hardware Capital Costs

Quantity	Unit	Description	Unit cost	Total
20	Each	1 Leased Line Modem for each RST Location	$500	$10,000
6	Each	CSU/DSU for Remote Workstations and Multiplexed RST Locations	$1,000	$6,000
1	Each	Concentrator	$10,000	$10,000
2	Each	Servers	$30,000	$60,000
2	Each	Remote Workstations	$20,000	$40,000
3	Each	Routers	$4,000	$12,000
			Total	**$138,000**

Installation Costs of the TRANSMIT RST Hardware

The cost estimates shown in Table 44 assume that communication and electrical utility services are already installed in the vicinity of the RST equipment cabinets. Additionally, the installation costs are based on estimates for a six-lane highway (estimates are based on the average cost of installation on either an existing sign structure or overpass).

Table 44. Installation Costs for a TRANSMIT RST (Six-Lane Highway).

Quantity	Unit	Description	Unit cost	Total
1	Each	Reader Cabinet	$3,500	$3,500
160	L.F.	Exposed Conduit	$60/ft.	$9,600
20	L.F.	Under Ground Conduit	$30/ft.	$600
300	L.F.	Cabling	$10/ft.	$3,000
4	Each	Antenna Installations	$500	$2,000
1	Each	Modem Installation/Line Testing	$500	$500
1	Each	Maintenance and Protection of Traffic	Lump	$2,500
			Total	**$21,700**

Maintenance and Operations Costs for the RSTs

There are two options for an extended warranty for the RST's Mark IV reader electronics; it could either be on-site or off-site. The on-site warranty provides a 24-hour response and repairs time and cost approximately $2,000 per RST per year. The off-site warranty requires TRANSCOM staff to diagnose the malfunction and ship the damaged component for repair. This option would most likely require an inventory of spare components to minimize downtime. TRANSCOM currently has an on-site maintenance agreement with Mark IV.

TRANSCOM's project manager performs and/or coordinates the other maintenance duties (troubleshooting communications and electrical problems, etc.) at the cost of approximately $400 per RST per year. In the last four years, no maintenance or re-aiming was required for the existing 65 overhead antennas in the TRANSMIT system.

Requirement for maintenance of ancillary equipment (modems, cables, back up power supplies, etc.) has been negligible and is estimated at $500 per RST per year. Table 45 depicts maintenance costs per RST and Table 46 lists the costs for the complete TRANSMIT system.

Table 45. Maintenance Costs for a TRANSMIT RST

Quantity	Unit	Description	Unit cost	Total
1	Each	On-site Operational Support for RST	$2,000	$2,000
1	Each	Personnel for Maintenance	$400	$400
1	Each	Ancillary Equipment Maintenance	$500	$500
			Total	**$2,900**

Maintenance of the central computer/communications hardware has been covered under an umbrella agreement available at TRANSCOM and can be estimated at 10% of the capital cost - approximately $12,000 per year. Telephone operations support for the software provided for the TRANSMIT system (including customized software and operating systems) is estimated at $12,000 per year.

Table 46. Maintenance Costs for the Complete TRANSMIT System

Quantity	Unit	Description	Unit cost	Total
22	Each	On-site Operational Support for RST	$2,000	$44,000
22	Each	Personnel for Maintenance	$400	$8,800
22	Each	Ancillary Equipment Maintenance	$500	$11,000
1	Lump	Software/Operations Support	Lump	$12,000
1	Lump	Central Computer/Communication	Lump	$12,000
			Total	**$87,800**

Table 47 presents the annual operations cost for a TRANSMIT RST.

Table 47. Annual Operations Costs for a TRANSMIT RST

Quantity	Unit	Description	Unit cost	Total
12	Month	Monthly Leased Line Costs for a RST	$150	$1,800
12	Month	Monthly Electric Charges	$20	$240
			Total	**$2,040**

The inclusion of TRANSMIT operations to the OIC duties required the hiring of three additional staff personnel. This was needed to ensure two people around the clock coverage at the OIC (previously the OIC had a seven-person staff with single-person coverage for the overnight period). The cost of the additional staff is approximately $150,000 per year. The annual operational costs for the complete TRANSMIT system are shown in Table 48. The operational costs for the complete TRANSMIT system include an annual communication cost of $18,000 for three 56 Kbits data circuits. Two are for the remote workstations at the NJHA and NYSTA. One is for the headend location in NYSTA for the multiplexed RTSs.

Table 48. Annual Operations Costs for the Complete TRANSMIT System

Quantity	Unit	Description	Unit cost	Total
22	Each	Annual Leased Line Costs for a RST	$1800	$39,600
22	Each	Annual Electric Charges for a RST	$240	$5,280
22	Each	Annual High Speed Data Circuit for Remote Workstations and Multiplexed RST's	$6,000	$18,000
1	Each	Operations Staffing	$50,000	$150,000
			Total	**$212,880**

6.3.2 ILDS System Costs

The costs listed below as well as the costs for the VIDS and MRDS systems were obtained from PB Farradyne, Inc. through manufacturers' list prices, installation and maintenance contracts for existing systems (e.g. PATH (California) and INFORM (Long Island, New York), and engineers' estimates for the applicable items.

The major hardware components of this system are:

- Two channel loop amplifier,
- Controller (170E, NEMA, etc.),
- Modem for leased telephone lines.

Their corresponding costs are listed in Table 49.

Table 49. ILDS System Equipment Costs for a Six-Lane Highway Location

Quantity	Unit	Description	Unit cost	Total
4	Each	Two Channel Amplifier	$400	$1,600
1	Each	Controller	$2,000	$2,000
1	Each	Modem	$500	$500
			Total	**$4,100**

Installation of the ILDS System

The cost estimates for the installation of the ILDS system shown in Table 50 assume that communication and electrical utility services are already in place in the vicinity of the equipment cabinet. The cost estimates are based on a six-lane highway.

Table 50. Installation Costs for an ILDS System (Six-Lane Highway)

Quantity	Unit	Description	Unit cost	Total
1	Each	Controller Cabinet	$3,500	$3,500
516	L.F.	Loop Installation (Saw Cut Roadway and Install Loop Wire)	$50/ft	$25,800
752	L.F.	Lead Cable	$5/ft.	$3,760
30	L.F.	Conduit Under Ground	$30/ft.	$900
120	L.F.	Conduit Under Roadway	$80/ft.	$9,600
2	Each	Pull box	$1,000	$2,000
1	Lump	Maintenance and Protection of Traffic	Lump	$5,000
			Total	**$50,560**

Maintenance and Operations Costs for the ILDS System

The maintenance costs for ILDS are dependent on the following:

- Condition of the roadway,
- Amount of traffic that travels over the loop,
- Roadway restorations that require reinstallation of the loop,
- Weather.

Approximately 30% of the loops malfunction or are damaged due to roadway repair (INFORM's managers interviewed) and need to be replaced during the course of a year. The maintenance cost listed in Table 51 below assumes two out of the eight loops at a detector location (25% conservatively) are replaced. Maintenance of the ancillary equipment (modems, cables, controller, loop amplifier, etc.) has been negligible and is estimated at $500 per location per year.

Table 51. Maintenance Costs for an ILDS System Location

Quantity	Unit	Description	Unit cost	Total
129	L.F.	25% Loop Installation (Saw Cut Roadway and Install Loop Wire)	$50/ft	$6,450
1	Each	Maintenance and Protection of Traffic	Lump	$1000
1	Each	Ancillary Equipment Maintenance	N/A	$500
			Total	**$7,950**

The annual operations costs for an ILDS system location are listed in Table 52.

Table 52. Annual Operations Costs for ILDS System Location

Quantity	Unit	Description	Unit cost	Total
12	Each	Monthly Leased Line Costs	$150	$1,800
12	Each	Monthly Electric Charges	$20	$240
			Total	**$2,040**

6.3.3 VIDS System Costs

The costs listed below were obtained from manufacturers' list prices, installation and maintenance contracts, and engineers' estimates for the applicable items.

The major hardware components of the VIDS system are:

- Camera assembly,
- Video image processor,
- Modem for leased telephone line.

The corresponding costs are shown in Table 53.

Table 53. VIDS System Equipment Costs for a Six-Lane Highway Location

Quantity	Unit	Description	Unit cost	Total
2	L.F.	Camera Assembly	$2,000	$4,000
1	Each	Video Image Processor	$20,000	$20,000
1	Each	Modem	$500	$500
			Total	**$24,500**

Installation of the VIDS

These cost estimates as listed in Table 54 are based on a six-lane highway installation assume that communication and electrical utility services are already in place in the vicinity of the equipment cabinet.

Maintenance and Operations Costs for VIDS

The camera lens and viewing window need to be cleaned periodically in dusty and seasonal areas. Sensitive electronics in the camera assembly will require additional maintenance.

Table 54. Installation Costs for a VIDS System (Six-Lane Highway)

Quantity	Unit	Description	Unit cost	Total
1	Each	Equipment Cabinet	$3,500	$3,500
2	Each	40 Foot Metal Pole and Foundation	$6,000	$12,000
160	L.F.	Exposed Conduit	$60/ft	$9,600
50	L.F.	Underground Conduit	$30/ft	$1,500
300	L.F.	Coaxial and Camera Power Cables	$80/ft	$14,000
2	Each	Pull Box	$1,000	$2,000
2	Each	Maintenance and Protection of Traffic	Lump	$2,500
			Total	**$45,100**

Maintenance on the camera assembly in a side-fired configuration requires lane closure since a larger truck is needed to reach camera assemblies installed on 40-foot poles. Depending on the location of the pole an attenuator truck may be required to back up bucket truck. The rates for a 40-foot truck and an attenuator truck, each with an operator/driver, are $1,100 and $700 per day, respectively. Work needs to be performed during the day, may require lane closures during the day if traffic congestion is dense. It is assumed that both bucket and attenuator trucks are required two maintenance visits per year per camera assembly at a cost of $3,600. It is also assumed that video image processing will be performed in the field and no extra data processing requirement is needed back at the central facility.

Maintenance of ancillary equipment (modems, cables, etc.) is similar to that of RSTs and is estimated at $500 per year. The annual maintenance costs for VIDS are listed in Table 55 and corresponding operation costs are shown in Table 56. The operations cost for VIDS system assumes that video is not transmitted back to the OIC/TOC.

Table 55. Maintenance Costs for VIDS System

Quantity	Unit	Description	Unit cost	Total
1	Each	On-site Operational Support for VIDS	$1,000	$1,000
2	Each	Personnel for Maintenance	$400	$800
1	Each	Ancillary Equipment Maintenance	N/A	$500
1	Each	Maintenance and Protection	Lump	$1,000
			Total	**$3,300**

Table 56. Annual Operations Costs for VIDS System

Quantity	Unit	Description	Unit cost	Total
12	Each	Monthly Leased Line Costs	$150	$1,800
12	Each	Monthly Electric Utility Charges	$20	$240
			Total	**$2,040**

6.3.4 MRDS System Costs

The costs listed below were obtained from manufacturers' list prices, installation and maintenance contracts, and engineers' estimates for the applicable items. The major hardware components of the MRDS system are:

- Radar detector unit,
- Controller,
- Modem for leased telephone line.

The hardware costs associated with the MRDS system are listed in Table 57.

Table 57. MRDS System Equipment Costs for a Six-Lane Highway Location

Quantity	Unit	Description	Unit cost	Total
6	Each	Radar Detector Unit	$4,000	$24,000
1	Each	Controller	$2,000	$2,000
1	Each	Modem	$500	$500
			Total	**$26,500**

Installation of the MRDS System Equipment

These cost estimates based on a six-lane highway are listed in Table 58 assume that communication and electrical utility services are already in place in the vicinity of the equipment cabinet.

Table 58. Installation Costs for an MRDS System (Six-Lane Highway)

Quantity	Unit	Description	Unit cost	Total
1	Each	Equipment Cabinet	$3,500	$3,500
210	L.F.	Exposed Conduit	$60/ft	$12,600
20	L.F.	Underground Conduit	$30/ft	$600
500	L.F.	Cabling	$10/ft	$5,000
1	Lump	Maintenance and Protection of Traffic	Lump	$3,500
			Total	**$25,200**

Maintenance and Operations Costs for an MRDS System Unit

The maintenance and operations costs for an MRDS system unit are listed in Table 59 and 60, respectively. Maintenance of ancillary equipment (modems, cables, etc.) is similar to that of RSTs and is estimated at $500 per year.

Table 59. Maintenance Costs for an MRDS System Location

Quantity	Unit	Description	Unit cost	Total
1	Each	On-site Operational Support	$2,000	$2,000
1	Lump	Personnel for Maintenance	N/A	$400
1	Lump	Ancillary Equipment Maintenance	N/A	$500
			Total	**$2,900**

Table 60. Annual Operations Costs for an MRDS System Location

Quantity	Unit	Description	Unit cost	Total
12	Month	Monthly Leased Line Costs	$150	$1,800
12	Month	Monthly Electric Utility Charges	$20	$240
			Total	**$2,040**

6.4 Benefits of Traffic Surveillance Systems

This section includes the benefits of the TRANSMIT system compared to other similar systems for traffic management, toll management, transit and fleet management, traveler information and transportation planning. In addition, the potential benefits of the TRANSMIT system for providing a permanent test bed for research purposes are identified.

6.4.1 Traffic Management

A comprehensive traffic management system requires estimates of the following traffic characteristics:

- **Automatic Vehicle Identification and Location Data** (Available in the current TRANSMIT system)**.**

Automatic Vehicle Identification/Location (AVI/L) data is becoming vital for various applications in traffic management such as: direct link travel time estimation, path travel time estimation, and identification of O-D patterns and vehicle location.

The TRANSMIT system has the capability to identify a tag equipped vehicle at every RST location. This provides the capability to obtain direct measurement of the link travel time between two consecutive readers and to track the path of the vehicle. Vehicle location may be estimated based on the projected distance from a specific RST utilizing the detection time of the vehicle. Vehicle position is readily available in the TRANSMIT system. The privacy of the driver is protected through encoding of the vehicle's tag ID that is implemented automatically at the OIC.

ILDS, VIDS and MRDS systems do not have the capability to identify each individual vehicle and track its path.

- **Link Travel Time Estimation** (Available in the current TRANSMIT system).

One of the important parameters for traffic management is the estimation of the vehicle individual link travel time and the link average travel time per time interval of the day.

The TRANSMIT system provides direct measurements of link travel times based on vehicles equipped with tags. The link average travel time per time interval is based on a sample of the link travel times of these vehicles. The larger the proportion of vehicles equipped with electronic tags in each time interval of the day, the greater is the accuracy of the link travel time estimates. Currently, a 10-second cycle length is used to provide link travel time estimates, which are aggregated to 15-minute time interval estimates.

ILDS, VIDS and MRDS could use the vehicle speed at a specific spot of the roadway to provide estimates of link travel times. This speed could be based on the space mean speed estimates of two consecutive detector stations. The space mean speed estimation based on detectors produces inaccuracies since it depends on a very short length (only a few feet). The basic assumption made is that the estimates of the space mean speed may be used for the whole section (link) of the roadway (implying a uniform speed distribution). However, this may not be accurate, since in many cases there is considerable speed variability within the link in determining this estimate. Thus, it necessitates the use of spacings of less than half a mile for providing more accurate estimates but still possibly not very accurate.

- **Path Travel Time Estimation** (presently available in the TRANSMIT system with a manual summation of link travel time estimates. This capability will be automated in the next updated version of software).

Path travel time is the accumulation of multiple link travel times.

The estimation of a vehicle's path travel time and the average path travel time per time interval of the day are also important in traffic management. These parameters can be used for ramp metering, incident management (e.g. development of route diversion plans) and for the quality of service of a transportation network, corridor or an individual path. Furthermore, the estimation of individual path travel times is very useful in distinguishing the travel time estimates of various classes of vehicles (e.g. automobiles, trucks, buses etc.).

Determination of a specific vehicle's actual path travel time is possible in the TRANSMIT system. Currently, this option is not embedded into the software. However, with minor software changes this information can be retrieved. Similarly, the path average travel time can also be estimated and retrieved with minor software modifications.

Direct measurements of an individual vehicle's path travel time from ILDS and MRDS are not feasible. Indirect average path travel time estimation is possible through the sum of the estimates of the average link travel times of each individual path. VIDS, using license plate recognition, have a limited capability in providing the path travel time if they are applied system wide.

- **Link Space Mean Speed Estimation** (Available in the current TRANSMIT system).

The estimation of the link space mean speed is directly associated with the link travel time estimation and is commonly used for traffic management. The link space mean speed may be used for incident detection, and serves as a measure of the level of service for a particular link within the roadway system.

The link space mean speed is estimated from the direct measurement of the link travel times due to individual tag equipped probe vehicles in the TRANSMIT system. This estimate may be extracted from a cycle interval which is updated every 10-seconds. This estimate as used in the incident detection algorithm currently is based on historical 15-minute time intervals and real time link speed estimates of individual vehicles. The reliability of the link space mean speed estimate depends on the number of tag equipped vehicles passing through the link during a specific time interval of the day.

Only indirect estimation of the link space mean speed is feasible through ILDS, VIDS and MRDS systems. This speed could be based on the space mean speed estimates of two consecutive detector stations. The space mean speed estimation based on detectors produces inaccuracies since it depends on a very short length (only a few feet). The basic assumption made is that the estimates of the space mean speed within a section of only a few feet may be used for the whole section (link) of the roadway (implying a uniform speed distribution). However, this may not be accurate, since in many cases there is considerable speed variability within the link in determining this estimate. Thus, it necessitates the use of spacing of less than half a mile in providing more accurate estimates but still possibly not very accurate. It is noted that VIDS has a similar potential to the TRANSMIT system in providing direct estimate of the space mean speed if it is used for license plate recognition.

- **Traffic Flow Rate (Volume) Estimation** (A study needs to be undertaken to assess whether the TRANSMIT system has the capability to provide this estimate).

The estimation of the traffic flow rate is another important parameter in traffic management.

The traffic flow rate in the TRANSMIT system may be estimated indirectly since only a certain percentage of the vehicles are currently equipped with E-ZPass tags. An accurate estimation of the traffic flow rate will require the knowledge of the actual percentage of vehicles equipped with tags for each link of the system. An approximate estimate of the percentage of tag equipped vehicles in the TRANSMIT system can be determined based on the traffic volumes and percentage of tags at the toll plazas.

ILDS systems have the capability to provide direct estimates of the traffic flow rate. These estimates are based on the number of axles crossing over the detection zone of a loop detector. The axle count is then converted into a number of vehicles per unit time based on historical measurements of the mixture of vehicles of the traffic stream for each location. This estimate is based on the total population of the vehicles unlike the TRANSMIT system where only a percentage of vehicles could be taken into account in the current state of the system.

VIDS systems provide direct detection of vehicles through the virtual detectors that are placed on the screen.

MRDS systems provide direct detection of vehicles as they intercept the back scattered signal. Both VIDS and MRDS systems can provide a direct measurement of the traffic flow rate.

- **Space Occupancy** (the TRANSMIT system cannot provide this estimate).

The space occupancy is used as a surrogate measure of the density of traffic. The space occupancy may be used together with the traffic volume and space mean speed to provide the status of the traffic conditions on a specific roadway link.

ILDS, VIDS and MRDS systems provide direct estimates of the space occupancy of the roadway.

- **Automated Incident Detection** (Available in the current TRANSMIT system).

Incident detection is an integral part of an efficient incident management system. The successful operation of the transportation facility depends on the timely detection/identification of a true incident, rapid response to the incident, optimization of the clearance time, and the speedy recovery of the highway operation to normal conditions.

The TRANSMIT system operates an automated incident detection algorithm based on the real-time acquisition of link travel time data of tag equipped vehicles. The algorithm requires the link travel time estimation of successive individual vehicles. The system has been found to accurately detect the occurrence of major incidents. Minor incidents that do not cause changes in the link travel time are likely not to be detected by the TRANSMIT system. The TRANSMIT system compares favorably with other automated incident detection systems reported in the literature. This evaluation provided estimates of incident detection rates ranging between 91% to 95% on NYST during a three-month period. The corresponding false alarm rates ranged between 0.0052% and 0.0124%.

Most of the automated incident detection systems currently in operation depend on loop detection technology. The California algorithm is commonly used in incident detection on various highway systems in the US. A major concern for these algorithms is the high occurrence of false alarms which in some cases forced the agencies to abandon its use (e.g. the INFORM system in Long Island, New York). Another major concern is the high percentage of inductive loop detectors that malfunction, (INFORM's managers report 30% or more) which further reduces the reliability of the incident detection.

VIDS and MRDS use similar techniques to detect incident as ILDS, which are based on the estimates of the traffic flow rate, space occupancy and space, mean speed. An advantage of VIDS is its ability to cover a larger area, however with diminishing accuracy, and provide estimates of the above parameters for various points within the video coverage region. In addition, in some VIDS, an incident may be detected directly based on the differences found on the consecutive images. Furthermore, an operator can observe the validity of an alarm as a true incident if it is within the camera's view, an option that is not available in other systems.

It may be argued that with the increase in the number of people who carry cellular phones it is unlikely that any automated algorithm could perform better than the timely information provided by the motorists. Cellular users may also provide a description of the nature of the incident. Various studies in the US and Europe indicate that this is essentially true. However, it is unlikely that users will be able to provide the traffic flow data that are necessary for incident management. Therefore, the use of an automated incident detection algorithm is still necessary to provide continuous estimates of the current traffic conditions (e.g. traffic flow rate at on/off ramps, the highway mainline and the arterial system; link travel time, space mean speed and space occupancy). Such data may be used for diversion techniques, arterial timing optimization and ramp metering at the vicinity of the incident. Furthermore, the incident related traffic flow data might be stored for future research. Such data will be helpful in developing improved versions of the current automated incident detection algorithms, incident diversion techniques and other aspects of incident management.

6.4.2 Toll Facility Management (Available in the current TRANSMIT system)

Toll facility management includes the scheduling of personnel and operation of the toll lanes, for optimum performance.

The travel time from one toll plaza to another is readily available from tag data in the TRANSMIT system. The percentage of vehicles equipped with E-ZPass tags is also known at each toll plaza. The historical trends of this data may be used in determining the level of staffing required at the tollbooths of each facility per time period of the day. The real time data can also be used to address non-recurrent conditions at the toll plazas or at any link of the system. The link travel time data from the upstream RSTs to the toll plaza may also be utilized in deciding the level of service at the toll plaza per time period of the day, in terms of the number of booths staffed and the number of toll booths that have to be kept open for E-ZPass users only. A better toll management scheme may then be devised which could be upgraded continuously according to changing traffic conditions.

ILDS, VIDS and MRDS systems may use the traffic flow parameter estimates for similar toll management issues. VIDS may be used for estimating the queue lengths at the toll lanes, which is also a very desirable feature.

6.4.3 Transit Fleet Management (the TRANSMIT system has the capability in providing AVI/L data which may be applied in transit fleet management)

One of the most important issues in transit fleet management is the prediction of the route travel time, adherence to the scheduled timetables, and timely knowledge of any delays experienced during the operation.

One of the advantages of the TRANSMIT system is its ability to track individual vehicles if they are equipped with E-ZPass tags. Transit agencies and private transit fleet operators can monitor their fleets on a continuous basis and optimize their schedules. Such use of the TRANSMIT system is in design for the Route 3/NJ-495/Lincoln tunnel corridor in New Jersey and New York. The system is to provide the approximate location of each tag-equipped bus, estimated arrival times to the Port Authority Bus Terminal and schedule adherence estimates. In addition, the system is also envisioned to include automated incident detection along the routes, including the exclusive bus lane on NJ-495 to the Lincoln Tunnel.

ILDS and MRDS systems do not have any AVI/L capabilities. VIDS has the capability of reading license plates, which may then be used for transit fleet management. This capability can be fully exploited by installing cameras in each lane, which will result in the increase of the costs of such a system. However, no application of this potential capability has been reported.

6.4.4 Freight Fleet Management (the TRANSMIT system has the capability in providing AVI/L data for freight fleet management)

One of the most important issues in freight fleet management is the prediction of the route travel time, adherence to the scheduled time tables, and timely notification of any incurring delays experienced during the operation. Minimizing unnecessary stops that trucks are subjected to in order to be inspected has to be considered as part of an efficient freight fleet management.

Similarly, the use of the E-ZPass tags could be used for the efficient development of truck scheduling, incident detection, and fleet management. Furthermore, the transponder may be used as a storage device of individual truck data, which could be updated in real time. Real time data may include the last time the truck was inspected and avoid unnecessary stops at weigh stations. The trucking companies could also have a means to ensure that trucks follow designated trucks routes and that they do not deviate from their scheduled routes. Similar to transit fleet management, only VIDS have the potential for a limited AVI/L functionality which can be used for similar functions as in the TRANSMIT system.

6.4.5 Traveler Information

The advances in technology made possible the proper collection and dissemination of data required for efficient realization of traveler information systems.

TRANSCOM currently provides information to the member agencies and a number of users associated with the agencies through a pager system. TRANSCOM is also interconnected to the Interchange Exchange Network (IEN) of the I-95 corridor coalition to provide traveler-related information. Currently, available information is not provided directly to the general public. **The TRANSMIT system has the capability to provide path travel time estimates, link travel time estimates, and presence of incidents for the route.** Presently, only the incident information is disseminated to the participating agencies. Once the TRANSMIT system is implemented in an expanded geographical area, it may become a valuable tool for real time traveler information services. This information would enable the users to make informed traveling decisions, such as route planning. VMS and HAR systems can be used to disseminate the collected data. Additionally, the traffic flow characteristics estimates produced by the TRANSMIT system may be made available to traveler dissemination services such as local TV and radio stations, Metro Traffic, Shadow Traffic, INTERNET, and to subscribers through fax, computer, pager, and telephone. Additionally, next generation tags will have read/write capabilities and sufficient memory which can be utilized to send traveler related information (e.g. delays, incidents, route planning, etc.) from the OIC/TOC to the drivers in-vehicle navigation and/or information systems. The RSTs hardware/software could be modified to perform two-way communications with the vehicles with minimal effort and cost.

ILDS, VIDS and MRDS systems could provide estimates of traffic flow rate, speed and occupancy, which can be used to characterize the traffic conditions. The AVI/L capabilities of the TRANSMIT system provide additional dimensions for traveler information. Only VIDS has also a potential in providing a similar AVI/L capability.

6.4.6 Transportation Planning

The primary goal of transportation planning is to define the optimal network configuration. Estimates of link travel time, link space mean speed, traffic flow rate (volume), space occupancy, path travel time, and the origin destination matrix are among the essential parameters that are utilized in transportation planning. However, the availability of data in smaller time intervals provides additional opportunities for transportation planners to use microscopic simulation in the evaluation of a variety of transportation projects. The TRANSMIT system has the capability in providing this real time data.

The capability of TRANSMIT to provide traffic flow rate estimates should be investigated since it is a very important parameter in the transportation planning process.

While the TRANSMIT system can provide direct estimates of the O-D matrices, ILDS and MRDS systems can not. O-D matrices can only be estimated indirectly based on traffic flow rate estimates and additional but costly O-D surveys. VIDS having the potential AVI/L capability may be used for O-D estimation, although costly due to the necessary addition of camera locations at each lane, on-ramps and off-ramps. In general the O-D estimation is considered one of the most difficult tasks for the transportation planners. A system like TRANSMIT, if expanded to cover a large geographical area, could become an invaluable source of O-D data for the metropolitan transportation network. Another application of O-D estimates is for capacity analyses of ramp and weaving sections on highways. Currently, there are no methodologies that provide direct O-D estimates for these types of highway sections. Traditional methods include manual O-D surveys, which are susceptible to errors and require considerable data collection efforts. Furthermore, O-D direct estimates may be used for more effective ramp metering control, as well as for the development of efficient incident management plans. Utilizing the knowledge of the O-D matrix provides a tool to predict the flow on the diverted paths, which can be used to develop appropriate traffic control policies under incident conditions. In combination with the other traffic flow data (link travel time, path travel time, volume) more accurate traffic assignment models can be developed.

In addition to the data mentioned above, the incident analysis may become part of the transportation planning process with more timely data. Presently, incident data are not readily available. Also, the effects of the incidents and construction, on traffic flow operations can be documented and the data may be used for more intelligent transportation planning practices. Furthermore, studies on the effects of VMS and HAR messages can be studied.

In essence, before and after analysis, traffic impact analysis, and general transportation planning processes can be contacted in a comprehensive and cost effective manner through the availability of all pertinent data.

6.4.7 Research for Traffic Flow Characteristics

The TRANSMIT system provides an excellent opportunity in becoming a permanent national test bed for traffic flow measurements. Its ability to track vehicles creates opportunities for extensive research that could not be realized before through conventional means or through extensive research, such as O-D surveys. One of the main advantages that the NY-NJ-CT metropolitan area offers is that the majority of the vehicles will soon be equipped with E-ZPass tags due to the wide acceptance of this system by the toll facilities. Currently a pool of 1.5 million tag-equipped vehicles operates in the metropolitan area. As more and more of the toll facilities of the metropolitan area are equipped with the E-ZPass system the number of tag-equipped vehicles will increase substantially. Essentially, this will create the largest pool of vehicle probes in the country. While several models have been developed that capture the relationship between space mean speed, traffic flow rate, occupancy and density, these models lack extensive validation. The conventional data collection procedures require extensive time and effort and are inadequate to provide comprehensive data for accurate estimates of these parameters. It is virtually impossible to track individual vehicles throughout a long stretch of the highway or a network with manual observations or through the usage of traditional loop detectors. TRANSMIT type systems can provide a continuous stream of traffic flow and travel time data on links of fixed length depending on the configuration of the system. Some of the benefits of an extended TRANSMIT system are identified as:

- The ability to provide estimates on link travel time may help to confirm the existing speed-flow relationships or lead to the enhancement of these models,
- Other traffic flow relationships may be developed that may relate the traffic flow to the path travel times. This capability may provide another measure of effectiveness for capacity analyses of highway sections and highway segments,
- The direct O-D estimation for a transportation network or corridor may further enhance the existing traffic assignment procedures which currently are based on very inadequate estimates,
- The O-D estimation and travel time estimation may enhance the present models that are used for capacity analyses of weaving sections; providing good estimates of the volumes entering and exiting the highway, estimates of the O-D distribution of the vehicles in the weaving area, and the travel times of the weaving and non-weaving vehicles. Similarly, the O-D estimation may aid the capacity analyses of ramp junctions. The analysis of weaving areas and ramp junctions will require the installation of portable RSTs at specific locations to capture all the detailed movements of the vehicles,
- One of the parameters in arterial capacity analysis is the travel time over a segment of the arterial. The TRANSMIT system provides direct measurements of this parameter based on the data collected at consecutive RSTs,
- The ability of the system to provide travel times from one intersection to another may provide another tool for signal timing optimization. Present traffic responsive systems provide estimates of the travel time between intersections based on loop detectors and a spot speed, which may lead to inaccurate estimates,
- The present configuration of the RSTs produces accurate and reliable results in link travel time, space mean speed, and incident detection. Future research should address how to maintain this accuracy and reliability with additional savings in costs,
- The AVI/L related data might aid to the development of more robust routing algorithms, which can aid transit and fleet management, in-vehicle navigation systems and dynamic traffic assignment models,
- The tag read/write capability of the system could be used for in-vehicle communications.

6.5 Agency Responses to Survey

As part of the evaluation, a survey was conducted to determine the participating agencies, the NJHA and the NYSTA, assessment of the TRANSMIT system's capabilities in terms of traffic management, traveler information and transportation planning. Two questionnaires were prepared, one for operators and another for traffic engineers, transportation managers or transportation planners. The questionnaire was also addressed to TRANSCOM as well, since they had more exposure to the operational characteristics of the TRANSMIT system as they are the principal operators. The questionnaire and the corresponding responses to the surveys are presented in Appendix D. A summary of the responses is outlined below:

6.5.1 Operators Responses

Overall, all operators found the performance of the TRANSMIT system as satisfactory and that it had a user-friendly interface that is rather easy to learn. The classification of alarms as true incidents or false alarms is found to be easy through TRANSMIT's user interface. The NJHA indicated that the remote workstation needed to be rebooted every few days, and the NYSTA noted that RST hardware problems were encountered.

The availability of link travel times and incident detection are considered very important to the agency operators. They are currently used to confirm problems, dispatch police and to compare delays between parallel routes (e.g. Tappan Zee Bridge versus George Washington Bridge). The use of O-D path travel time data would be useful in informing travelers of incident conditions through VMS/HAR, upstream of incidents. The traffic flow rate (volume) is not considered very useful to operators.

They also indicated that CCTV would help to expedite the classification of alarms and the confirmation process. Also, the user interface could be further improved to expedite the shutdown/rebooting procedures. Furthermore, they indicated that in the future, the system should be integrated with CCTV/HAR/VMS/IEN and in vehicle communications. TRANSCOM indicated that for the present system they had to add three more operators at the OIC to ensure a two-person coverage throughout the 24-hour period of the day.

6.5.2 Responses of Traffic Engineers, Transportation Managers and/or Transportation Planners

The performance of the TRANSMIT system was found to be satisfactory in terms of the communication system's transmission rate and the incident detection rate. The incident detection rate is expected to be higher than 95% from both agencies, where NYSTA indicated that they would like to see an improvement of up to 99% for peak periods, and a detection time of less than one-minute for peak periods and less than five minutes during off-peak periods. The false alarm rate of the TRANSMIT system was found acceptable, however a more stringent false alarm rate is expected from the system in the future of less than 5%. The NJHA is committed to an incident response time of less than 20-minutes. The incident detection capability is also found important in maintaining a historical database of incidents and their effects. The hardware and software reliability levels are expected to be very high, at 99% of the time. The also indicated that it is unacceptable to have links off-line.

The availability of link travel times and incident detection are found to be very useful in determining delays along the roadway and responding to incidents. In addition they indicate the usefulness of this information to be provided in real time to the travelers through VMS/HAR. TRANSCOM is currently disseminating this information to the other agencies and is looking forward in providing this information directly to VMS and HAR through the

NY-WINS program, and in-vehicle communications once two-way communication systems are embedded into the vehicles and the RSTs.

NYSTA found the TRANSMIT system useful for toll plaza staffing. They also found it useful in balancing the flow on different facilities by comparing the information from TRANSMIT to conditions on other facilities (e.g. major George Washington Bridge construction projects) and relaying this information to affected agencies and/or VMS/HAR.

Institutional issues were resolved through normal cooperating efforts and the unique contractual agreement among TRANSCOM, the agencies and the consultant.

The availability of continuously updated historical link travel time data are found to be very useful in identifying future trends, identifying patterns especially during holiday periods, as well as for other transportation planning purposes such as future capacity enhancements at critical points of the roadway. It is also particularly useful in the continuous enhancement of the incident detection algorithm since it is one of the primary parameters. The response to the archiving of data is mixed where NJHA would like to have archiving done only on as needed basis and the NYSTA would prefer to have a more automated archiving especially when the system is being expanded.

The TRANSMIT system is envisioned to be integrated to the arterial system in the future, and it could be used for route diversion techniques to handle various levels of congestion, and tied to HAR and VMS, to provide more specific information to travelers. The estimate of the traffic flow rate (volume) is found useful for manning toll plazas and help in anticipating potential problems (delays) due to increases in volumes at certain sections of the roadway. The traffic volume is also useful for trend and O-D analyses. The identification of O-D patterns per vehicle class, the identification of high incident links, tracking of EMS/police/transit vehicles are envisioned by the agencies to be available by the TRANSMIT system in the future. Furthermore, it is envisioned that the TRANSMIT system data could be communicated to the users through in-vehicle communication systems. The TRANSMIT system is also envisioned to be useful to truck fleet operators who could take advantage of the AVI/L capabilities in monitoring and managing their fleets.

NJHA and NYSTA expressed an indication that they would invest in expanding the TRANSMIT system on their facilities. One of the anticipated problems is the cost related to the Operations and Maintenance.

6.6 Institutional Issues

TRANSCOM is governed by a Steering Committee, which is comprised of members from the participating agencies in the NY-NJ-CT metropolitan area. TRANSCOM's primary responsibility is to acquire transportation information and coordinate interagency responses to incidents in the metropolitan area for the participating agencies. TRANSCOM also facilitates the coordination of construction and maintenance activities and serves as an ITS test bed for its members. The TRANSMIT system is an important extension to the responsibilities of

TRANSCOM, that raised additional institutional issues when first conceived and implemented. The initial challenge was the installation and operation of the TRANSMIT system on a portion of two facilities of its member agencies, the NJHA and the NYSTA.

6.6.1 TRANSMIT System Implementation

The implementation of the TRANSMIT system was managed by the Federal Highway Administration (FHWA) and the following TRANSCOM participating member agencies:

- New Jersey Highway Authority (NJHA),
- New York State Thruway Authority (NYSTA),
- New Jersey Department of Transportation (NJDOT),
- Port Authority of New York and New Jersey (PANYNJ).

Issues regarding the TRANSMIT system were resolved through regular meetings between the participating agencies. Implementation of the TRANSMIT system required the resolution of a number of issues due to the multi-jurisdictional nature of TRANSCOM's responsibilities:

- Items such as insurance, minority participation, bonding, etc. were defined in the contracts in such a way to be consistent with the laws and statutes of all jurisdictions. This resulted into a set of boilerplate contract requirements that were acceptable to all jurisdictions,
- All technical requirements were defined as necessary to meet all the needs of the local agencies. As an example, the cabinet and poles at the RSTs had to be designed differently to meet the specific needs of each agency,
- Each agency required its own inspection procedure. Therefore, different boilerplates were included to accommodate the needs of each agency, which sets the stage for expansion where eight agencies are involved.

The TRANSMIT system implementation included preparation of plans, specifications and cost estimates (PS&E) and the provision of software and system integration services [7]. The consulting services could not be retained by TRANSCOM since it does not have at present contracting authority, and they were contracted with the Port Authority of New York and New Jersey. This resulted into a unique contracting arrangement where the project operation and supervision were undertaken by TRANSCOM, (administered through PB Farradyne Inc.) while adhering to the legal and technical requirements of NJDOT, FHWA, NYSTA and NJHA.

6.6.2 Legal Issues between the Agencies, the Private Sector and TRANSCOM

The multi-jurisdictional nature of the TRANSMIT project required the development of a new type of contracting mechanism, "systems implementer". This contracting approach is attributed to TRANSCOM's desire to overcome certain obstacles of a traditional contracting procedure and the willingness of the participating agencies to accept it. The principal characteristics of this approach were:

- The consultant, PB Farradyne Inc., assumed turnkey responsibility for the system implementation. The consultant had undertaken the contracting responsibilities of NJHA and NYSTA, mainly, preparing the plans and specifications, received bids, pre-qualified contractors, and awarding contracts,
- The participating agencies, NJDOT, NJHA, NYSTA, and FHWA continued to exercise oversight over the project.

This contracting approach provided flexibility to the project implementation by resolving effectively any incompatibilities among the participating agencies. This process is an enhanced systems manager approach, but without the full implementation responsibility of a turnkey contracting approach. The primary advantage of this approach is the ability to move the project forward by resolving multi-jurisdictional problems in an efficient and timely manner. The consultant and TRANSCOM staff act as a communicator between all the agencies, becomes knowledgeable of the contracting requirements, laws and statutes of each agency, and proposes compromise solutions that are acceptable to all participants. A key to the implementation of this type of a contract is the ability of the consultant and TRANSCOM to resolve technical issues in a unified way rather than compromising the efficiency of the system in order to meet the requirements of each agency. In other words, in many cases, the consultant and TRANSCOM proposed modifications to each agency's specifications and requirements and thus did not compromise the functionality of the system. The consultant who undertakes the responsibility to carry out such a project should have the necessary skills and sufficient experience in multi-jurisdictional projects to carry out these complex tasks.

The new contracting mechanism provided to resolve administrative and technical problems between the agencies more rapidly and to reduce the system implementation time by at least three months [7].

6.6.3 Privacy Issues in Vehicle Identification

The TRANSMIT system has implemented a procedure which encodes the vehicle's tag ID upon receipt at the OIC computer. The encoded ID data is then processed immediately and the encoded tag IDs are not stored. Encoded data are saved only for evaluation purposes and validation of the algorithms of the system. The privacy of the motorists is therefore ensured. It is noted though that this encoding is based on the policy of TRANSCOM. This policy should be preserved in the future as the TRANSMIT system is expanded.

6.7 Conclusions and Recommendations

6.7.1 Summary and Conclusions

The goal of this aspect of the evaluation was to assess the costs associated with the TRANSMIT system, with comparison to other similar systems, ILDS, VIDS and MRDS; the benefits they can provide in terms of traffic management, traveler information and transportation planning; and the institutional issues associated with the involved agencies, the private sector and the general public. A summary and principal conclusions of this evaluation are presented below.

Comparison of Traffic Surveillance System Costs

A summary for the field equipment of the TRANSMIT system costs per RTS and of the ILDS, VIDS, and MRDS systems per site is presented in Table 61:

Table 61. Comparative Costs per Detection Site (Six-Lane Highway)

Description	TRANSMIT	ILDS	VIDS	MRDS
Capital Cost:				
• Hardware	$14,700	$4,100	$24,500	$26,500
• Installation	$21,700	$50,560	$45,100	$25,200
Total Capital Costs	**$36,400**	**$54,660**	**$69,600**	**$51,700**
Maintenance Costs/Year	$2,900	$7,950	$3,300	$2,900
Operations Costs/Year	$2,040	$2,040	$2,040	$2,040
Total Annual Costs	**$4,940**	**$9,990**	**$5,340**	**$4,940**
Total Cost for One Year	**$41,340**	**$64,650**	**$74,940**	**$56,640**

The total cost for one year, including the capital and annual for a TRANSMIT system RST site represents 64%, 55%, and 73% of the corresponding detection site costs for ILDS, VIDS and MRDS systems, respectively (see Table 61).

Equipment capital costs per detection station include the field components. The principal components of the field equipment consist of the detection and communication peripherals. The system installation cost covers the field installation of hardware, cabinet/foundation, cables, etc., and inspection. The maintenance costs for the field equipment include on-site hardware and software support and personnel expenses. Operations costs involve costs due to leased telephone lines and utilities expenses.

TRANSMIT Benefits

The TRANSMIT system provides a number of advantages over conventional traffic surveillance techniques for traffic management, traveler information and transportation planning. Its principal advantage lies in its ability to track vehicles in consecutive roadway segments. This capability provides the basis for the TRANSMIT system to determine estimates of the link space mean speed and path travel time at short time intervals in real time. In addition, it has the potential to provide estimates of the traffic flow rate at each RST location although it is not yet implemented. Additionally, its main function to detect major incidents is a useful feature of any traffic management system.

The comparative benefits summary of the TRANSMIT, ILDS, VIDS, and MRDS systems is presented in Table 62.

Table 62. TRANSMIT, ILDS, VIDS and MRDS Systems Benefits

Benefits	Implemented (I)[A], Future Potential (P)[B]			
	TRANSMIT	ILDS	VIDS	MRDS
Traffic Flow Parameters				
• AVI/L	(I)	N/A	(P)	N/A
• Link Travel Time	(I)	(P)	(P)	(P)
• Path Travel Time	(P)	(P)	(P)	(P)
• Link Space Mean Speed	(I)	(I)	(I)	(I)
• Traffic Flow Rate	(P)	(I)	(I)	(I)
• Space Occupancy	N/A	(I)	(I)	(I)
• Incident Detection	(I)	(I)	(P)	(I)
• Roadway Density	(P)	(P)	(P)	(P)
• O-D data	(P)	N/A	N/A	N/A
Toll Facility Management	(I)	N/A	(P)	N/A
Transit Fleet Management	(P)	N/A	(P)	N/A
Freight Fleet Management	(P)	N/A	(P)	N/A

The principal benefits of the currently implemented TRANSMIT system are:

- An automated incident detection algorithm,
- Direct estimates of link travel time and space mean speed.

The potential benefits of TRANSMIT system that may be implemented without any substantial effort and cost, include the estimation of the following traffic flow characteristics:

- Vehicle position and tracking,
- Vehicle classification,
- Path travel time estimation,
- O-D estimation,
- Traffic volume estimation.

These characteristics could be used for a more efficient traffic management system, for traveler information system and provide the basis for more accurate transportation planning studies, as well as the advancement of the traffic flow theory. Furthermore, they could be used for effective transit and fleet management.

Institutional Issues Associated with TRANSMIT

The TRANSMIT system is an example of a multi-jurisdictional cooperation between different public agencies and the private sector. One of the primary challenges of any multi-jurisdictional type of project is the contracting approach. TRANSMIT, through the innovative

[A] Implemented (I): Available as an output feature in the current system.

[B] Future Potential (P): Could be made available in the future modified system.

ideas of TRANSCOM and the cooperation of the member agencies has developed an alternative contracting approach for handling multi-jurisdictional projects. The new mechanism is a revised systems management contracting approach where the member agencies review the bid packages and the contractor selection. The consultant resolves technical incompatibilities between the systems of the different agencies in a unified way that results in a simpler system.

The new contracting mechanism, provided flexibility to TRANSCOM through PB Farradyne Inc. to resolve administrative and technical problems between the agencies more rapidly and to reduce the system implementation time (from the onset of design to close of the construction contract was 18-months).

The privacy of the identity of the vehicles equipped with the E-ZPass tags was set as a requirement by TRANSCOM and the member agencies prior to the implementation of the project. The vehicle ID is encoded immediately upon reception at the OIC. This policy avoided any potential negative public reactions towards the system and lead to a smooth implementation of the TRANSMIT system.

6.7.2 Recommendations

The link and path travel time estimation is not currently used for traveler information. This information can be provided through the INTERNET to the users where the link speed and/or travel time may be depicted on a map and may be provided to TV stations through Traffic Services as well as to other information providers. Additionally, the raw TRANSMIT data may be made accessible for: academic research in universities, consulting firms in calibrating their models, and traveler information providers who may utilize it in developing link travel time and route planning algorithms for their applications.

It should be noted that with the increase in the number of people who carry cellular phones it is unlikely that any automated algorithm could perform better than the timely information provided by the drivers themselves. The automated incident detection algorithm should still be part of the TRANSMIT system. TRANSMIT's incident detection algorithm generates information that cellular users can not provide, such as the traffic flow characteristics under normal and incident conditions.

The TRANSMIT system's data should be enhanced to provide estimates of the effects of incidents. Once the incident is detected, its severity should be identified through available mechanisms, such as local emergency response units, which should inform TRANSCOM on the expected incident clearance time. Then, an automated approach has to be developed to estimate the recovery of the traffic flow to its normal conditions after the incident is removed.

TRANSMIT has been primarily funded with federal resources. Future funding from the federal government may not be adequate enough to support expansions of the system as well as to sustain its operation. Various innovative alternative-funding mechanisms should be sought for establishing public/private partnerships for future expansion and operation. The private sector may undertake part of the expenditures and in return permitted to have access to the

TRANSMIT data. Travelers, truck and transit private companies as well as traveler information providers may also assume part of the expenditures of capital and operational costs of an expanded TRANSMIT system.

Another recommendation is the designation of the TRANSMIT system as a national test bed laboratory for acquiring traffic flow data for the advancement of the traffic flow theory. The Committee on Traffic Flow Characteristics of the Transportation Research Board in collaboration with FHWA has created a task force for identifying the necessary data required for the advancement of the traffic flow theory. A fully expanded TRANSMIT system may offer perhaps one of the most advantageous ITS systems for collecting the necessary traffic flow characteristics data. Its main advantage lies in its potential of having a large number of vehicle probes for gathering (without any intrusion to the privacy or inconvenience to the driver) the location of a vehicle at a particular time. The TRANSMIT system provides one of the best opportunities for the USDOT in examining the development of a comprehensive traffic management/traveler information system. As a national laboratory, it would become a case study for other areas in the country that can learn from the lessons learned in the NY/NJ/CT metropolitan area. This is particularly important with the forthcoming of the Transportation bill which provides the opportunity to state DOTs to install tolls on the interstate highways, which will provide the opportunity for other areas in the country to implement TRANSMIT type systems.

In addition, the TRANSMIT system should become a case study for multi-jurisdictional type of projects. The contracting mechanism, while it is efficient, also implies that the consultant must have competent personnel who are sensitive to the priorities of each member agency. The personnel must be technically competent and knowledgeable in various aspects of transportation and system engineering including a variety of different communication systems, computer systems, electrical wiring, and transportation systems. The consultant should be knowledgeable in the multi-disciplinary nature of transportation and system engineering including the state-of-the-art in ITS technologies and advise the member agencies in new developments, especially on standards and the national system architecture. The consultant throughout the project duration acquires considerable in-depth knowledge on the characteristics of these technologies, as well as difficulties encountered within the project in dealing with technical or institutional issues. The consultant must make the member agencies aware of any problems in a timely manner and be able to propose solutions. These qualifications and requirements are critical in developing systems having open architecture and upgrade capabilities, in ensuring timely completion of projects, and in establishing the synergism between the agencies to reach the common goals.

Two of the areas of the 1994 Highway Capacity Manual (HCM) that require revision are the weaving areas and ramps and ramp junctions. The O-D data may be used for the development of more accurate weaving section capacity analysis models than those presented in the 1994 HCM. One of the problems associated with the weaving area operation is the tracking of the origin and destination of each vehicle. This is usually accomplished by surveys that are carried out for a limited time period of the year. The TRANSMIT system can provide these data on a continuous basis, throughout the year, subjected to different environmental, traffic and roadway conditions. This research would require the additional installation of reader antennas at the ramp entrances and exits as well as the mainline of the weaving area.

The present configuration of the RSTs produces accurate and reliable results in link travel time, space mean speed, and incident detection. Future studies should address how to maintain this accuracy and reliability with additional savings in costs.

7 REFERENCES

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6. Subramaniam, S., "Literature Review of Incident Detection Algorithms to Initiate Diversion Strategies," Working Paper, University Center for Transportation Research, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 1991.
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APPENDICES

Appendix A. Communication Message Types

```
>LANE<06:56:13>-A Lane 3 Pgm    Txn:10694 Ag: 4 Sn:  100493 TB3RS0103..>COM3
  *>FSM_<06:56:15>RFC not responding, attempt 1
  *>FSM_<06:56:17>RFC not responding, attempt 2
  *>FSM_<06:56:19>RFC not responding, attempt 3
***>FSM_<06:56:19>02/29/96 RFC not responding  SB1201-A0000 >COM1
======================================================================
TFD207C/TCM207R Basic Reader Firmware
Copyright (C) 1994 MARK IV INDUSTRIES LTD.  All Rights Reserved.
022996 065628 TIME)  008 AID)  000 PID)  0025 RID)  S TY)  0 SYNC)  010 TTO)
0 TMP)  2 TFRM)  30 TTP)  05 SFT)  8 MFT)  9 PTO)
0 ST)  19 BR)  N PA)  8 CS)  1 SB)  N FC)  1 CC)
500 PTGONE)   D RFCMODE)
Lane Status: -A010-A020-A030-O040-O050-O060-O070-O080
COM1)-196N81N  COM2)-096N81N  COM3)-096N81N  COM4)-096N81N
COM5)--119N81N  COM6)--119N81N  COM7)--119N81N  COM8)--119N81N
CHKSUM [DAEF]
======================================================================
VIEW New Value = A
VIEW AVI mode active. Hit <Enter> for Configuration Mode
**1PROT<06:56:28>02/29/96 R1 IN
   >LANE<06:56:28>Reader State *Active*   SB1200-A0000 >COM1
   >LANE<06:56:28>Reader State *Active*   SB2200-A0000 >COM2
   >LANE<06:56:28>Reader State *Active*   SB3200-A0000 >COM3
   >LANE<06:56:28>Reader State *Active*   SB4200-O0000 >COM4
   >LANE<06:56:28>Reader State *Active*   SB5200-O0000 >COM5
   >LANE<06:56:28>Reader State *Active*   SB6200-O0000 >COM6
   >LANE<06:56:28>Reader State *Active*   SB7200-O0000 >COM7
   >LANE<06:56:28>Reader State *Active*   SB8200-O0000 >COM8
   >LANE<06:56:28>-A Lane 2 Pgm    Txn:    1 Ag: 4 Sn:  127081 TB2RS0000..>COM2
   >LANE<06:56:28>-A Lane 3 Pgm    Txn:    2 Ag: 4 Sn:  143809 TB3RS0000..>COM3
```

Type 1 Message: RFC Error, Location 25, Thursday, 2/29/96

```
   >LANE<08:04:02>-A Lane 1 Pgm    Txn: 1780 Ag: 4 Sn:   99411 TB1RS0344..>COM1
  *1PROT<08:04:03>Timex
   >LANE<08:04:04>-A Lane 4 Pgm    Txn: 1781 Ag: 4 Sn:  165287 TB4RS0360..>COM4
 **1PROT<08:04:04>02/28/96 PROTOCOL: Duplicate Ack
   >LANE<08:04:04>-A Lane 4 Pgm    Txn: 1782 Ag: 4 Sn:  110655 TB4RS0399..>COM4
   >LANE<08:04:06>-A Lane 4 Pgm    Txn: 1783 Ag: 4 Sn:  141934 TB4RS0499..>COM4
```

Type 2 Message: Timex, Location 11, Wednesday, 2/28/96

Type 3 Message: Duplicate Ack, Location 11, Wednesday, 2/28/96

```
>LANE<17:03:59>-A Lane 1 Pgm    Txn:31270 Ag: 4 Sn:  149726 TA1RS0341..>COM1
```

```
   >LANE<17:04:02>-A Lane 4 Pgm    Txn:31271 Ag: 4 Sn:  100951 TA4RS0326..>@@@@
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
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@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@@@@@@@@@@@@@@@@@@@@@@@@@ Pgm    Txn:31278 Ag: 4 Sn:  108373 TA1RS0549..>COM1
   >LANE<17:04:33>-A Lane 3 Pgm    Txn:31279 Ag: 4 Sn:  100443 TA3RS0444..>COM3
   >LANE<17:04:40>-A Lane 3 Pgm    Txn:31280 Ag: 4 Sn:  133025 TA3RS0345..>COM3
```

Type 5 Message: @@@@@, Location 10, Thursday, 2/29/96

```
   >LANE<17:44:52>-A Lane 3 Pgm    Txn:49335 Ag: 4 Sn:  106406 TB3RS0310..>COM3
  *1PROT<17:44:53>Timex
  *1PROT<17:44:54>Timex
   >LANE<17:44:55>-A Lane 3 Pgm    Txn:49336 Ag: 4 Sn:  102928 TB3RS0314..>COM3
 **1PROT<17:44:55>03/28/96 PROTOCOL: Duplicate Ack
   >LANE<17:44:55>-A Lane 3 Pgm    Txn:49337 Ag: 4 Sn:  148630 TB3RS0317..>COM3
 **1PROT<17:44:55>03/28/96 PROTOCOL:(b) Wrong Sequence Number
 **1PROT<17:44:55>03/28/96 ** SeqNumErr **
 **1PROT<17:44:55>03/28/96 PROTOCOL: READ ERROR
 **1PROT<17:44:55>03/28/96 R1 IN
 **1PROT<17:44:55>03/28/96 PROTOCOL: Duplicate Ack
 **1PROT<17:44:55>03/28/96 PROTOCOL:(b) Wrong Sequence Number
 **1PROT<17:44:55>03/28/96 ** SeqNumErr **
 **1PROT<17:44:55>03/28/96 PROTOCOL: READ ERROR
 **1PROT<17:44:55>03/28/96 R1 IN
   >LANE<17:44:56>-A Lane 3 Pgm    Txn:49340 Ag: 4 Sn:  149864 TB3RS0308..>COM3
   >LANE<17:44:57>-A Lane 3 Pgm    Txn:49338 Ag: 4 Sn:  164762 TB3RS0328..>COM3
```

Type 6 Message: Wrong Sequence Number, Location 28, Thursday, 3/28/96

Type 7 Message: READ ERROR, Location 28, Thursday, 3/28/96

```
   >LANE<06:38:32>-A Lane 2 Pgm    Txn: 9291 Ag: 4 Sn:  116184 TB2RS2828..>COM2
   >LANE<06:38:32>-A Lane 3 Pgm    Txn: 9292
   >LANE<06:38:35>-A Lane 3 Pgm    Txn: 9293 Ag: 4 Sn:  116502 TB3RS0331..>COM3
```

Type 8 Message: Blank, Location 25, Thursday, 2/29/96

```
   >LANE<07:24:25>-A Lane 3 Pgm    Txn:61897 Ag: 4 Sn:  208510 TA3RS0312..>COM3
   >LANE<07:24:36>-A Lane 2 PU     Txn:61898 Ag: 8 Sn:  165083 TA2RU0404..>COM2
   >LANE<07:24:36>-A Lane 2 PU     Txn:61898 Ag: 8 Sn:  165083 TA2RU0202..>COM2
   >LANE<07:24:49>-A Lane 2 Pgm    Txn:61899 Ag: 8 Sn:  163634 TA2RS0202..>COM2
```

Type 9 Message: Duplicate Read, Location 1, Tuesday, 2/27/96

```
   >LANE<16:34:40>-A Lane 2 Pgm    Txn: 3473 Ag: 4 Sn:  124143 TB2RS0319..>COM2
   >LANE<16:34:41>-A LaneRS0349..>COM2
   >LANE<16:34:45>-A Lane 2 Pgm    Txn: 3475 Ag: 4 Sn:  127684 TB2RS0332..>COM2
```

Type 10 Message: Cut and Shift, Location 20, Monday, 3/4/96

```
 >LANE<17:36:41>-A Lane 3 Pgm    Txn:48910 Ag: 4 Sn:  117076 TB3RS0328..>COM3
 >LANE<17:36:41>-A Lane 2 Pgm    Txn:48911 Ag: 4 Sn:  147813 TB2RS0303..>COM2 Pgm
Txn:48912 Ag: 4 Sn:  113745 TB3RS0310..>COM3
 >LANE<17:36:42>-A Lane 3 Pgm    Txn:48913 Ag: 4 Sn:  100271 TB3RS0333..>COM3
 >LANE<17:36:43>-A Lane 1 Pgm    Txn:48914 Ag: 4 Sn:  119309 TB1RS1019..>COM1
```

Type 11 Message: Continuation, Location 28, Thursday, 3/28/96

```
 >LANE<09:24:06>-A Lane 4 Pgm    Txn:62704 Ag: 4 Sn:   97135 TA4RS0322..>COM4
 >LANE<09:24:09>-A Lane 4 PF     Txn:62705 Ag: 4 Sn:  125878 TA4RF0304..>COM4
 >LANE<09:24:10>-A Lane 4 PF     Txn:62705 Ag: 4 Sn:  125878 TA4RF0404..>COM4
 >LANE<09:24:23>-A Lane 4 PF     Txn:62706 Ag: 4 Sn:  101087 TA4RF0404..>COM4
```

Type 12 Message: Multiple Read, Location 1, Tuesday, 2/27/96

```
 >LANE<07:23:39>-A Lane 1 Pgm    Txn:   61 Ag: 4 Sn:  167102 TB1RS0399..>COM1
 >LANE<07:23:40>-A Lane 1 Pgm    Txn:   62 Ag: 4 Sn:  101594 TB1RS0372..>COM1
 >LANE<07:23:41>-A Lane 3 Pgm    Txn:   63 Ag: 4 Sn:  167273 TB3RS0399..>COM3
 >LANE<07:23:43>-A Lane 1 Pgm    Txn:   64 Ag: 4 Sn:  115977 TB1RS0303..>COM1
 >LANE<07:23:43>-A Lane 3 Pgm    Txn:   65 Ag: 4 Sn:  113327 TB3RS0333..>COM3
 >LANE<07:23:43>-A Lane 2 Pgm    Txn:   68 Ag: 4 Sn:  124326 TB2RS0303..>COM2
 >LANE<07:23:44>-A Lane 1 PU     Txn:   67 Ag: 4 Sn:  101594 TB1BU0316..>COM1
 >LANE<07:23:44>-A Lane 2 PU     Txn:   66 Ag: 4 Sn:  123033 TB2BU0336..>COM2
 >LANE<07:23:45>-A Lane 1 Pgm    Txn:   71 Ag: 4 Sn:  101594 TB1RS0101..>COM1
 >LANE<07:23:45>-A Lane 2 PF     Txn:   69 Ag: 4 Sn:  100883 TB2BF0101..>COM2
```

Type 12 Message: Multiple Read, Location 25, Thursday, 2/29/96

```
 >LANE<06:41:00>-A Lane 5 Pgm    Txn: 1751 Ag: 4 Sn:  121579 TB5RS0351..>COM5
*1PROT<06:41:00>Timex
 >LANE<06:41:00>-A Lane 2 PU     Txn: 1752 Ag: 4 Sn:  121579 TB2BU0303..>COM2
 >LANE<06:41:01>-A Lane 1 Pgm    Txn: 1753 Ag: 4 Sn:  127266 TB1RS0312..>COM1
 >LANE<06:41:02>-A Lane 1 Pgm    Txn: 1756 Ag: 4 Sn:  110705 TB1RS0304..>COM1
 >LANE<06:41:02>-A Lane 2 Pgm    Txn: 1755 Ag: 4 Sn:  116687 TB2RS0202..>COM2
**1PROT<06:41:02>03/28/96 PROTOCOL: Exceeds Protocol Length
**1PROT<06:41:02>03/28/96 ** CRC___Err **
*1PROT<06:41:02>Timex
 >LANE<06:41:03>-A Lane 2 Pgm    Txn: 1758 Ag: 4 Sn:   96583 TB2RS0314..>COM2
 >LANE<06:41:04>-A Lane 2 PU     Txn: 1757 Ag: 4 Sn:  166510 TB2BU0322..>COM2
*1PROT<06:41:04>Timex
 >LANE<06:41:04>-A Lane 5 Pgm    Txn: 1759 Ag: 4 Sn:  166510 TB5RS0344..>COM5
```

Type 13 Message: Exceeds Protocol, Location 27, Thursday, 3/28/96

Type 14 Message: CRC__Err, Location 27, Thursday, 3/28/96

```
 >LANE<07:19:49>-A Lane 2 Pgm    Txn:  556 Ag: 4 Sn:  120897 TB2RS0305..>COM2
*1PROT<07:19:49>Timex
 >LANE<07:19:49>-A Lane 1 Pgm    Txn:  557 Ag: 4 Sn:  211331 TB1RS0463..>COM1
**1PROT<07:19:50>03/28/96 PROTOCOL: Invalid Frame Type
**1PROT<07:19:50>03/28/96 ** BadTypErr **
 >LANE<07:19:50>-A Lane 2 PU     Txn:  558 Ag: 4 Sn:  120909 TB2BU0354..>COM2
*1PROT<07:19:51>Timex
```

```
  >LANE<07:19:51>-A Lane 4 Pgm    Txn:  559 Ag: 4 Sn:  105107 TB4RS0202..>COM4
```

Type 15 Message: BadTypErr, Location 27, Thursday, 3/28/96

Type 16 Message: Invalid Frame, Location 27, Thursday, 3/28/96

```
  >LANE<06:54:05>-A Lane 1 Pgm    Txn:10494 Ag: 4 Sn:  118254 TB1RS0303..>COM1
**1PROT<06:54:06>02/29/96 PROTOCOL: Duplicate Ack
  >LANE<06:54:06>-A Lane 3 Pgm    Txn:10493 Ag: 4 Sn:  122712 TB3RS0389..>COM3
**1PROT<06:54:06>02/29/96 PROTOCOL:(b) Wrong Sequence Number
**1PROT<06:54:06>02/29/96 ** SeqNumErr **
**1PROT<06:54:06>02/29/96 PROTOCOL: READ ERROR
**1PROT<06:54:06>02/29/96 R1 IN
**1PROT<06:54:06>02/29/96 PROTOCOL: Duplicate Ack
**1PROT<06:54:06>02/29/96 PROTOCOL:(b) Wrong Sequence Number
**1PROT<06:54:06>02/29/96 ** SeqNumErr **
**1PROT<06:54:06>02/29/96 PROTOCOL: READ ERROR
**1PROT<06:54:06>02/29/96 R1 IN
  >LANE<06:54:08>-A Lane 1 Pgm    Txn:10495 Ag: 4 Sn:  166791 TB1RS0357..>COM1
  >LANE<06:54:08>-A Lane 1 Pgm    Txn:10496 Ag: 4 Sn:  170066 TB1RS0309..>COM1
```

Type 17 Message: SeqNumErr, Location 25, Thursday, 2/29/96

Type 18 Message: R1 IN, Location 25, Thursday, 2/29/96

Appendix B. Toll Plaza Traffic Volumes

Table B1. Hillsdale Toll Plaza Sunday - Total and EZ Pass Hourly Volumes - 11/17/96

Time	# Veh. per hour	# Veh. NB	# Veh. SB	# Veh. w/ EZ Pass NB	# Veh. w/ EZ Pass SB	% Veh. w/ w/ EZ Pass NB	% Veh. w/ EZ Pass SB
00:00 - 01:00	766	430	336	44	14	10.19%	4.18%
01:00 - 02:00	421	277	144	24	9	8.73%	6.58%
02:00 - 03:00	315	180	135	16	9	9.10%	7.02%
03:00 - 04:00	207	101	106	10	14	10.30%	13.47%
04:00 - 05:00	293	91	202	9	13	10.00%	6.36%
05:00 - 06:00	652	316	336	9	9	2.92%	2.57%
06:00 - 07:00	889	502	387	11	15	2.12%	3.78%
07:00 - 08:00	1491	796	695	17	19	2.19%	2.68%
08:00 - 09:00	2252	1187	1065	19	28	1.63%	2.63%
09:00 - 10:00	3172	1663	1509	27	44	1.59%	2.94%
10:00 - 11:00	3870	2020	1850	36	58	1.79%	3.15%
11:00 - 12:00	4565	2301	2264	42	63	1.81%	2.79%
12:00 - 13:00	4458	2281	2177	55	77	2.40%	3.54%
13:00 - 14:00	4582	2214	2368	60	66	2.73%	2.81%
14:00 - 15:00	4420	2065	2355	58	65	2.83%	2.77%
15:00 - 16:00	4595	2104	2491	72	56	3.42%	2.25%
16:00 - 17:00	4500	2077	2423	85	48	4.09%	1.97%
17:00 -18:00	3798	1749	2049	81	45	4.64%	2.21%
18:00 - 19:00	3206	1593	1613	73	38	4.55%	2.38%
19:00 - 20:00	2718	1324	1394	68	31	5.13%	2.21%
20:00 - 21:00	2024	1048	976	65	25	6.19%	2.52%
21:00 - 22:00	1450	731	719	55	20	7.58%	2.80%
22:00 - 23:00	904	459	445	45	19	9.80%	4.21%
23:00 - 24:00	538	273	265	28	12	10.10%	4.66%
DAILY TOTAL	56086	27782	28304	1009	799	3.63%	2.82%

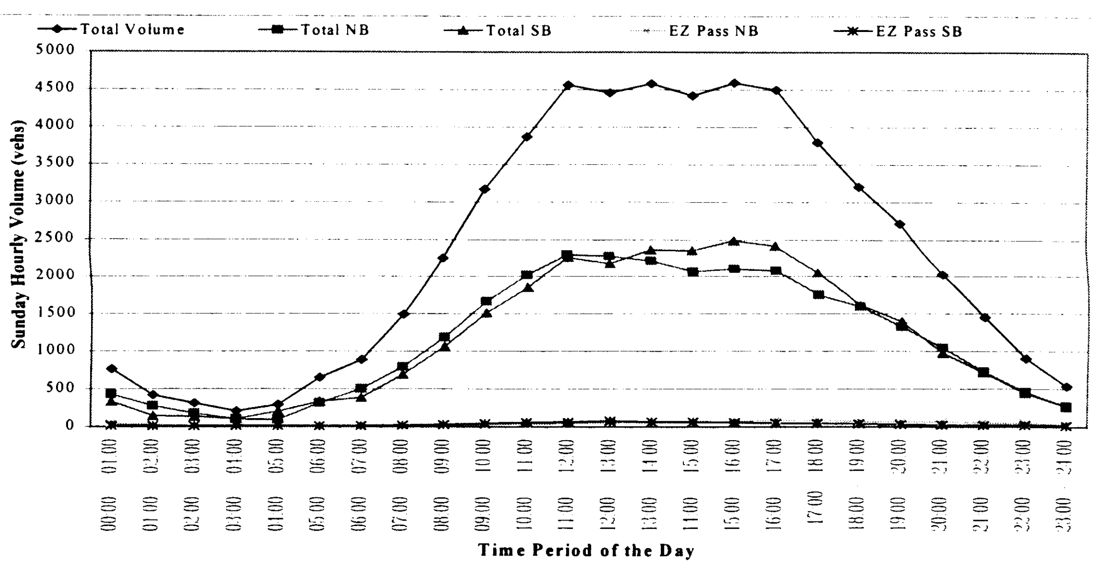

Figure B1. Hillsdale Toll Plaza Sunday - Total and EZ Pass Volume vs. Hour of the Day

Table B2. Hillsdale Toll Plaza Weekday - Total and EZ Pass Hourly Volumes - 11/18-22/96

Time	# Veh. per hour	# Veh. NB	# Veh. SB	# Veh. w/ EZ Pass NB	# Veh. w/ EZ Pass SB	% Veh. w/ w/ EZ Pass NB	% Veh. w/ EZ Pass SB
00:00 - 01:00	223	116	107	15	9	13.36%	8.16%
01:00 - 02:00	179	101	79	12	6	11.48%	8.24%
02:00 - 03:00	130	71	59	10	6	13.69%	10.20%
03:00 - 04:00	208	101	108	7	7	7.37%	6.12%
04:00 - 05:00	703	343	360	9	8	2.65%	2.23%
05:00 - 06:00	2750	1355	1395	37	27	2.71%	1.90%
06:00 - 07:00	5929	2837	3092	197	87	6.95%	2.83%
07:00 - 08:00	7274	3943	3331	232	232	5.89%	6.95%
08:00 - 09:00	4474	2308	2165	214	262	9.25%	12.10%
09:00 - 10:00	3346	1577	1769	111	139	7.04%	7.87%
10:00 - 11:00	3308	1548	1760	59	94	3.79%	5.36%
11:00 - 12:00	3377	1606	1772	62	78	3.89%	4.40%
12:00 - 13:00	3515	1754	1761	76	83	4.34%	4.74%
13:00 - 14:00	3865	1967	1898	99	74	5.03%	3.88%
14:00 - 15:00	4552	2278	2274	111	75	4.87%	3.28%
15:00 - 16:00	5787	2718	3069	143	92	5.25%	3.00%
16:00 - 17:00	7326	3563	3763	214	123	6.02%	3.27%
17:00 -18:00	5849	3105	2744	319	197	10.28%	7.16%
18:00 - 19:00	3790	2009	1781	265	199	13.19%	11.16%
19:00 - 20:00	2540	1420	1121	134	114	9.43%	10.14%
20:00 - 21:00	2044	1233	811	89	53	7.21%	6.48%
21:00 - 22:00	1581	886	695	79	32	8.97%	4.59%
22:00 - 23:00	1083	608	475	53	23	8.78%	4.78%
23:00 - 24:00	636	363	274	28	15	7.64%	5.52%
DAILY TOTAL	74473	37810	36664	2576	2033	6.81%	5.55%

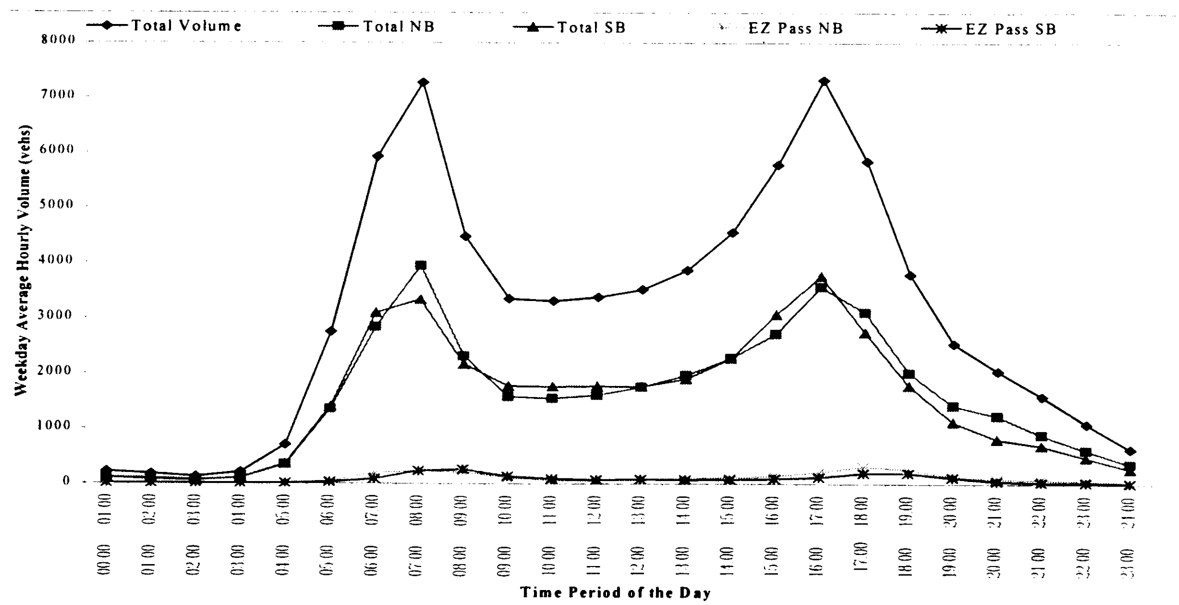

Figure B2. Hillsdale Toll Plaza Weekday - Total and EZ Pass Volume vs. Hour of the Day

Table B3. Hillsdale Toll Plaza Saturday - Total and EZ Pass Hourly Volumes - 11/23/96

Time	# Veh. per hour	# Veh. NB	# Veh. SB	# Veh. w/ EZ Pass NB	# Veh. w/ EZ Pass SB	% Veh. w/ w/ EZ Pass NB	% Veh. w/ EZ Pass SB
00:00 - 01:00	306	198	108	26	12	13.20%	10.78%
01:00 - 02:00	427	243	184	20	9	8.02%	4.96%
02:00 - 03:00	289	174	115	11	11	6.43%	9.50%
03:00 - 04:00	242	138	104	9	17	6.59%	16.50%
04:00 - 05:00	439	181	258	10	11	5.75%	4.09%
05:00 - 06:00	1181	555	626	10	13	1.76%	2.05%
06:00 - 07:00	1631	855	776	19	26	2.19%	3.40%
07:00 - 08:00	2668	1271	1397	31	42	2.44%	2.98%
08:00 - 09:00	3477	1594	1883	33	60	2.04%	3.20%
09:00 - 10:00	4043	1799	2244	35	91	1.97%	4.06%
10:00 - 11:00	4425	2101	2324	45	107	2.16%	4.60%
11:00 - 12:00	4620	2208	2412	64	116	2.89%	4.83%
12:00 - 13:00	4646	2223	2423	87	126	3.90%	5.19%
13:00 - 14:00	4720	2281	2439	95	117	4.17%	4.81%
14:00 - 15:00	5094	2610	2484	108	109	4.15%	4.40%
15:00 - 16:00	4506	2361	2145	124	97	5.26%	4.53%
16:00 - 17:00	4424	2214	2210	146	85	6.60%	3.84%
17:00 -18:00	4470	2536	1934	135	83	5.34%	4.30%
18:00 - 19:00	3188	1627	1561	106	90	6.54%	5.78%
19:00 - 20:00	2276	1262	1014	89	73	7.04%	7.17%
20:00 - 21:00	2073	1216	857	81	44	6.68%	5.08%
21:00 - 22:00	1878	1093	785	92	25	8.42%	3.18%
22:00 - 23:00	1767	894	873	73	23	8.13%	2.63%
23:00 - 24:00	1393	724	669	68	20	9.35%	3.01%
DAILY TOTAL	64183	32358	31825	1518	1407	4.69%	4.42%

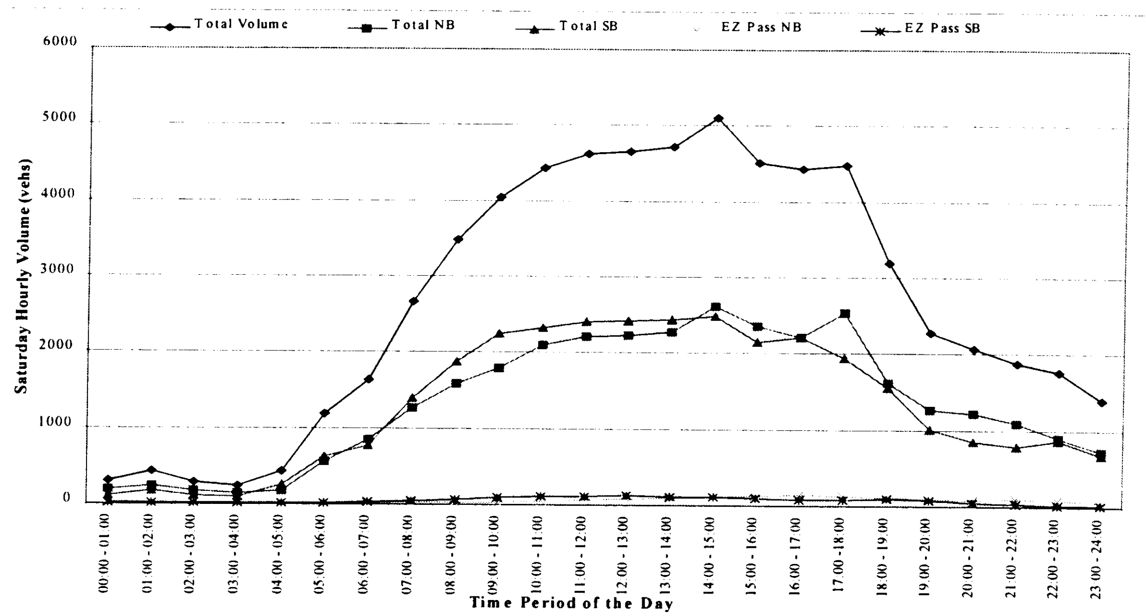

Figure B3. Hillsdale Toll Plaza Saturday - Total and EZ Pass Volume vs. Hour of the Day

Table B4. Tappan Zee Bridge Sunday - Total and EZ Pass Hourly Volumes - 11/17/96

Time	# Veh. SB	# Veh. w/ EZ Pass SB	% Veh. w/ EZ Pass SB
0:00	955	152	15.92%
1:00	560	76	13.57%
2:00	323	42	13.00%
3:00	229	40	17.47%
4:00	237	53	22.36%
5:00	304	119	39.14%
6:00	790	477	60.38%
7:00	915	420	45.90%
8:00	1264	450	35.60%
9:00	1814	560	30.87%
10:00	2488	673	27.05%
11:00	2872	776	27.02%
12:00	3164	725	22.91%
13:00	3369	763	22.65%
14:00	3138	809	25.78%
15:00	3315	765	23.08%
16:00	3481	720	20.68%
17:00	3286	706	21.49%
18:00	2966	640	21.58%
19:00	2590	513	19.81%
20:00	2391	410	17.15%
21:00	1696	356	20.99%
22:00	1477	348	23.56%
23:00	899	177	19.69%
DAILY TOTAL	44523	10770	24.19%

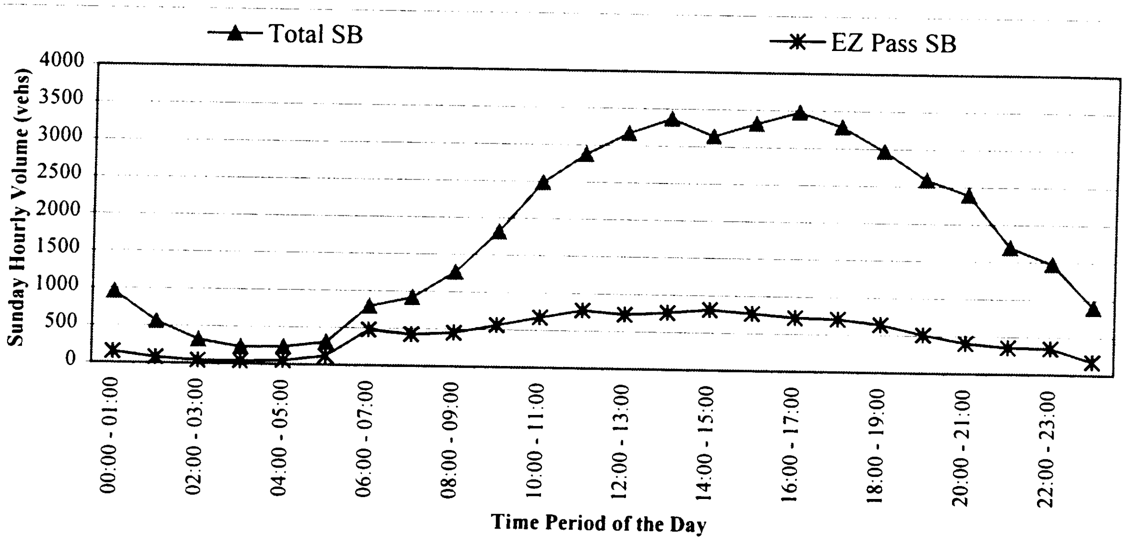

Figure B4. Tappan Zee Bridge - Total and EZ Pass Volumes vs. Hour of the Day

Table B5. Tappan Zee Bridge Weekday - Total and EZ Pass Hourly Volumes - 11/18-22/96

		# Veh. w/	% Veh. w/
Time	# Veh.	EZ Pass	EZ Pass
	SB	SB	SB
00:00 - 01:00	513	92	17.98%
01:00 - 02:00	375	53	14.10%
02:00 - 03:00	332	51	15.37%
03:00 - 04:00	359	87	24.15%
04:00 - 05:00	582	226	38.80%
05:00 - 06:00	1710	1074	62.79%
06:00 - 07:00	5738	4237	73.84%
07:00 - 08:00	7068	5198	73.55%
08:00 - 09:00	6127	4130	67.42%
09:00 - 10:00	4353	2163	49.69%
10:00 - 11:00	3100	1071	34.56%
11:00 - 12:00	2787	782	28.05%
12:00 - 13:00	2660	680	25.55%
13:00 - 14:00	2738	709	25.90%
14:00 - 15:00	3067	921	30.02%
15:00 - 16:00	3315	990	29.85%
16:00 - 17:00	3650	1275	34.92%
17:00 -18:00	4125	1858	45.04%
18:00 - 19:00	3495	1499	42.90%
19:00 - 20:00	2494	868	34.82%
20:00 - 21:00	1738	477	27.45%
21:00 - 22:00	1525	423	27.77%
22:00 - 23:00	1228	409	33.28%
23:00 - 24:00	844	235	27.86%
DAILY TOTAL	63923	29508	46.16%

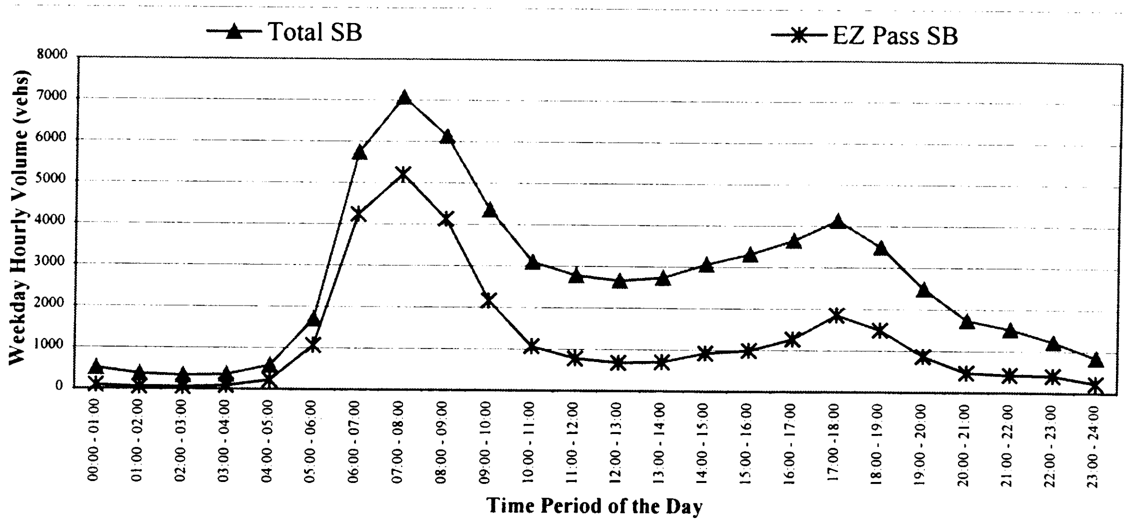

Figure B5. Tappan Zee Bridge - Total and EZ Pass Volume vs. Hour of the Day

Table B6. Tappan Zee Bridge Saturday - Total and EZ Pass Hourly Volumes - 11/23/96

Time	# Veh. SB	# Veh. w/ EZ Pass SB	% Veh. w/ EZ Pass SB
0:00	728	159	21.84%
1:00	435	63	14.48%
2:00	387	67	17.31%
3:00	244	47	19.26%
4:00	370	97	26.22%
5:00	162	78	48.15%
6:00	518	349	67.37%
7:00	947	579	61.14%
8:00	1214	651	53.62%
9:00	4240	1458	34.39%
10:00	2853	777	27.23%
11:00	2983	733	24.57%
12:00	3010	748	24.85%
13:00	2866	706	24.63%
14:00	3192	877	27.47%
15:00	3267	725	22.19%
16:00	3332	726	21.79%
17:00	3592	742	20.66%
18:00	3472	841	24.22%
19:00	2680	542	20.22%
20:00	2002	383	19.13%
21:00	1678	328	19.55%
22:00	1668	421	25.24%
23:00	1383	333	24.08%
DAILY TOTAL	47223	12430	26.32%

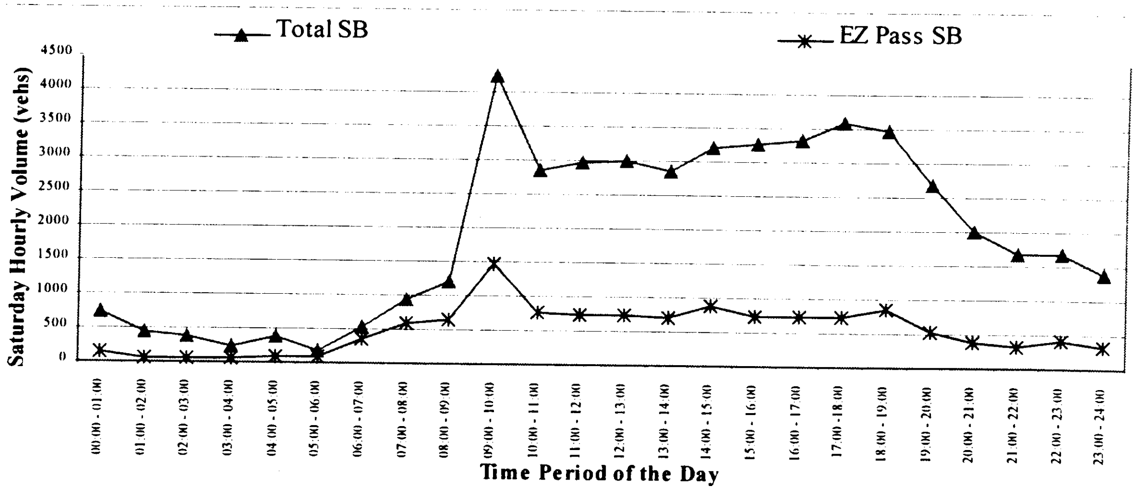

Figure B6. Tappan Zee Bridge - Total and EZ Pass Volume vs. Hour of the Day

Table B7. Spring Valley Toll Plaza Sunday - Total and EZ Pass Hourly Volumes - 11/17/96

Time	# Veh. per hour	# Veh. NB	# Veh. SB	# Veh. w/ EZ Pass NB	# Veh. w/ EZ Pass SB	% Veh. w/ w/ EZ Pass NB	% Veh. w/ EZ Pass SB
00:00-01:00	1238	746	492	121	74	16.22%	15.04%
01:00-02:00	744	428	316	76	47	17.76%	14.87%
02:00-03:00	442	229	213	36	24	15.72%	11.27%
03:00-04:00	368	224	144	17	15	7.59%	10.42%
04:00-05:00	388	230	158	23	14	10.00%	8.86%
05:00-06:00	461	239	222	22	29	9.21%	13.06%
06:00-07:00	847	533	314	54	92	10.13%	29.30%
07:00-08:00	1304	889	415	107	88	12.04%	21.20%
08:00-09:00	1998	1287	711	136	138	10.57%	19.41%
09:00-10:00	2773	1760	1013	198	182	11.25%	17.97%
10:00-11:00	4039	2514	1525	289	282	11.50%	18.49%
11:00-12:00	4887	2981	1906	364	351	12.21%	18.42%
12:00-13:00	5349	1760	3589	370	423	21.02%	11.79%
13:00-14:00	5281	2884	2397	337	386	11.69%	16.10%
14:00-15:00	5295	2550	2745	325	418	12.75%	15.23%
15:00-16:00	5639	2495	3144	316	455	12.67%	14.47%
16:00-17:00	5993	2532	3461	379	472	14.97%	13.64%
17:00-18:00	5582	2210	3372	330	457	14.93%	13.55%
18:00-19:00	4968	1932	3036	290	408	15.01%	13.44%
19:00-20:00	3826	1490	2336	227	318	15.23%	13.61%
20:00-21:00	3211	1314	1897	218	239	16.59%	12.60%
21:00-22:00	2276	977	1299	147	164	15.05%	12.63%
22:00-23:00	1587	687	900	90	118	13.10%	13.11%
23:00-24:00	1049	454	595	67	83	14.76%	13.95%
DAILY TOTAL	69545	33345	36200	4539	5277	13.61%	14.58%

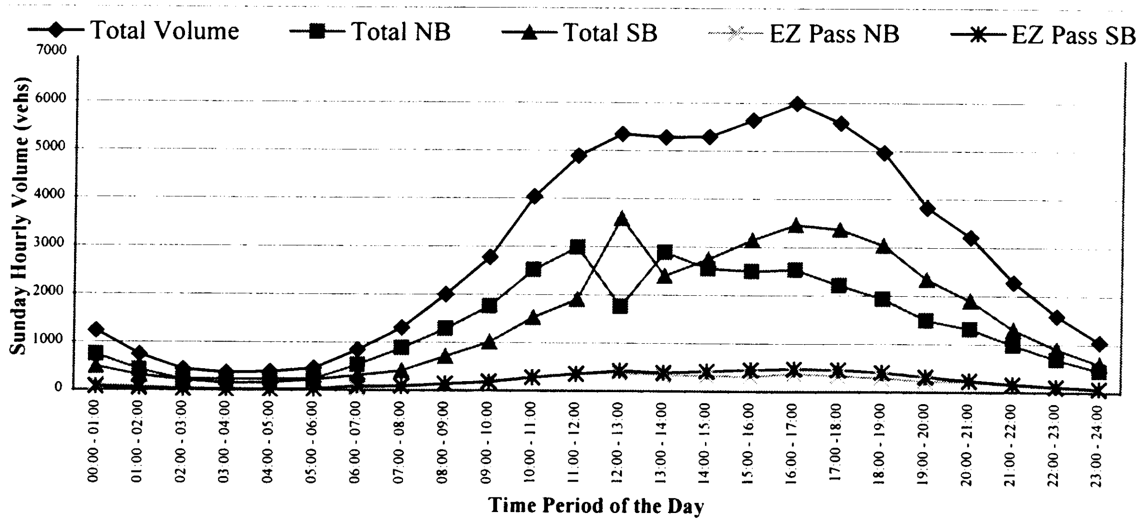

Figure B7. Spring Valley Toll Plaza - Sunday - Total and EZ Pass Volume vs. Hour of the Day

Table B8. Spring Valley Toll Plaza Weekday - Total and EZ Pass Hourly Volumes - 11/18-22/96

Time	# Veh. per hour	# Veh. NB	# Veh. SB	# Veh. w/ EZ Pass NB	# Veh. w/ EZ Pass SB	% Veh. w/ w/ EZ Pass NB	% Veh. w/ EZ Pass SB
00:00-01:00	709	331	378	53	30	16.01%	7.99%
01:00-02:00	538	232	306	28	16	11.91%	5.29%
02:00-03:00	487	187	300	11	17	5.88%	5.67%
03:00-04:00	523	227	296	17	21	7.48%	7.10%
04:00-05:00	641	263	378	28	40	10.81%	10.58%
05:00-06:00	1256	354	902	57	255	16.04%	28.24%
06:00-07:00	3632	896	2736	259	1218	28.94%	44.53%
07:00-08:00	5142	1847	3294	702	1387	37.99%	42.11%
08:00-09:00	5650	2242	3408	790	1319	35.22%	38.70%
09:00-10:00	3977	1702	2275	356	644	20.90%	28.33%
10:00-11:00	3477	1641	1836	244	361	14.90%	19.68%
11:00-12:00	3446	1612	1834	265	327	16.44%	17.84%
12:00-13:00	3518	1637	1881	257	337	15.67%	17.94%
13:00-14:00	3631	1730	1902	321	337	18.54%	17.70%
14:00-15:00	4094	2012	2082	382	367	19.00%	17.61%
15:00-16:00	4835	2634	2201	612	423	23.24%	19.22%
16:00-17:00	5743	3284	2459	1017	571	30.98%	23.23%
17:00-18:00	6453	3699	2753	1327	832	35.87%	30.21%
18:00-19:00	4964	2780	2184	1040	587	37.40%	26.86%
19:00-20:00	3511	1898	1613	566	359	29.81%	22.28%
20:00-21:00	2611	1392	1219	373	220	26.80%	18.05%
21:00-22:00	2142	1155	987	297	185	25.72%	18.76%
22:00-23:00	1554	818	736	194	124	23.73%	16.83%
23:00-24:00	1127	564	562	119	83	21.05%	14.80%
DAILY TOTAL	73660	35139	38521	9314	10061	26.51%	26.12%

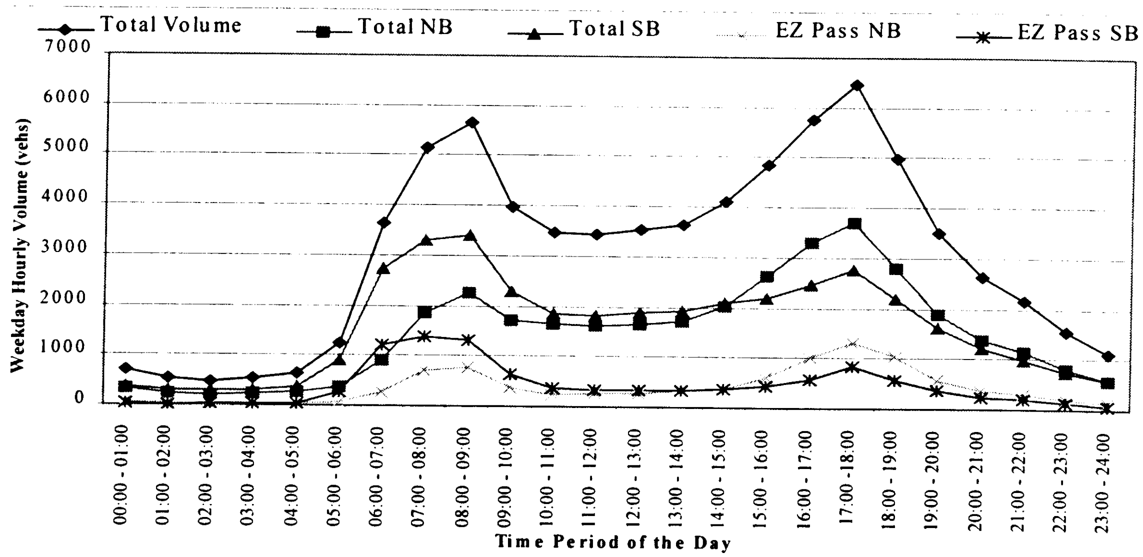

Figure B8. Spring Valley Toll Plaza - Weekday Total and EZ Pass Volume vs. Hour of the Day

Table B9. Spring Valley Toll Plaza - Saturday Total and EZ Pass Hourly Volumes - 11/23/96

Time	# Veh. per hour	# Veh. NB	# Veh. SB	# Veh. w/ EZ Pass NB	# Veh. w/ EZ Pass SB	% Veh. w/ w/ EZ Pass NB	% Veh. w/ EZ Pass SB
00:00-01:00	1137	631	506	130	65	20.60%	12.85%
01:00-02:00	717	409	308	52	39	12.71%	12.66%
02:00-03:00	589	332	257	29	22	8.73%	8.56%
03:00-04:00	577	379	198	33	13	8.71%	6.57%
04:00-05:00	710	485	225	47	13	9.69%	5.78%
05:00-06:00	734	409	325	39	53	9.54%	16.31%
06:00-07:00	1296	676	620	101	178	14.94%	28.71%
07:00-08:00	2113	1179	934	155	242	13.15%	25.91%
08:00-09:00	2810	1542	1268	254	286	16.47%	22.56%
09:00-10:00	3589	2078	1511	287	291	13.81%	19.26%
10:00-11:00	4117	2365	1752	336	314	14.21%	17.92%
11:00-12:00	4429	2113	2316	326	341	15.43%	14.72%
12:00-13:00	4450	2447	2003	338	334	13.81%	16.67%
13:00-14:00	4399	2394	2005	376	357	15.71%	17.81%
14:00-15:00	4511	2320	2191	377	342	16.25%	15.61%
15:00-16:00	4564	2256	2308	409	367	18.13%	15.90%
16:00-17:00	4493	2061	2432	402	383	19.51%	15.75%
17:00-18:00	4503	2041	2462	369	370	18.08%	15.03%
18:00-19:00	3970	1641	2329	307	392	18.71%	16.83%
19:00-20:00	3076	1325	1751	242	293	18.26%	16.73%
20:00-21:00	2421	1037	1384	171	202	16.49%	14.60%
21:00-22:00	1956	941	1015	181	150	19.23%	14.78%
22:00-23:00	1711	822	889	169	148	20.56%	16.65%
23:00-24:00	1516	815	701	179	125	21.96%	17.83%
DAILY TOTAL	64388	32698	31690	5309	5320	16.24%	16.79%

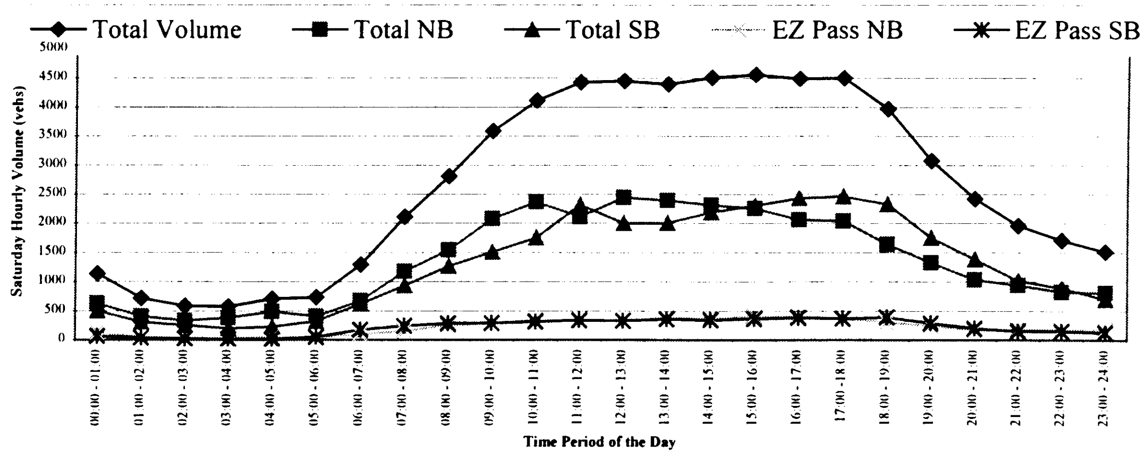

Figure B9. Spring Valley Toll Plaza - Saturday Total and EZ Pass Volume vs. Hour of the Day

Table B10 below presents the matched vehicle probe and the corresponding OIC data per link and time period of the day.

Table B10. Number of Link Travel Times Matched between Vehicle Probe and OIC Data per Link and Time Period of the Day; March 1996

Locations From - To	Link	6:30 - 9:00	9:00 - 11:00	11:00 - 13:00	13:00 -16:30	16:30 -18:30
2 - 1	1	2	2	3	4	5
1 - 2	2	4	N/A	1	3	6
3 - 2	3	8	2	6	N/A	9
2 - 3	4	11	3	11	4	7
4 - 3	5	15	4	15	10	18
3 - 4	6	11	N/A	14	6	11
7 - 4	7	11	4	12	7	14
4 - 7	8	9	1	11	5	11
9 - 7	9	10	3	8	1	13
7 - 9	10	7	2	4	2	5
10 - 9	11	14	3	9	5	17
9 - 10	12	14	3	13	5	12
10 - 13	14	11	3	14	5	14
14 - 10	15	9	2	10	5	13
25 - 27	17	9	6	11	3	13
28 - 27	18	6	1	8	6	15
23 - 25	19	13	3	15	7	17
27 - 24	20	13	5	12	3	17
20 - 23	21	18	N/A	12	3	22
24 - 20	22	11	3	11	8	17
18 - 20	23	13	3	11	2	13
20 - 18	24	1	1	4	2	5
16 - 18	25	3	N/A	7	N/A	6
18 - 16	26	10	4	8	9	19
13 - 16	27	12	3	14	7	14
16 - 14	28	13	4	13	10	19

Appendix C. Incident Detection Data

Table C1 presents the false alarms in the TRANSMIT system per link and month on NYST. The corresponding false alarms observed on GSP are presented in Table C2.

Table C1. False Alarms in TRANSMIT system per Link and Month on NYST

Link	Jan	Feb	Mar	Apr	Total Number of False Alarms
15	3	0	1	0	4
17	0	0	2	2	4
18	0	2	1	1	4
19	1	4	2	0	7
20	0	0	1	0	1
21	0	3	0	4	7
22	0	1	1	0	2
23	1	3	1	1	6
24	0	1	3	3	7
25	0	2	1	3	6
26	0	2	1	0	3
27	0	0	0	2	2
28	0	0	0	2	2
29	0	0	0	1	1
30	1	2	0	0	3
TOTAL	6	20	14	19	59

Table C2. False Alarms in TRANSMIT system; per Link and Month; GSP

Link	Jan	Feb	Mar	Apr	Total Number of False Alarms
3	2	0	1	2	5
6	0	0	2	1	3
8	1	0	0	0	1

Table C3 presents the confirmed incidents observed in the TRANSMIT system per link and month on NYST.

Table C3. True Incidents in TRANSMIT System per Link and Month on NYST; 1996

Link #	Jan	Feb	Mar	Apr	Total
13		1		1	2
14		3			3
15		1	1		2
16		2	1	1	4
17	3	1	17	13	34
18	13	2	17	5	37
19	8	11	12	9	40
20	1	1	14	6	22
21	3	9	11	15	38
22	3	11	9	21	44
23	11	9	9	7	36
24	11	27	32	33	103
25	6	18	24	24	72
26	3	3	1	2	9
27	4	8	8		20
28	1	2	1	1	5
29	1	3			4
30		2	1	2	5
TOTAL	68	114	158	140	480

The following figures present the frequency distribution of the true incidents and false alarms occurred on NYST per time period of the day and per TRANSMIT link. The day is divided into the following time periods:

- the morning peak from 6:30 AM to 9:00 AM,
- the morning off-peak from 9:00 to 11:00 AM,
- the noon peak from 11:00 to 13:00 PM,
- the afternoon off-peak from 13:00 to 16:30 PM,
- the evening peak from 16:30 to 18:30 PM,
- the evening off-peak from 18:30 to 6:30 AM.

The corresponding frequency diagrams in terms of these time intervals due to recorded incidents and false alarms are summarized in Figures C1- C5. Figures C1, C2, and C3 present the weekday frequency distribution of valid incidents, incidents due to roadwork, and false alarms, respectively. Figures C4, C5 and C6 present the frequency distribution of valid incidents, incidents due to roadwork, and false alarms on Saturdays and Sundays.

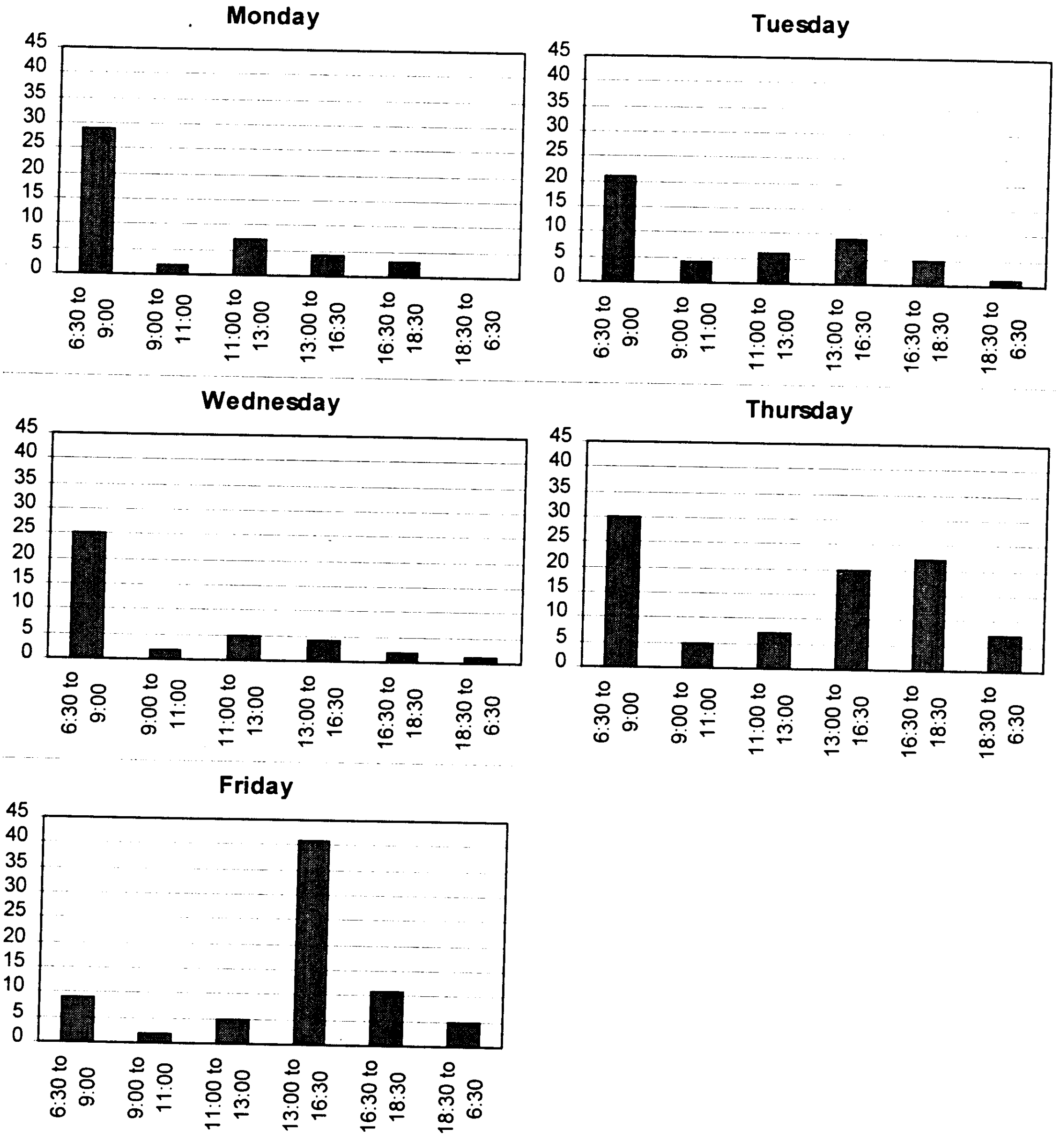

Figure C1. Frequency Distribution of Confirmed Incidents on NYST per Time Period of the Day; Weekdays - January 1 to April 30, 1996

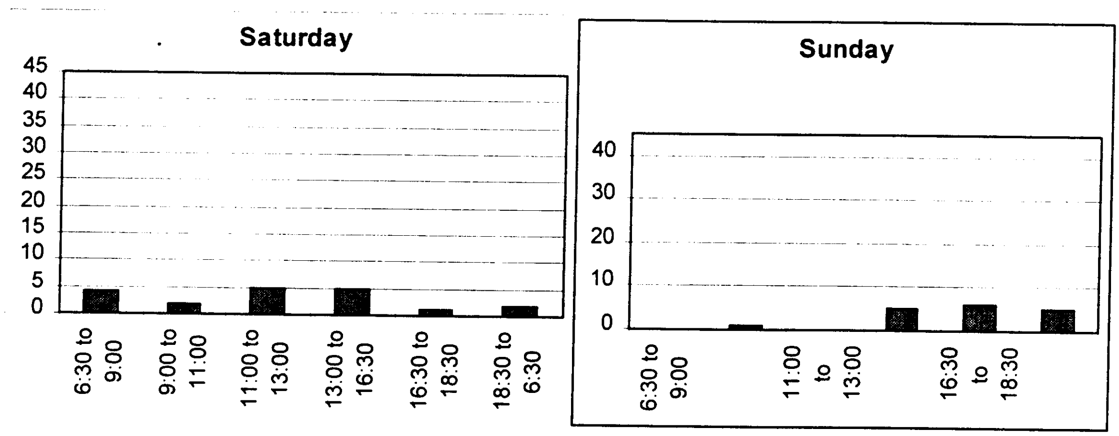

Figure C2. Frequency Distribution of Confirmed Incidents on NYST per Time Period of the Day; Saturday and Sunday - January 1 to April 30,1996

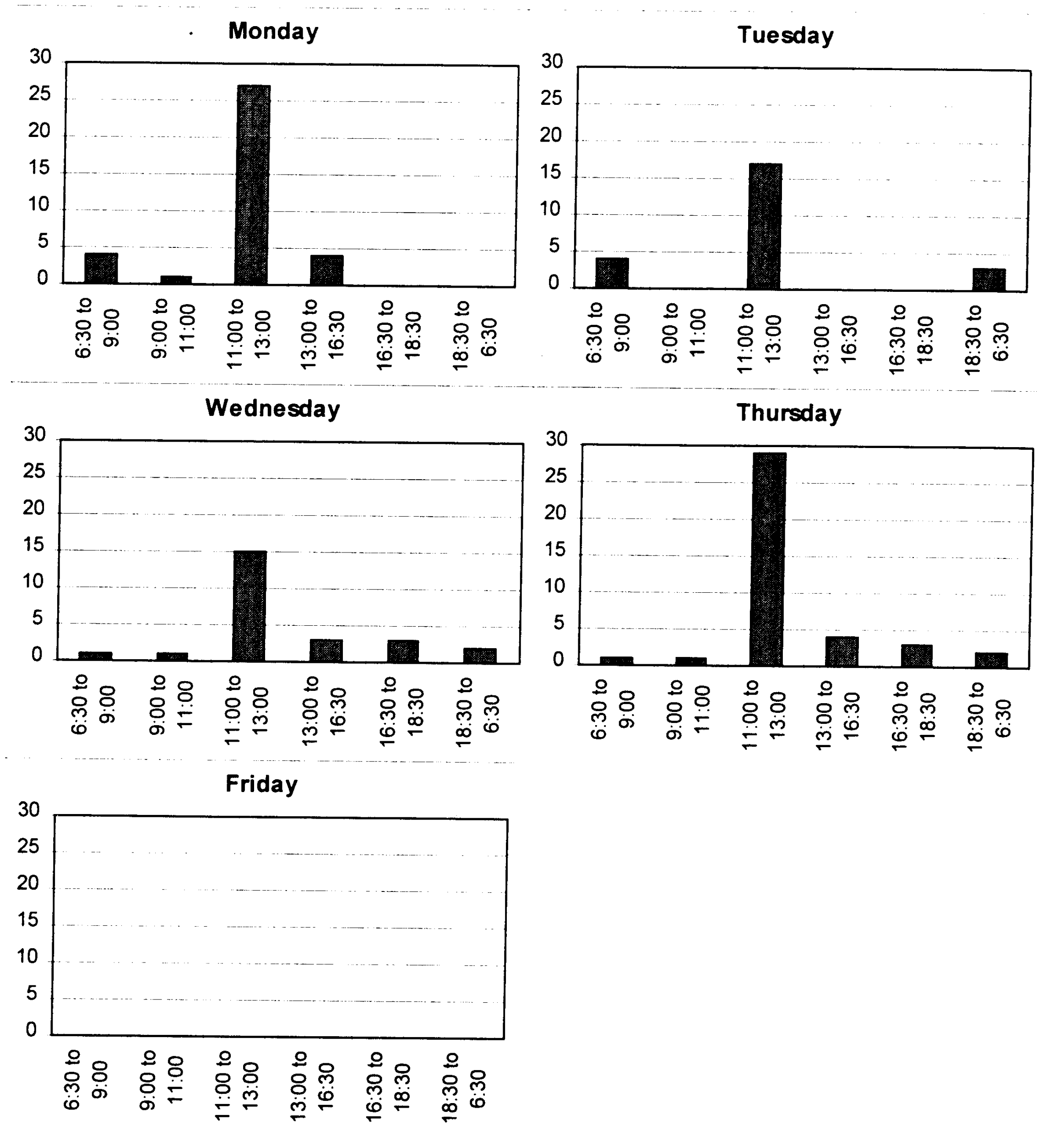

Figure C3. Frequency Distribution of Roadwork Incidents on NYST per Time Period of the Day; Weekdays - January 1 to April 30, 1996

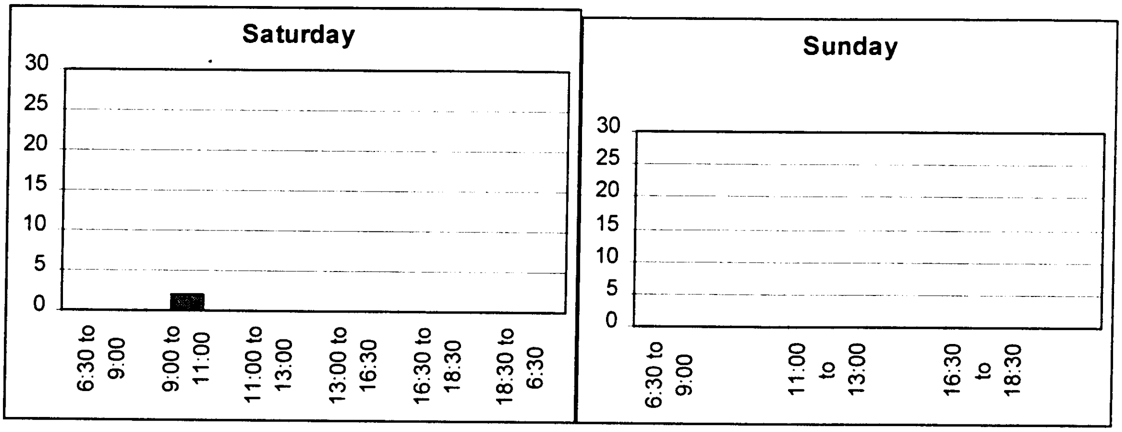

Figure C4. Frequency Distribution of Roadwork Incidents on NYST per Time Period of the Day; Saturday and Sunday - January 1 to April 30, 1996

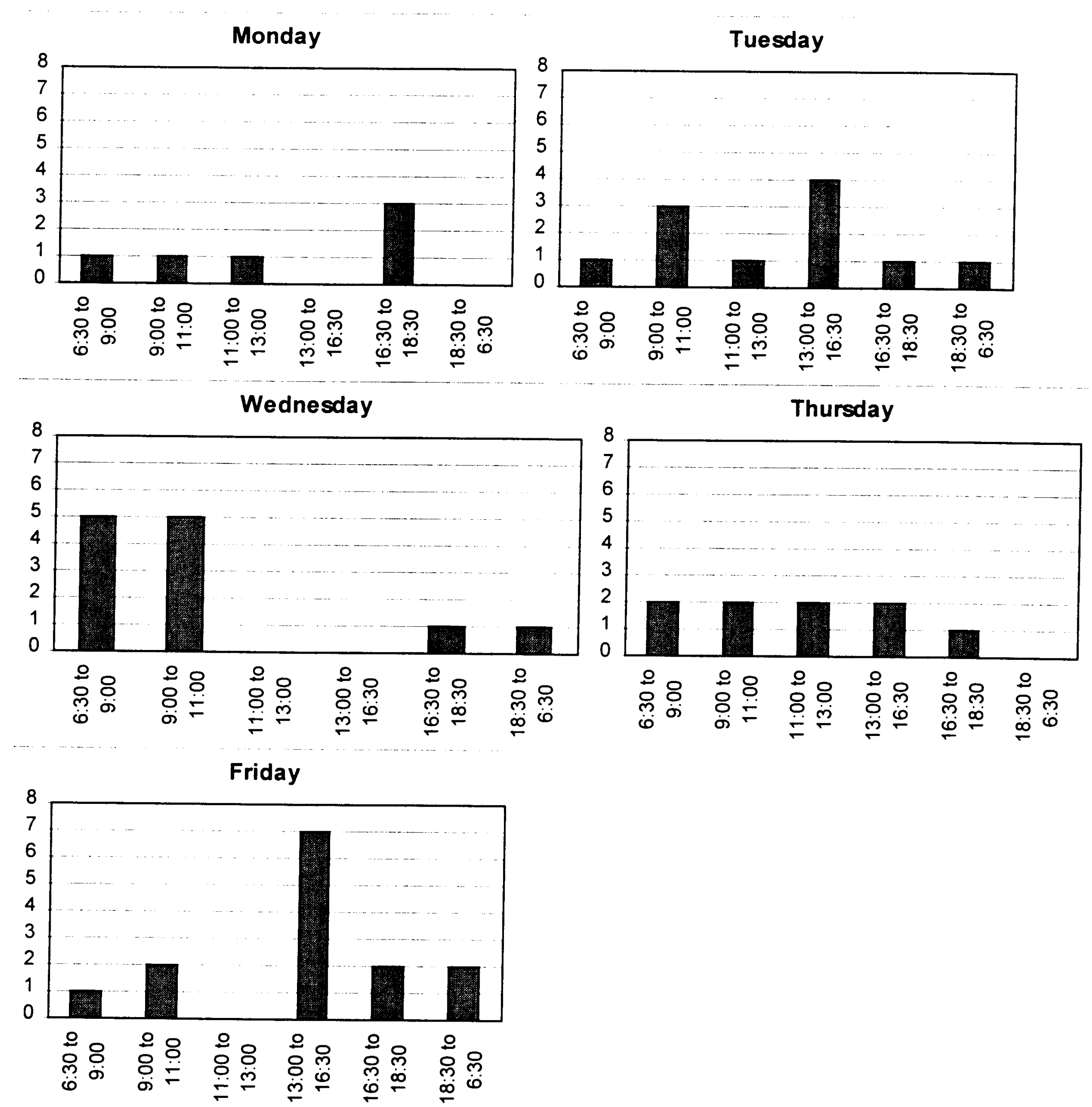

Figure C5. Frequency Distribution of False Alarms on NYST per Time Period of the Day; Weekdays - January 1 to April 30, 1996

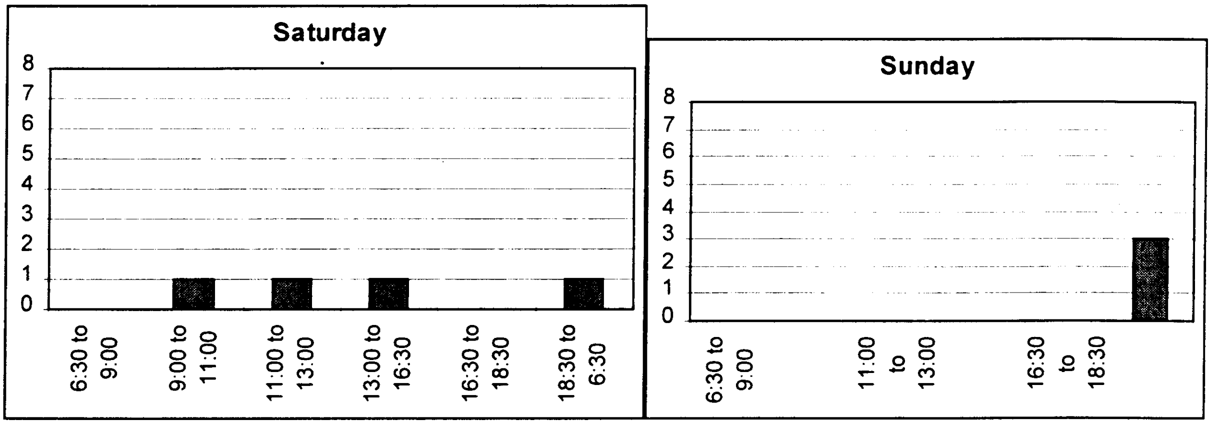

Figure C6. Frequency Distribution of False Alarms on NYST per Period of the Day; Saturday and Sunday - January 1 to April 30, 1996

Appendix D1.
TRANSMIT Survey for the Operators of NYST, NJHA and TRANSCOM

TRANSCOM's System for Managing Incidents and Traffic (TRANSMIT) is currently operational on approximately 19 miles of New York State Thruway and Garden State Parkway. It utilizes electronic toll and traffic management (ETTM) equipment, which is compatible with the EZ-Pass system, for its traffic surveillance and incident detection purposes. A joint team consisting of New Jersey Institute of Technology (NJIT), TRANSCOM, PB Farradyne Inc., FHWA, Booz•Allen & Hamilton Inc., New Jersey Highway Authority, New York State Thruway Authority, New Jersey Department of Transportation, is evaluating the TRANSMIT system. NJIT is participating as the independent evaluator of the TRANSMIT project.

This survey is being conducted as a supplement to the evaluation to determine the participating agencies' assessment of TRANSMIT's capabilities. Please review the attached evaluation reports of the system:

- TRANSMIT - Evaluation of the Communication System,
- TRANSMIT - Evaluation of the Traffic Flow Parameters,
- TRANSMIT - Evaluation of the Incident Detection System.

The respondents are encouraged to contact NJIT or TRANSCOM if they have any ambiguities in the survey. Also the two agencies, NJHA and NYSTA, are encouraged to provide additional inputs that they feel are necessary to have a more complete picture of the performance of TRANSMIT, and suggest enhancements to be implemented into the system.

This survey is to be completed by the system operator of each agency.

TRANSMIT's Current Uses

1. How important is the availability of travel time and vehicle speed data in real time, for a specific link along the TRANSMIT route, for your operation? Indicate how it is being used currently.

   NJHA: *Very Important.*

   NYSTA: *Accidents/Dispatching State Police, Confirm Problems.*

   TRANSCOM: *Very important (travel times more important than speed). Determine delays - compare delays on parallel routes (TZB/GWB).*

2. How important is the incident detection capability of the TRANSMIT system to your operation? Indicate how it is being used currently.

   NJHA: *Same as 1.*

   NYSTA: *Same as 1.*

   TRANSCOM: *Very important; at alarm call authority to dispatch.*

3. How easy was it to learn the operation of the TRANSMIT incident detection system as an operator? Indicate any specific problems that you encountered in the learning phase.

   NJHA: *Pretty Easy - User Friendly.*

   NYSTA: *Moderate - Refer to TRANSCOM.*

   TRANSCOM: *Overall - easy, user friendly. During normal operation easy. When system problems - more difficult, should have mouse/windows driven shutdown/reboot procedures.*

4. How easy it is to handle an alarm from the TRANSMIT incident detection system? Indicate any specific problems that you encountered in responding to such alarms.

   NJHA: *Refer to TRANSCOM.*

   NYSTA: *Easy - again user friendly.*

   TRANSCOM: *Very easy.*

5. Based on your experience and your continuous communication with the New York State Highway Authority and New Jersey Highway Authority, how difficult is it to classify an

alarm as a confirmed incident? Indicate any particular difficulties in identifying alarms as true incidents or as false alarms (specific to TRANSCOM's operators).

NJHA: *N/A.*

NYSTA: *N/A.*

TRANSCOM: *Not difficult, but CCTV (for confirmation) would expedite the confirmation process.*

6. Are there any other uses that are not mentioned above for the data obtained from the TRANSMIT system?

   NJHA: *VMS/HAR tie in.*

   NYSTA: *None.*

   TRANSCOM: *None.*

7. How severe are any hardware/software problems occurred at specific Roadside Terminal (reader) locations to your operation? Indicate any short term and long term effects.

   NJHA: *None.*

   NYSTA: *None.*

   TRANSCOM: *Although they have effect, capability of the system to skip over off-line reader keeps the system operational.*

8. Are you satisfied with the current overall performance of the TRANSMIT system?

   NJHA: *Yes - Remote system needed to be rebooted every two-three days.*

   NYSTA: *Yes - Except RST hardware.*

   TRANSCOM: *Yes.*

TRANSMIT's Potential Uses

1. TRANSMIT has the capability to provide travel time data from an origin to a destination (O-D path travel time data) for a specific vehicle, in real time. How useful would this information be for your operation?

   NJHA: *No - Not for operators.*

   NYSTA: *None.*

   TRANSCOM: *Very useful in determining the utilization of traveler information system (VMS/HAR) upstream of incidents.*

2. How useful would the real time estimate of the number of vehicles present along each link of the TRANSMIT system be to your operation? Indicate how would you use such information.

   NJHA: *Possibly help out in mitigating problem.*

   NYSTA: *None.*

   TRANSCOM: *Not very.*

3. What other features would you like to be incorporated into the TRANSMIT system in the near future?

   NJHA: *Integrate system with IEN.*

   NYSTA: *None.*

   TRANSCOM: *Integrate with CCTV/IEN/HAR/VMS - in vehicle communications.*

APPENDIX D2.
TRANSMIT Survey for NYSTA, NJHA and TRANSCOM Traffic Engineer, Transportation Manager, and/or Transportation Planner.

TRANSCOM's System for Managing Incidents and Traffic (TRANSMIT) is currently operational on approximately 19 miles of New York State Thruway and Garden State Parkway. It utilizes electronic toll and traffic management (ETTM) equipment, which is compatible with the EZ-Pass system, for its traffic surveillance and incident detection purposes. A joint team consisting of New Jersey Institute of Technology (NJIT), TRANSCOM, PB Farradyne Inc., FHWA, Booz•Allen & Hamilton Inc., New Jersey Highway Authority, New York State Thruway Authority, New Jersey Department of Transportation, is evaluating the TRANSMIT system. NJIT is participating as the independent evaluator of the TRANSMIT project.

This survey is being conducted as a supplement to this evaluation to determine the participating agencies' assessment of TRANSMIT's capabilities in terms of traffic management, traveler information, and transportation planning. Please review the attached evaluation reports of the system:

- TRANSMIT - Evaluation of the Communication System,
- TRANSMIT - Evaluation of the Traffic Flow Parameters,
- TRANSMIT - Evaluation of the Incident Detection System.

The respondents are encouraged to contact NJIT or TRANSCOM if they have any ambiguities in the survey. Also the two agencies, NJHA and NYSTA, as well as TRANSCOM, are encouraged to provide additional inputs that they feel is necessary to have a more complete picture of the performance of TRANSMIT, and suggest enhancements to be implemented into the system.

This survey is to be completed by the traffic engineer and/or transportation manager and/or transportation planner of each agency.

TRANSMIT's Current Uses

1. How important is the availability of travel time and vehicle speed data in real time, for each link along the TRANSMIT route, for each of the specific applications to your agency? Indicate how it is currently being applied or expected to be applied.

- Traffic Management applications

  NJHA: *Noted that the current sections of the GSP that are part of TRANSMIT are low incident, low volume sections; beneficial because this is not a heavily patrolled portion of their facility; looking towards expanding this to other corridors. NJHA is committed to a 20-minute response time to incidents and this will assist in this commitment.*

  NJHA: *None.*

  NYSTA: *Using to monitor traffic conditions for peak periods along corridors. Observed speeds and travel times as an indication of delay. Very important.*

  TRANSCOM: *Very important in our goal of obtaining real time information on all the major roadways in the region.*

- Traveler Information applications

  NJHA: *Useful; information is related to customers through VMS and those who inquire about travel conditions; looks toward making real time connection to graphic depiction of travel conditions.*

  NYSTA: *Relay information on HAR (e.g. construction delays on Tappan Zee Bridge) very important service.*

  TRANSCOM: *Relays this information to affected agencies, media services, and assists the NYSTA in the HAR usage. Plan to tie this information directly to VMS and HAR systems through NYWINS program. Also plans to tie this data directly into the vehicle through the use of the MARK IV next generation tag.*

- Transportation Planning applications

  NJHA: *Currently not used but in the future could use this to identify improvements in their roadway configuration (identifying lower speeds on the main line in the vicinity of on and off-ramps).*

  NYSTA: *Manually recording information on holiday periods for historical purposes; very important.*
  TRANSCOM: *None.*

2. How important is the availability of historical travel time and speed data for each link along the TRANSMIT route for each of the specific applications to your agency? Indicate how it is currently being applied or expected to be applied.

- Traffic Management applications

  NJHA: *Knows their road but can use it to compare current and historical data.*

  NYSTA: *Laborious to recall information, it is currently recorded manually, archiving not done to permit access.*

  TRANSCOM: *Makes possible the incident detection capability. Also allows break down by season and holidays, which are very different than normal.*

- Traveler Information applications

  NJHA: *Calculate delays especially for holidays; frequently get calls for troublesome links.*

  NYSTA: *For public relations could relay anticipated delays (e.g. mother's day).*

  TRANSCOM: *None.*

- Transportation Planning applications

Same as traveler information for both agencies.

3. How important is the availability of incident detection for each of the specific applications to your agency? Are you satisfied with the present performance of the TRANSMIT incident detection algorithm. Indicate your agency's desired incident detection rate (e.g. 90%, 95% accuracy etc.). Indicate your agency's desired mean time to detect an incident (e.g. 5 minutes, 4 minutes).

- Traffic Management applications

  NJHA: *Very Important; Primary purpose of TRANSMIT; GSP has over one million vehicles a day on its 172 mile facility; need automated detection; early detection increases safety. Very satisfied with the current performance; 95% is the desired; less than five minutes for incident detection (improved as conditions and technologies warrant); works for rubbernecking.*

  NYSTA: *Very important; 99% desired; during peak periods within one-minute, off-peak within 5 minutes.*

TRANSCOM: *Satisfied; very important to our agencies, will work towards improving the algorithms performance to meet the agencies needs.*

- Traveler Information applications

NJHA: *Makes VMS/HAR more useful. Provides quicker and more reliable information to their customers.*

NYSTA: *Very important. Help us reduce the impact of incidents and secondary accidents.*

TRANSCOM: *Very important, quicker identification of incidents results in quicker regional reactions.*

- Transportation Planning applications

NJHA: *Archiving data.*

NYSTA: *Important.*

TRANSCOM: *Provides historical database on incidents and their effects.*

4. Are you satisfied with the reported false alarms rates? Indicate your agency's tolerable level of false alarms (e.g. 5%, 10%, etc.).

NJHA: *Satisfied, 5% false alarm rate, should improve with increase tag percentage.*

NYSTA: *Yes; 1-5% false alarm rate.*

TRANSCOM: *Yes; will continue to improve the performance of the algorithm.*

5. Are there any other current uses of the information and data obtained from the TRANSMIT system by your agency that are not mentioned above?

NJHA: *E-ZPass market penetration estimates. Future uses for vehicle classification/speed differential by class.*

NYSTA: *Toll plaza staffing.*

TRANSCOM: *Balancing traffic flow on different facilities. (e.g. major George Washington Bridge construction projects; work with facility operators who relay observed conditions. TRANSCOM staff compares observed conditions with the information from TRANSMIT and subsequently adjusts messages on regional VMS and HAR.)*

6. What is the level of hardware/software failures that your agency can accept? (e.g. 5%, 10%, other).

   NJHA: *Out of service less than 1% of the time.*

   NYSTA: *Same.*

   TRANSCOM: *Will work to ensure the system meets the agencies' requirements.*

7. How do you rate the present performance of the TRANSMIT communication system in terms of the detection and transmission rates of tag equipped vehicles? Indicate your tolerable levels for the detection rate and transmission rate, respectively (e.g. 90%, 95%, other).

   NJHA: *Adequate; 95% for both detection and transmission. Hopefully will increase with more tags.*

   NYSTA: *Excellent; would like to see 95% to 99% detection and transmission rates.*

   TRANSCOM: *Adequate; will work to improve the detection rate at certain locations to above 95%, and meet agencies' requirements..*

8. Is the personnel available at the Traffic Operations Center of your agency adequate to perform the daily operations of a TRANSMIT based system? If not indicate the additional required personnel.

   NJHA: *No; for an expanded TRANSMIT application on the GSP will need another operator for peak periods (6-9AM and 4-7PM) and would like to see an external visual indicator for an alarm.*

   NYSTA: *No; needs one full time person.*

   TRANSCOM: *Yes; noted that they added three staff persons to insure two-person round the clock coverage at their OIC (previously during the overnight period only one person staffed the OIC).*

9. The TRANSMIT system generates a wealth of traffic flow data. Is there a mechanism in your agency for database management of the generated data of TRANSMIT, including the archiving and analysis of the historical travel time, incidents, false alarms databases? If not do you foresee the establishment of such database management system in the near future? Describe the existing database management of your agency related to TRANSMIT.

NJHA: *No; only on as needed basis; do not wished to archive delays daily except for major and unusual delays; continually would require staffing and might raise liability issues.*

NYSTA: *Yes as part of the expansion to be more automated; now manual during specific periods as needed.*

TRANSCOM: *Yes; archive historical databases semiannually, will enhance capabilities in expansion.*

10. Have you experienced any significant institutional issues in implementing TRANSMIT? How did you resolve these issues?

    NJHA: *Implementation spanned across jurisdictional line; met and resolved issues.*

    NYSTA: *None.*

    TRANSCOM: *Through our normal cooperating effort and our unique contractual arrangement; progressed project successfully.*

11. Are you satisfied with the current overall performance of the TRANSMIT system? Indicate specific advantages or any concerns to your agency of the TRANSMIT system.

    NJHA: *Yes; advantages: see above (incident detection); additional uses of E-ZPass Concerns: privacy.*

    NYSTA: *Yes; but number of individual links off-line at times unacceptable.*

    TRANSCOM: *Yes; will work with MARK IV and PB Farradyne to improve system.*

TRANSMIT's Potential Uses

1. TRANSMIT has the capability to provide travel time data from an origin to a destination (O-D path travel time data) for a specific vehicle, in real time and historically. The O-D path travel times and the origin and destinations of tag equipped vehicles could be stored into a historical database. How useful would this information be for your applications? Indicate potential uses per application area.

- Traffic Management applications

  NJHA: *Help to effectively and efficiently use roadway (redistribute traffic and improve service (i.e. interface with traffic signal system)).*

  NYSTA: *Very useful being able to provide appropriate levels of service.*

  TRANSCOM: *Allow for more efficient use of roadways during incidents by having the information available to redistribute diverted traffic.*

- Traveler Information applications

  NJHA: *Tie it to HAR, historical O-D travel times (provide current route conditions at specific locations).*

  NYSTA: *Useful.*

  TRANSCOM: *Useful in future to give specific info to travellers.*

- Transportation Planning applications

  NJHA: *Noted that every few years need comprehensive O-D analysis for capital improvements (very expensive) provide information on long and short trips (GSP is not a closed toll system), future planning.*

  NYSTA: *Very useful; gives VMT, future demand combined with land use information.*

  TRANSCOM: *Information will be helpful for the MPO/research institutions inquiries for data.*

2. How useful would the real time estimate of the number of vehicles (traffic volumes) present along each link of the TRANSMIT system for your applications? Indicate how would you use such information if made available, relevant to the following areas:

- Traffic Management applications

NJHA: *Assist in manning toll plazas; help anticipate near term problems (i.e. incident management, how it will impact the roadway).*

NYSTA: *Very useful, allowed to relate volume to speeds to queues on particular links and anticipate delays.*

TRANSCOM: *Allow speed volume comparisons.*

- Traveler Information applications

N/A

- Transportation Planning applications

NJHA: *Volume shows trends (growth and AADT) between links and O-D patterns.*

NYSTA: *None.*

TRANSCOM: *MPO and academic institutions could use in modeling verification.*

3. What other features would you like to be incorporated into the TRANSMIT system in the near future?

NJHA: *O-D, vehicle operating characteristics by vehicle class (e.g. grade problems impacting larger vehicles); ability to preset links for parameter characteristics; identify high incident links; database searches for volume, speeds, per vehicle class; integrate into regional systems (i.e IEN), more user friendly data search.*

NYSTA: *Archiving data, tracking NYSTA/EMS/police/transit vehicles, vehicle classification.*

TRANSCOM: *O-D, travel time for sections for traveler information, in-vehicle communications.*

4. Is your agency planning in investing on expanding and operating TRANSMIT?

NJHA: *Yes.*

NYSTA: *Yes.*

TRANSCOM: *Many agencies have already committed funding for the expansion of the TRASNMIT system.*

5. Is your agency planning in investing in other traffic surveillance technologies? Please elaborate on any plans that your agency is already considering.

NJHA: *Yes; video surveillance, 911 (*77), note that EDP study recommends expansion of TOC, TRANSMIT, and ATIS.*

NYSTA: *Yes; CCTV; notes expansion of VMS, HAR, and involvement in the NY WINS program (in-vehicle communications).*

TRANSCOM: *Federal funding available for member agencies to install CCTV.*

6. Other public agencies/private sector/general public potential uses of the TRANSMIT system. Indicate any other agencies/private sector/general public who could use the Automatic Vehicle Identification/Location capabilities of the TRANSMIT system. Identify potential uses (e.g. fleet management, towing services, commercial vehicles, transit operations).

   NJHA: *Any transportation agency (in addition to highway) such as airports, ports, CVO, large fleets (UPS), state police would find it useful, NJHA vehicles.*

   NYSTA: *Truckers, transit, general public (in-vehicle communications); state police and towing companies.*

   TRANSCOM: *Fleet administrators (transit and CVO) for fleet management, all transportation agencies including airports for management of their facilities and providing traveler information.*

7. Do you anticipate any potential institutional issues in expanding the TRANSMIT system to your facility? How do you anticipate resolving these issues?

NJHA: *Cost (capital and O&Ms) privacy.*

NYSTA: *No.*

TRANSCOM: *Costs (O&M) need to be looked at as to where appropriate funding can be obtained.*

8. Are there any other concerns or uses of the TRANSMIT system that you would like to elaborate on?

NJHA: *No.*

NYSTA: *No.*

TRANSCOM: *No.*