

USER'S MANUAL OF TRANSIT DATA GATHERING AND EVENTS RECORDING PROGRAM WITH SAMPLE APPLICATION

by

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ABSTRACT

This report presents a detailed description of the user's manual and application of a transportation data gathering program using events recorder and global positioning systems (GPS). The Transportation Event and Data Recording software, "*TEDR*", is a powerful field data gathering tool developed in the Civil Engineering and Land Surveying Department of the University of Puerto Rico at Mayagüez (UPRM). "*TEDR*" was used for data collection for transit studies and subsequent analysis of a fixed bus route service.

An analytical representation of fixed bus route services presents some of the most important performance parameters that must be calculated when analyzing and designing these kinds of systems.

A comparison between manual data gathering techniques and the GPS and computer-aided tool was performed during the case study of the Metrobus I Express route, which runs from Old San Juan to Sagrado Corazón station of the Tren Urbano. The results show the benefits of working with the program in terms of efficiency and data quality. Sample calculations of the described performance parameters were performed with the data obtained from both methods in order to be compared and evaluated

The results obtained lead to the conclusion that the computer-aided data gathering tool is more powerful, efficient and reliable than traditional manual methods, and further investigation should be promoted in the use of technological applications for transportation studies.

RESUMEN

Este informe presenta una descripción detallada del manual de usuario y aplicación de una herramienta computacional de recolección de datos de transportación utilizando registro de eventos y sistemas de posicionamiento global (GPS). “*TEDR*” es una ponderosa herramienta de recolección de datos de campo desarrollada en el Departamento de Ingeniería Civil y Agrimensura del Recinto Universitario de Mayagüez de la Universidad de Puerto Rico. El programa fue utilizado para la recolección de datos para estudios de sistemas de transporte colectivo y subsiguiente análisis de una ruta de autobuses de servicio fijo.

Una representación analítica de los servicios de autobuses de ruta fija presenta algunos de los parámetros de desempeño más importantes que deben ser calculados al momento de analizar y diseñar este tipo de sistemas.

Durante el estudio de la ruta Metrobús I Expreso, la cual sirve desde el Viejo San Juan hasta la estación Sagrado Corazón del Tren Urbano, se llevó a cabo la comparación entre el método asistido por computadora de recolección de datos y el manual tradicional. Se calcularon algunos de los parámetros de desempeño descritos, a modo de poder evaluar los resultados logrados con los datos obtenidos de ambos.

Los resultados obtenidos permiten concluir que el programa para la recolección de datos es más ponderoso, eficiente y confiable que los métodos manuales, por lo que se debe promover la investigación futura del uso de nuevas aplicaciones tecnológicas en estudios de transportación.

“Dedicated to God, the most high Soulfly.”

-Max Cavallera.

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List of Acronyms

ATI	Integrated Transportation Alternative
DOT	United States Department of Transportation
MBA	Metropolitan Bus Authority
FTA	Federal Transit Administration
GIS	Geographic Information Systems
GPS	Global Positioning Systems
HOV	High Occupancy Vehicles
LOS	Level of Service
OSJ	Old San Juan
PDA	Personal Digital Assistant
PRHTA	Puerto Rico Highway and Transportation Authority
PRPB	Puerto Rico Planning Board
QOS	Quality of Service
ROW	Right-of-Way
SC	Sagrado Corazón
TCQSM	Transit Capacity and Quality of Service Manual, 2 nd Edition
TEDR	Transportation Data and Event Recorder
TRB	Transportation Research Board
TTI	Texas Transportation Institute

List of Acronyms (continued)

TU Tren Urbano

UPRM University of Puerto Rico at Mayagüez

1 INTRODUCTION

This report presents a detailed description of the user's manual and application of a transportation data gathering program using events recorder and global positioning systems (GPS). The Transportation Event and Data Recording software, referred herein as "*TEDR*", is a powerful field data-gathering tool developed in the Civil Engineering and Land Surveying Department of the University of Puerto Rico at Mayagüez (UPRM). "*TEDR*" was used for data collection for transit studies and subsequent analysis of a fixed bus route service.

The current methods used in the study of transportation systems come as a result of ongoing work carried out with a great degree of scientific and intellectual development over the past half century. Through these methods, the measures of the different critical variables can be obtained, thus resulting in an adequate and precise design. The need for these scientific methods and measures explains why these studies require great amounts of information, which, in turn, is mathematically processed to obtain the necessary output and findings.

"*TEDR*" was developed in order to capitalize on this knowledge by providing an efficient and easy-to-use tool that can collect precise information in larger amounts than traditional manual methods.

1.1 Problem Statement

Two of the most common types of transportation studies that require the collection of individual events are related to intersection and transit services. The outcomes of these studies establish the foundations for proper transportation infrastructure and services in urban and rural areas, in order to accommodate population growth and their expanding needs.

Traditionally, data collection for these transportation related studies has been done manually, requiring a significant number of trained personnel, which can escalate the costs of the studies and can ultimately lead to an increased risk of reaching a higher margin of error and lack of precision in the information that is gathered. The amount of information that can be gathered with manual methods is also limited when compared to those obtained using automated techniques.

During the last decade, Global Positioning Systems (GPS) technology has resulted in significant advances in terms of precision at a cost affordable for many engineering applications. During the same period, computer technology has continued its incredible development, with particular emphasis in increasing processing speed and memory capability. The work presented in this project consists of developing a User's Manual and demonstrating the application of "TEDR", a software program developed to combine an Event Data Recorder with GPS tracking technology. The project will also demonstrate the advantages of using GPS and Data Event Recorder Technology over manual methods for transit data collection processes.

1.2 Justification

The current and future challenges faced by transportation systems are immense, because of their primary role and impact on society's social and economic development. Guaranteeing accessibility and mobility in existing and proposed systems is one of the most important priorities of our times, due to the tremendous repercussions these might have on the economy and lifestyle of the society.

The 2007 Texas Transportation Institute (TTI) annual report [Schrank et al., 2007], indicates that:

“The nation’s longest-running study of traffic jams this year shows urban congestion growing in three increasingly visible ways.

- *The time penalty for making ‘rush-hours’ trips is greater.*
- *The period of time travelers might encounter traffic congestion is longer.*
- *The percentage of streets and freeways that are congested is higher.”*

Furthermore, Schrank et al. [2007] reflects upon its findings, indicating positive and negative aspects of the current and future conditions of traffic in the nation:

“The good news is that there are solutions that can make a positive difference in addressing the problem. The bad news is that even if transportation officials do all the right things, the likely effect is that congestion will continue to grow, even if more slowly, because not enough is being done.”

Some of the solutions to the traffic congestion problem presented in the above-referenced report include more roadway and transit, ramp metering, providing more high occupancy

vehicle (HOV) lanes, incentives to make trips at different times, and better incident management.

Applications of transit studies should be a priority for all government agencies that wish to provide users a safe, secure, reliable, comfortable, and efficient public transit system. The only way to design routes that fit the above descriptions is through the use of precise data and statistics, which can only be obtained by practicing these studies.

By being able to obtain more precise data from field studies, the society can benefit from better designed bus routes that provide higher levels of service to its users, thus presenting a viable alternative to the and a step forward in solving traffic congestion problems.

The user's manual for the software presented in this document is an effective and easy-to-use guide for the applications of this tool, which can significantly improve the data collection process for public transportation studies.

1.3 Objectives

The objectives of this project are threefold:

- To provide a detailed review of public transportation studies, including state of the practice for public transportation studies and new technologies;
- To present a detailed description of “*TEDR*”, a computer-aided data gathering and event data recording tool developed in the Department of Civil Engineering and Land Surveying;

- To provide a comparison between the use of the traditional manual data gathering techniques and the use of the above-mentioned software for a fixed bus route service application.

1.4 Activities Performed

In order to accomplish these objectives, the following activities were performed:

- A comprehensive literature review in the field of transportation studies and data gathering techniques, as well as in the use of applicable current technologies;
- An analytical representation of a Fixed Bus Route Service, including the variables and equations which describe its performance and quality of service;
- A step-by-step user's manual of the computer-aided data gathering tool "*TEDR*";
- A case study of an existing route, applying the manual method and the computer program, for validation consistency check purposes in terms of general trends;
- Computation of principal variables required for the analysis and design of fixed bus route service based on the data collected.

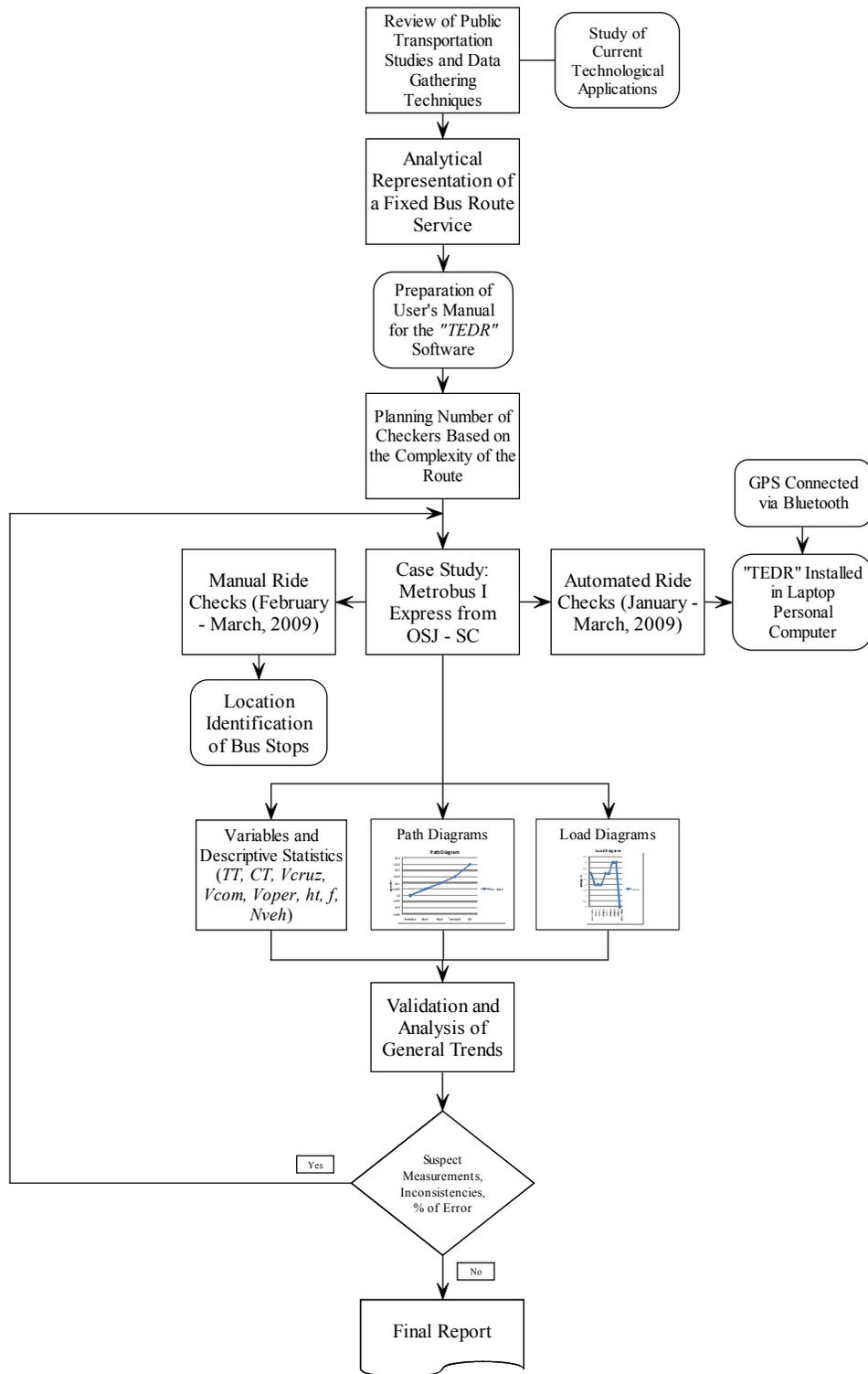


Figure 1.1 Graphical Representation of the Activities Performed

1.5 Scope of Project

The scope of this project is primarily on ride and point checks applicable to public transportation studies.

The step-by-step presentation of the use of the field data gathering software that was applied in the Metrobus I Express route, which runs from Old San Juan (OSJ) to Sagrado Corazón (SC) station of the Tren Urbano (TU), serving the Puerto Rico Convention District.

Manual and computer-aided data gathering techniques were applied in this case study to determine the following bus route design parameters: travel and cycle times; cruising, commercial and operational speeds; number of vehicles needed for the route; and, path and load diagrams. Data were checked for consistency in terms of general trends.

1.6 Expected Benefits

The expected benefits of this project include demonstrating that by being able to obtain more precise data from field studies, more efficient bus routes can be designed in order to provide higher levels of service to its users.

The software presented in this document is an effective and easy-to-use data gathering tool, which can significantly improve the data collection process for public transportation studies.

Public agencies like the Metropolitan Bus Authority (MBA) and the Integrated Transportation Alternative (ATI), and private operators could certainly benefit from a more efficient and precise method for collecting data that will allow them to assess their current

quality of service (QOS) and implement changes based on reliable and up-to-date information.

2 PERFORMANCE, QUALITY OF SERVICE AND ANALYTICAL REPRESENTATION OF FIXED BUS ROUTES

2.1 Introduction

The need for mobility and accessibility of the different transportation systems is a continuous and growing concern of planners and operators of networks around the world. Being able to maintain an efficient and balanced transportation system that is able to comply with the required levels of service is a tremendous challenge in a world which becomes more globalized every day.

The dynamic nature that has been characteristic to transportation systems makes it necessary for models used in estimating flow and demand to be constantly revised and updated. The needs and requirements of the users of these systems are ever-changing and, thus, agencies in charge should keep up-to-date information of the different systems which allows them to satisfy the people's needs.

2.2 Transportation Overview

Throughout the last half of the past century, the development of transportation infrastructure in the United States and Puerto Rico focused on highway construction [Luyanda, 2004]. Even though the primary goal was to have a proper highway system for defense and military

purposes by having connecting routes along the entire territory, this also served as a major opportunity to empower commercial and scenic routes that would allow for extensive economical development throughout the nation.

However, this development of highway infrastructure left mass transit in almost complete abandonment during most of the later part of the 1900's, giving way to private vehicles in almost every home in the United States. Currently, in the Metropolitan Area of San Juan, the rate of persons per private motor vehicle is approximately 2.53 [Luyanda, 2004]. This statistic has also awarded Puerto Rico with having one of the highest ranks in private motor vehicles per kilometers of roadways [Luyanda, 2004].

According to Schrank et al. [2007]: *“Even the best efficiency–boosting ideas can't entirely take the place of new roads. The few cities that have added roads at the same rate that they've added car travel have seen slower congestion growth. ”*

Roadway expansion cannot be considered as the only alternative to solving traffic congestion because of the difficulties it presents in terms of funding and approval.

Having efficient mass transit routes is essential in order to present an alternative that can seduce drivers away from their private vehicles. A route that is designed with correct and complete field information can guarantee future users an appropriate level of comfort while riding a bus and confidence in a system that will serve with punctuality and that will provide accessibility and mobility throughout their city of residence.

Schrank et al. [2007] indicate the following trends about traffic congestion in the United States:

- The annual time penalty has jumped from 16 hours in 1982 to 62 hours per peak period traveler in 2000.
- The period of time when travelers might experience congestion has increased from 4.5 hours in 1982 to 7 hours in 2000.
- The volume of roadways where travel is congested has grown from 34% in 1982 to 58% in 2000.

The numbers presented above are shocking and alarming, especially when considering that a 7-hour congestion period in a major city means almost an entire working day spent in traffic. The economic implications and consequences are obvious. Furthermore, having 58% of the nation's roadways where travel is congested means that people will continuously encounter traffic, regardless of using alternate routes.

Most importantly, if two daily traffic peak periods are considered, 124 hours per peak period traveler are annually lost [Schrank et al., 2007]. Considering the U.S. Department of Labor's "Minimum Wage Laws in the States" [Labor, 2008], Puerto Rico has minimum wage rates that vary from \$4.25 to \$7.25 per hour according to the industry. Based on an average \$6.55 minimum wage, approximately \$812 per peak period traveler is lost in Puerto Rico, yielding a total of \$1.218 Million, considering the sole concept of minimum wage for an approximate total work force of 1.5 million persons [PRPB, 2000].

Even a marginal reduction in the approximate losses previously quantified would mean an important improvement to the local economy. Thus, the value and need for achieving accurate metrics soon, in order to find new systems and solutions to correct and minimize existing problems, is evident.

2.3 Performance of Bus Routes

As with any engineering project, when designing new bus routes or re-designing existing systems, specific parameters must be computed in order to aim for a reliable, safe, comfortable, and efficient system.

By interpreting the statistics computed with the data obtained in the field, combined with preliminary graphical analysis of relevant variables, the Designer can calculate the key operational elements for a bus route, which will serve as the cornerstone of the route's service, as well as a baseline for comparison once the route becomes operational.

2.3.1 *Travel and Cycle Times*

The first design element is Travel Time (TT), which is defined as the total time it takes a bus to go from Terminal A to Terminal B. As shown in Equation 2.1, TT can be calculated by adding the individual times it takes for the bus to cover the total number (n) of bus stops located between terminals.

$$TT = \sum_1^n t_i \tag{2.1}$$

The second design element, and one of the key factors used in the design of bus routes, is Cycle Time (CT). CT is defined as the sum of the travel times plus the recovery time given to drivers to rest between runs (T_R) at each terminal, as shown in Equation 2.1 below. In other words, CT is the time needed for the bus to make a complete circuit of the route.

$$CT = TT_{AB} + TT_{BA} + T_{RB} + T_{RA} \quad 2.2$$

Controlling the Cycle Time of any bus route is critical since it has a direct impact to its operational costs. Good CT management proves to be efficient use of the operator's resources, both human and machinery.

2.3.2 Cruising, Commercial and Operational Speeds

In public transportation studies, the following three (3) speeds are evaluated for any particular route, namely: cruising, commercial and operational.

The cruising speed of a bus (V_{Cruz}) is the speed that can be measured as the bus moves along the route. The cruising speed can be observed in the speedometer of the vehicle in order to then establish an average. This factor is influenced by vehicle specifications, traffic congestion, traffic signal systems along the route, and traffic conditions, in general. Furthermore, the cruising speed of a bus will be heavily influenced by the driver's driving habits; some are more heavy-footed than others.

The bus's Commercial Speed (V_{Com}) is the speed that can be calculated by using the distance of the route and the CT . This is the speed that is most important to the route's operator, due to the fact that it is the one that is the most determining in the cost of operation since it is

based on the CT . The distances from Terminal A to Terminal B (S_{AB}), and B to A (S_{BA}) have to be added to calculate the length of the route, as shown in Equation 2.3.

$$V_{Com} = (S_{AB} + S_{BA}) / CT \quad 2.3$$

Equation 2.3 above can be used directly to obtain the Commercial Speed in miles-per-hour (mph) if the time data is in hours. However, if the time data gathered in the field is in minutes, a conversion factor of 60 would be needed, as shown in Equation 2.4.

$$V_{Com} = (S_{AB} + S_{BA}) * 60 / CT \quad 2.4$$

Another key design parameter is the Operational Speed (V_{Oper}). This is the speed that is most important to the users of the system, since it's the perceived speed at which they are moving along the route. The Operational Speed is obtained from the distance of the route and the sum of the two (2) travel times, thus not including the time for drivers to rest and only the times during which the bus is moving. The operational speed is always greater than the commercial speed of a bus route because of the time differences.

The V_{Oper} of a bus is usually calculated for each direction of the route separately, since there are different factors that can affect it, like exclusive high occupancy vehicle (HOV) lanes. As with the V_{Com} , a conversion factor of 60 would be required in Equation 2.5 if the time data was gathered in minutes and not hours.

$$V_{Oper} = (S_{AB} + S_{BA}) / (T_{AB} + T_{BA}) \quad 2.5$$

The speed is calculated in mph and, as stated above, it is usually obtained by working with the directional distances and times.

All systems comply with the following relationship:

$$V_{Cruz} > V_{Oper} > V_{Com}.$$

2.3.3 Intervals and Frequency

An interval (h_t) is defined as the time elapsed between the passings of two (2) consecutive vehicles. This is a very important variable for any fixed bus route system, since it will determine how much time a user will have to wait at a bus stop; the shorter the interval, the shorter the waiting time.

The interval can then be used to determine the rate at which the buses will be passing every hour by the different bus stops along the route (veh / hr). This rate is defined as the route's frequency, which can be calculated with the following equation:

$$f = 60 / h_t \tag{2.6}$$

Once again, a conversion factor of 60 has been included in the equation in lieu of time data gathered in minutes. If time data were to be collected in hours, the frequency would only be calculated using the reciprocal of h_t .

2.3.4 Load Factor

The Load Factor (LF) is an important indicator of the route's operation, in terms of quality of service and the efficient use of resources. LF can be calculated using the Peak Load (PL) of a bus route and the number of seats available in the vehicle (N_s) being used as shown below:

$$LF = PL / N_s \tag{2.7}$$

2.3.5 Number of Vehicles

Being able to precisely calculate the number of vehicles (N_{veh}) of the fleet needed for a fixed bus route is crucial, since it is one of the greatest capital investments that the operator will have to make.

If $h_t < CT$, more than one vehicle is needed for the fixed bus route; whereas if $h_t \geq CT$, only one (1) vehicle would be needed to cover it.

Furthermore, the number of vehicles needed for a fixed bus route is directly proportional to CT and inversely proportional to h_t , which leads to the following equations:

$$N_{veh} = CT / h_t \quad 2.8$$

$$N_{veh} = (f * CT) / 60 \quad 2.9$$

$$N_{veh} = 60 * (S_{AB} + S_{BA}) / V_{Com} * h_t \quad 2.10$$

$$N_{veh} = (S_{AB} + S_{BA}) * f / V_{Com} \quad 2.11$$

2.3.6 Path Diagrams

Path diagrams are one of the most commonly applied tools when evaluating fixed bus routes. This diagram allows operators to verify that the bus is on schedule and arriving at the different bus stops at the specified times. If there are any specific delays associated to any particular stops along the route, they can be identified and promptly investigated.

Staying on schedule is a key factor in the success of a bus route, since it will make the user determine whether the service is reliable or not. Once intervals between buses or specific

times of arrivals at stops are presented to the user of the system, he / she will plan his / her trip according to these. Therefore, not being able to comply with these schedules will make the user seek more suitable alternatives.

A path diagram provides a time – space representation of the route, which allows designers and operators to locate a bus in any particular stop along its route and be able to determine if the time when the bus reached the selected stop complied with the established schedule.

Figure 2.1 is a sample path diagram, in which the time – space relationship of a bus traveling from Terminal A to Terminal B is being represented. The x – axis shows the stops along the bus’s route, while the y – axis shows the time when the bus reached these.

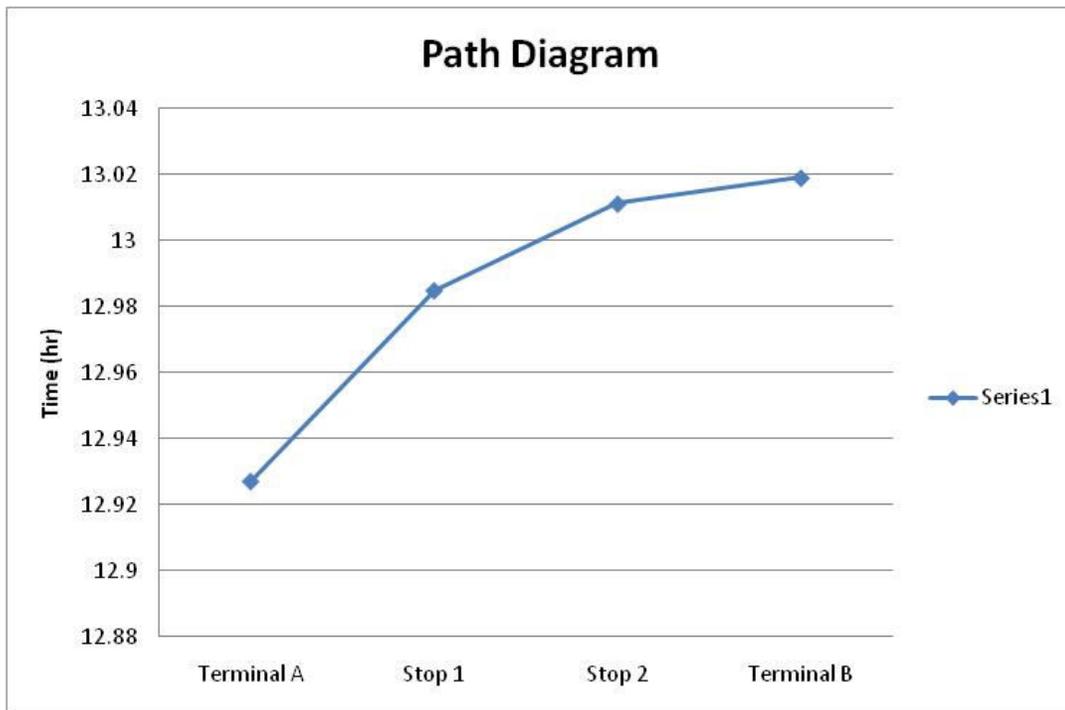


Figure 2.1 Sample Path Diagram

2.3.7 Load Diagrams

Another important method of analyzing a bus route is the Load Diagram, which allows designers to visualize the volume of passengers the bus route is currently serving. This diagram is fundamental when assessing current and future levels of service on a bus route, as well as determining if a route is efficiently serving the public or if stops can be added or eliminated.

A Passenger Load Diagram graphically represents the relationship between the different bus stops along the route and the number of passengers onboard at the time of departure from each. The graph represents the total passenger load on the bus (*PaxLoad*) at any given time during the route, which is a result of the accumulated sum of boarding passengers (*BoardingPax*) minus the accumulated sum of alighting passengers (*AlightingPax*).

$$PaxLoad = \sum BoardingPax - \sum AlightingPax \quad 2.12$$

During the data validation phase of a project, load diagrams can be used to assess trends for passenger loads in each direction. Although passenger totals vary from trip to trip, once a graphical trend is observed, any major difference that is identified can be interpreted as a deviation from the standard and, thus, a need for revision of the particular data file.

Figure 2.2 shows a sample load diagram. Since all passengers are required to alight the bus when it reaches a terminal station, the graph reaches zero (0) as shown.

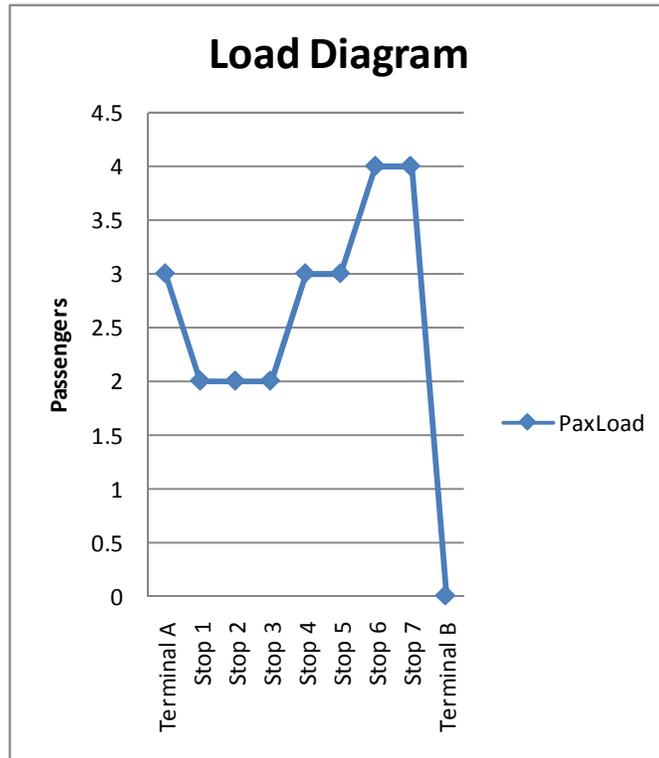


Figure 2.2 Sample Load Diagram

2.4 Quality of Service

The Quality of Service (QOS) of any transit system is an essential factor to be considered by operators and designers. The very existence of a bus route depends upon its riders and the corresponding fare they pay, which is why having an adequate QOS is so important. A good Quality of Service promotes ridership which translates into more revenues for the operator; the opposite translates into preferring other modes of transportation, which in the United States and Puerto Rico typically is the private motor vehicle.

According to the Transit Capacity and Quality of Service Manual (TCQSM), the:

Quality of Service must reflect the transit user's perspective and must measure how a transit route, service, facility, or system is operating under various demand, supply, and control conditions [TRB, 2003].

The TCQSM focuses on measures that reflect the quality of the service provided to transit passengers. These measures reflect the decisions potential passengers make, consciously or not, when deciding whether to use transit or another mode, usually the private motor vehicle.

Quality of Service levels for a fixed bus route have been established based on several key factors that will be present in a user's decision whether to use the service or not. The five (5) categories defined by the TCQSM are the following:

- Availability: how easily passengers can access and use transit service;
- Service Monitoring: measures of passengers' day-to-day experiences using transit;
- Travel Time: how long it takes to make a trip;
- Safety and Security: real and perceived chances of being involved in an accident (safety) or being the victim of a crime (security) while using transit; and
- Maintenance and Construction: impacts of maintenance program quality and construction activity on passenger trips.

Availability is the most important category, since it can actually determine whether or not a transit service is an option to users. Based on the coverage area of the service, the route may or may not be accessible to some potential users. Also, the route's availability to a user can be determined on how accessible it is to the trip's origin or destination.

Service monitoring and travel time are also very important in the determination of the route's QOS, since these are the predominant factors considered for the comfort and convenience of the service. The user will evaluate transit comfort based on the amount of time he / she spends standing up while riding the bus, the time spent waiting for a bus to arrive and its compliance with the service schedule, time of trips and cost of use compared with alternate modes, among others.

As with highways, the TCQSM assigns letter grades that range from A to F to the different levels of service (LOS) of a bus route. The manual is very specific about advising its readers not to be compelled to look for an A grade ("excellent") for every service category. Although an F grade ("failure") is always unacceptable, designers and operators have to evaluate the different QOS parameters in order to have the best possible perception among users, while attending to the efficient use of resources and maintaining costs under control.

The Quality of Service Framework for fixed bus route systems is presented in Figure 2.3 [TRB, 2003] and shows the relationship between the two (2) fundamental QOS categories, availability, and comfort and convenience, with the key variables that will affect them.

At a transit stop, the user will evaluate the QOS based on availability depending on the frequency at which the bus is passing, while the comfort and convenience perception will depend on the passenger load of the bus at the specific stop.

Similarly, the LOS for the segment of the route will be based on the hours of service it provides (hours on which the service is available to users) and how reliable the service is, in terms of compliance with schedule.

Finally, the availability of a fixed bus route system is greatly determined by its coverage. As stated before, if the bus does not serve the areas of destination of the user, it will not be an option to consider. Meanwhile, in terms of comfort and convenience, the user will establish a comparison between the time needed to travel in the system and the time needed to reach his / her destination using a private automobile.

	<u>Service Measures</u>		
	<u>Transit Stop</u>	<u>Route Segment</u>	<u>System</u>
Availability	Frequency	Hours of Service	Service Coverage
Comfort & Convenience	Passenger Load	Reliability	Transit-Auto Travel Time

Figure 2.3 TCQSM Exhibit 1-1

The performance parameters presented in the previous section are essential in determining the QOS level of an existing route, as well as for the design of a new route based on adequate levels of QOS for its end users.

3 TRANSPORTATION STUDIES

3.1 Description of Transit Data Collection Methods

As previously stated, transportation studies are the foundation for the improvement of public infrastructure designed earlier and are built to satisfy the citizenship's needs and requirements of an efficient, safe, and comfortable transportation network.

Since the transportation network of any major city or urban area is composed of several modes, transportation engineers have developed different analytical procedures that they incorporate in their transportation studies that allow designers to gather the appropriate data and make the necessary calculations, in order to be able to provide the system with the required levels of service, safety standards, and cost efficiency.

Data collection techniques for transportation systems are based on two (2) dimensions:

- How data collection resources are deployed; and
- Types of counts and readings that are done.

Within these dimensions, the following are the four (4) different resources and personnel deployment options used on the field when mass transit system studies are performed:

- Ride check studies: a checker rides the route onboard collecting data, such as load, travel times, boarding and de-boarding passengers, and other. For these studies, at least one checker onboard is necessary for every hour of service of the vehicle.

- Point check studies: the checker gathers data from a fixed spot. This allows the checker to collect data from all the vehicles that drive by that point during the observation period, like routes and buses' identification numbers, number of passengers boarding and alighting at stop, and passenger loads. According to González [2006], point check studies can be classified in the following four (4) categories:
 - Peak Point Check: when conducted at the bus stop where the peak load of a bus route is observed.
 - Undesignated Point Check: when the location of the checkers is selected arbitrarily.
 - Multiple Point Check: when more than one location is selected and checkers are stationed on each to measure the different bus routes serving those locations.
 - Endpoint Check: when it is performed at the end of the route, that is, when the bus reaches its respective terminal.
- Driver check studies: the driver of the vehicle is equivalent to the role of the checker and collects the data for the study. The quality and reliability of the data resulting from these studies is questionable, since the driver has to be more focused on driving the vehicle rather than gathering the required data. However, this is the most economical data collection method of all.

- Automated checks studies: results from the implementation of automated data collection systems in mass transit vehicles.

In Table 3.1, a summary of data collection methods for the transit studies mentioned above and their main characteristics is presented.

TABLE 3.1 Summary of Transit Studies

Major Data Collection Deployment Options		
Data Collection Option	Description	Resources Required
1. Ride Check	Checker rides on board bus.	1 checker – hr / vehicle – hr
2. Point Check	Checker stands at roadside; may or may not board bus momentarily.	1 checker – hr / direction / point – hr
a. Peak Point Check	Checker stationed at peak load point.	
b. Undesignated Point Check	Point at which checker is stationed is flexible within a certain range.	
c. Multiple Point Check	Checkers stationed at selected timepoints.	
d. Endpoint Check	Checkers stationed at endpoints.	
3. Driver Check	Driver records data.	Very little cost; data reliability may be suspect, however.
4. Automated Checks	Buses equipped with automated passenger counters.	1 vehicle – hr / vehicle – hr

3.2 Technological Applications in Transportation

3.2.1 Global Positioning Systems (GPS)

According to Quiroga and Bullock [1999]: *“Travel time data collection techniques can be grouped into roadside techniques and vehicle techniques. Roadside techniques use detecting devices physically located along the study routes whereas vehicle techniques use detecting devices carried inside vehicles. Vehicle techniques, particularly those based on probe vehicles, are perhaps the most commonly used techniques. Global Positioning System (GPS) technology is increasingly being used for this purpose. GPS provides consistency, automation, finer levels of resolution, and better accuracy in measuring travel time and speed than traditional techniques. Furthermore, GPS provides the capability to easily integrate the resulting travel time data with GIS-based databases.”*

The interface between a computer and a GPS device is achieved by the development of computer algorithms. The result is a very powerful working tool for the operator, with which it can simultaneously gather passenger load data and graphically trace the route that the bus is taking. GPS tracking gathers North – East coordinates, as well as elevations of all the points it collects on the field.

In addition, the use of programming languages that are not bound to a specific manufacturer or operating system can be used to create executable applications that can be integrated to a great variety of computer programs that are available on the market, allowing a significant number of potential users to benefit from these applications.

3.2.2 Data Gathering

Data gathering is one of the most crucial stages in the development of any transportation-related study. The quality of these data will greatly determine the reliability and precision of the calculations made for the prediction of demand and use.

Field work has traditionally been performed manually, which has a greater percentage of error than those obtained by automated processes. An automated system allows the user to obtain more precise and consistent data, thus diminishing the quantity of data validation work that needs to be done afterwards.

Automated systems can simultaneously add more than one data item at the click of a button, like location and time, automatically synchronizing the information into the computer database.

3.2.3 Development of an Computer-Aided Data Gathering Tool

The initial version of the software, named “*Contador 7.1*”, was programmed by Kelvin Santiago based on the general conceptual designed of doctor Sergio L. González (Santiago and González [2006]) using Visual Basic .NET. Although this programming language has been developed by the Microsoft Corporation (as part of its Visual Studio suite), the applications that can be developed with it are suitable to be used as stand-alone executable programs.

The updated version, “*TEDR*”, allows users to systematically gather field data, integrating the functionality and precision of GPS technology. This way, the operator who is gathering field data does not need to worry about counting, and taking time and location simultaneously, since the program does it automatically when data is entered into the program.

The software is oriented to be used in the following studies: traffic counts at intersections, and ride check and point check transit studies.

Intersection traffic counts are necessary to determine the need to install traffic signals or other controls at intersections, in order to make the intersection’s operation safer and more efficient. Calculations for signal phases and timings have a direct dependence on field data, which is why the quality of this information is of the utmost importance. Incorrect or imprecise field data can cause miscalculation in signal times, which can lead to sub-standard system performances and levels of service, excessive time delays, and queues.

On the other hand, ride check and point check studies are used for designing bus routes. These studies allow the Designer to determine passenger loads on existing routes, which helps in determining if these are the most efficient routes possible, in terms of spatial use, coverage, and levels of service to users.

The software allows the user to register data of passengers boarding and alighting a bus, current and cumulative passenger load on a bus, time on each stop, time between stops, times of boarding and alighting of passengers, as well as other data relevant to the design process. Because the program is connected to a GPS device, the program gathers points of the route,

in order to be able to create a graphical interface using Geographic Information Systems (GIS).

Once the data in the system has been validated by an analyst, it can be used to calculate operational and commercial speeds of a bus, as well as cycle times, recovery times for drivers, times on each stop, and the frequency that the route requires in order to be able to comply with a pre-determined level of service.

Current technology, like portable computers, Personal Digital Assistants (PDA's), and satellite communications, facilitates the development of easy-to-use and accessible tools which provide better performance and precision for data collection processes. The percent of error can also be dramatically reduced when using computerized systems when data gathering. Additional data, which is very difficult to obtain with manual methods, can also be obtained.

Portable computers and Global Positioning Systems (GPS) can now be easily combined to work together during field data gathering, whether it is at a specific location (like an intersection or bus stop), or while riding a bus or train.

Developing technological tools that facilitate and improve transportation studies should be an ongoing and dynamic process. The User's Manual presented in this report provides guided instructions for the use of a powerful application developed by the Transportation Department of the Civil Engineering and Land Surveying School of the University of Puerto Rico at Mayagüez (UPRM).

The “*TEDR*” software was developed to be used in three different transportation studies: ride and point check studies, and intersection traffic counts. However, the primary focus of the program is on the first two of these. Thus, the manual will guide the User through the detailed steps which need to be understood in order to be able to properly use the program while performing one of these two types of transit studies.

3.3 Ride Check Studies

Papacostas [2008] describes ride check studies in the following way: *“in the case of ride check surveys, also known as on-off counts, surveyors ride selected bus-trips and count the passengers that board and de-board the bus at each bus-stop. Running time checks and bus arrival/departure times at selected bus-stops visited and at other schedule timepoints are sometimes taken in conjunction with ride check surveys.”*

As one can infer from the above reference, ride check studies are used to gather the maximum amount of possible data from a single bus route. Because field personnel rides on the bus during the route, boarding and alighting passengers can be counted, time spent at bus stops can also be determined, and total route timings can be obtained. This information can then be used to calculate the entire statistical references relevant to the Designer for the design or re-design of a new or existing bus route, respectively.

Nonetheless, ride check studies are very difficult and expensive to perform. Since there is so much information to be gathered at every bus stop, which includes head counts, exact timings, among others, it is necessary to have at least two checkers on board every bus that is

Manual counts have been the standard since the earliest stages of ride check studies. Checkers onboard are expected to count boarding and alighting passengers, clock times at every bus stop, and write down all of this information on paper. Many times, when two or more checkers are working onboard the same bus, one writes, while the other(s) provide the information. Whichever the case, it leads to a significant amount of error in the data that is collected, which then has to be carefully validated for its use.

The typical process for gathering data at each bus stop while performing a ride check study can be summarized in a seven-step process:

- Clock time of arrival at the bus stop
- Clock time when the doors of the bus open
- Count all boarding and alighting passengers
- Read odometer
- Clock time when doors close
- Clock time when bus starts accelerating
- Verify that current passenger load matches the number recorded up to the last bus stop

Technological breakthrough and the accelerated development of communication tools now allow users to integrate Global Positioning Systems (GPS) into these studies. By using laptop computers during their time onboard a bus, checkers can gather geographical data of

the transit routes, while simultaneously collecting all of the data that has been discussed previously in this section.

The integration of GPS into ride check studies significantly contributes to reducing the margin of error on the data that is collected in the field and, at the same time, a smaller margin of error, thus promoting faster availability of the data for its processing and corresponding analysis.

GPS tracking devices can easily be connected to laptop computers or PDA devices nowadays. Bluetooth Technology allows for rapid connectivity among devices, providing users with immediate setup and start-up times. This ease of integration facilitates its use onboard a bus, thus allowing checkers to have a complete ride check station in a single seat of the bus.

Having a GPS device track the route of the bus eliminates the need to read the odometer and clock the times when the bus stops, departs, and opens and closes its doors. Being integrated with the computer or PDA, the GPS automatically gathers all this information and records it with the point it is marking on its track record.

Therefore, a checker equipped with this kind of technology will experience a reduced amount of input required, which translates into a lesser amount of error. Using an appropriate algorithm and computer software, the checker will only need to count the boarding and alighting passengers, and inform the program when a new event occurs. Typical events include bus stops, doors open, doors close, and bus departures.

GPS tracking not only reduces the amount of error in the data gathered on the field, but it also provides the Designer a tremendous degree of precision in the data it collects. GPS devices can be set up to collect one point every five (5) seconds or more, which transpires in an explicitly detailed route of the bus, including horizontal and vertical alignments, North – East coordinates on a predetermined datum base, and the exact time when each event happened. This information is obtained in combination with the computer or PDA.

Since the information available to the Designer is more precise, so will the calculations and parameters set forth for the redesigned or new route. Although future events cannot be absolutely predetermined, establishing precise parameters and statistical calculations helps in presenting the best possible scenario.

3.4 Point Check Studies

Point check studies are the second type of mass transit study that will be discussed in this report and whose application using the newly developed software will be analyzed as well.

The two major reasons why a public transportation agency would prefer doing a point check study over a ride check study are budget limitations and the need for immediate data on more than one bus route.

Just as ride check studies focus on obtaining the most amount of information from a single bus along a specific route, point check studies have as their primary objective to gather information of all the bus routes that go by a specific point.

Therefore, instead of selecting a bus route, checkers select a spot where they can obtain information of buses serving different areas, thus covering different routes. Usually, the preferred choice for checkers to establish their operations is a bus stop that serves more than one bus route, or is the peak load point for a specific route. The bus stop is selected by analyzing any previous data collection study, so a bus stop serving the most people is selected since it will probably have the most number of buses stopping to receive and leave passengers.

Point check studies are very straightforward; they measure the passenger load on every bus that passes through a specific geographic point that is selected for the study. A typical point check field sheet is shown in Figure 3.2 [Robertson et al., 2000].

According to Papacostas [2008]: *“Point check surveys are taken at a few points along each route, often at the maximum load point, or at selected major checkpoints where multiple routes can be observed.”*

After selecting a bus stop to conduct the data collection, the following information is gathered for every bus that passes by:

- Time when the bus stops
- Time when the bus opens its doors
- Number of passengers on the bus upon its arrival
- Number of passengers boarding and de-boarding the bus
- Time when the bus closes its doors

Since the bus will stop at the check point only if passengers need to board or alight, it will sometimes go past the stop where the checkers are located without stopping. On these occasions, the checkers will only establish the time when the bus passed the checkpoint, the bus's number and assigned route, and an estimate of the passenger load at that time.

The reader must note that, when performing point check studies, checkers are advised to establish passenger load parameters according to the type of bus that is being surveyed. More often than not, bus stop times are not sufficient enough for checkers to count the exact number of passengers onboard a bus. Furthermore, tinted glasses or publicity sometimes makes it difficult to see through to the inside of the vehicle, thus complicating passenger counts.

When faced with these obstacles, checkers will establish passenger load approximations based on bus capacities. For instance, a bus with a 39-seating capacity and approximately same capacity for standing passengers should be separated into several categories, such as: almost empty, with approximately 10 passengers onboard; fully seated, with 39 passengers onboard; almost full, with 39 seated passengers plus 20 standing passengers onboard; and full capacity.

Although passenger loads will not be completely accurate, an estimated reference will be enough for the Designer to determine future capacity needs when redesigning the route or presenting a new route to be implemented.

Point check studies can be performed by a single checker, but it is preferable to have at least two persons working together. As in the case of ride check studies, the checker counting and

obtaining all the other information can transmit it to the other person in charge of doing the corresponding input.

Even though the amount of information for each bus is not as much as in a ride check study, the checker is often faced with the problem of having two or more buses arrive at the same time. Having two or more checkers posted at the same control station is very positive for the study when these situations happen.

The data gathering and corresponding data entry process for this type of study also have an inherent amount of error associated with them. Performing these processes with the aid of computers proves to be very useful while performing field work, as well as while validating the data for its future use.

4 APPLICATION OF THE “TEDR” SOFTWARE

This chapter focuses on guiding the User through each of the steps needed to operate the “*TEDR*” software. The chapter has been sub-divided into nine (9) topics, in order to facilitate reading, and for the reader’s convenience in finding specific information required during the use of the program.

“*TEDR*” was developed to collect data and facilitate its validation and confirmation. Since all data are collected directly into the software, all errors associated with data entry are eliminated. The only two (2) processes done automatically by the program are time and coordinates recording, since this information is obtained directly from the computer and the GPS, respectively.

4.1 Installing the Software

The reader has already been informed that the “*TEDR*” software has been developed as a Windows application and, therefore, shares many of its basic operations with commonly used Windows-based programs.

To install the program, open the folder where it was saved and double click on the Setup icon or click Start \Rightarrow Run \Rightarrow Setup. The program will be installed in the user’s computer and ready to be used immediately afterwards.

4.2 Opening the Software

Once the program has been installed, the User can open the program by opening the folder where the file is located and double clicking the corresponding icon.

This will open the application just like any other Windows-based program installed in the User's computer. The program's main window is easily and neatly arranged for ease of use and reading of the current data being used.

Figure 4.1 shows the program's main screen.

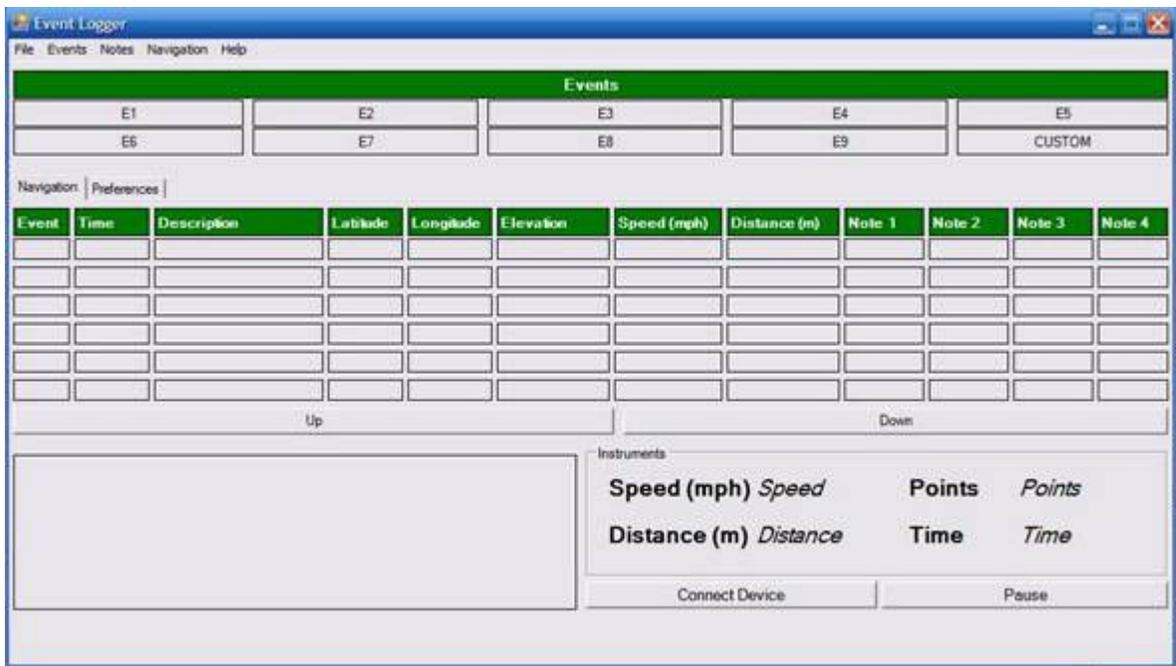


Figure 4.1 Main screen of the software

The program has two (2) tabs to work from. The Navigation tab is the one that will be used for gathering field data for a bus route during a ride check study or at a specific location for a point check study (see Figure 4.1).

4.3 User Preferences

The program allows the User to format the most important data features, prior to starting its use. The main User Preferences defined in the program that can be formatted for every individual use are the following:

- Time Interval (sec): time interval between the collection of data points along the route. The User can select from four (4) pre-determined time intervals (1, 5, 10, 15), in which the program will be continuously collecting horizontal and vertical coordinates of the bus's location.
- Saving Location: the User can define the folder and location where he / she wishes to store the current project by clicking the "Location" button in the "Saving Location" panel. The project's default saving location is C:\Event Recorder\Track 1.xls. Every time the program is started, a new "Track" number will be assigned to the .xls file (Track 1.xls, Track 2.xls, Track 3.xls, etc).
- Time: the User can choose using the laptop's internal clock or the one on the GPS device, although not all devices have an internal clock as a feature.

- Speed: the User can select calculating speed in miles per hour (MPH) or kilometers per hour (KPH).
- Distance: the program can store distances in meters, kilometers, miles, or feet.

Figure 4.2 shows the Preferences tab of the program. The items described above can be observed to the left of the program's window.

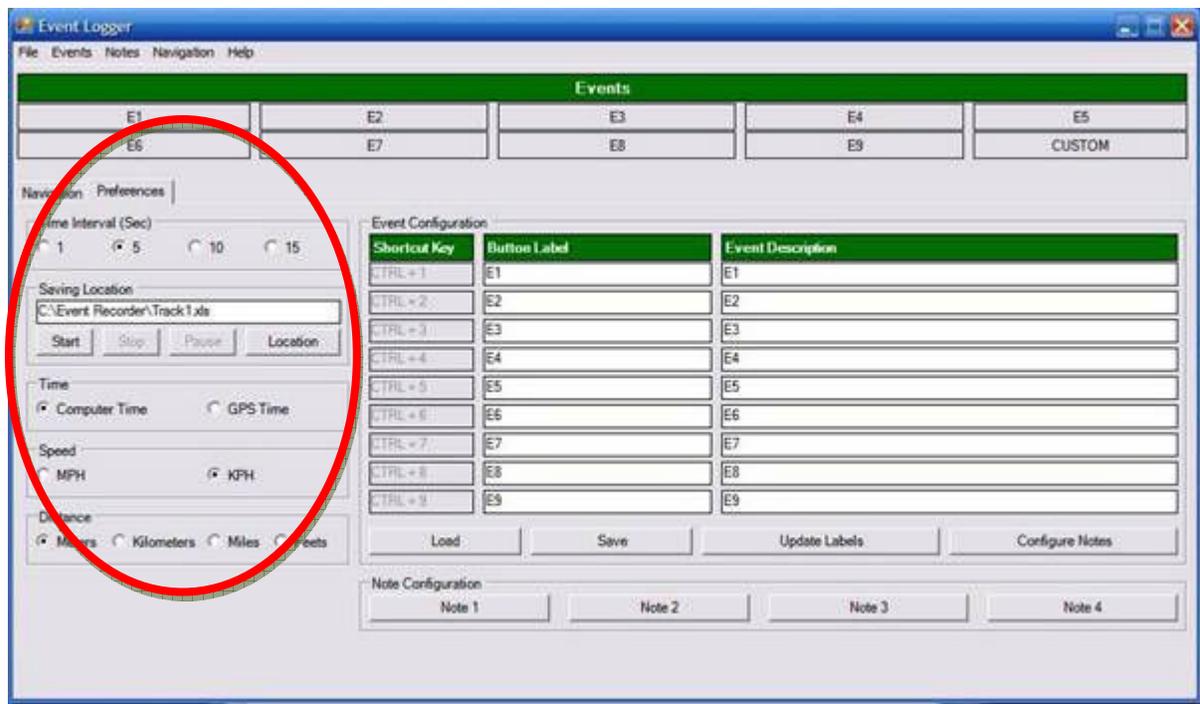


Figure 4.2 Preferences Tab

User Preferences are a very important aspect of the program. The User is advised to use a standardized measuring system, whereas it may be Kilometers / Meters and KPH, or Miles / Feet and MPH. This will facilitate future use of the data that is collected and minimize errors in recommendations and / or conclusions made afterward.

Although four (4) pre-determined time intervals are presented for the User's selection, a five (5) second time interval is recommended for most studies. This time interval allows the User to obtain sufficient information on the route for precise assessments, and accurately map it for graphic representation.

One (1) second intervals should be used on short routes because the amount of data would be too immense if selected for typical or long ones. This time interval has been presented as an option to be used on occasions in which extra precision is necessary for a particular route or segment of it.

Ten and fifteen – second intervals are presented as a possible preference, as well. These are recommended for longer-than-typical routes, in which a 5-second interval would result in more data than the one needed to properly assess a route and give recommendations for its improvement. These time intervals can also be set when the laptop that is being used for the study does not have large amounts of free storage space (not likely to happen with today's technology).

Clock selection is another important feature in the User's Preferences tab. The User can set the program to use the laptop's internal clock, as well as the GPS's. Using the laptop's internal clock is highly recommended (it is the program's default setting).

Although Bluetooth connectivity is very reliable, the GPS device and the laptop could disconnect at some point during the route. Under these circumstances, the program would stop collecting coordinates and elevations, but the User would still be able to associate events

like bus stops and departures with their respective times, if the laptop's internal clock is being used.

4.4 Event Configuration

Configuring events in the program is a very important task, and one that shall be done in coordination with all team members that will have access to the program during the duration of the study.

The Event Configuration preference allows the User to determine what each of the control buttons in the program will register when clicked. The program has ten (10) of these buttons. Nine (9) of the buttons can be configured by the User and can also be activated using the laptop's keyboard. The remaining button has been named "CUSTOM" because it can be customized by the User every time it is used.

A custom button is very useful since there are events in a route that are not easy to standardize (it is not efficient to use configurable buttons for non-standardized events) and are specific events that happen once or do not happen at all. For example, if a bus has a flat tire or suffers engine breakdown during the route (an unlikely event), the User can use the "CUSTOM" button to record the event.

Figure 4.3 shows the Event Configuration table in the Preferences tab of the program.

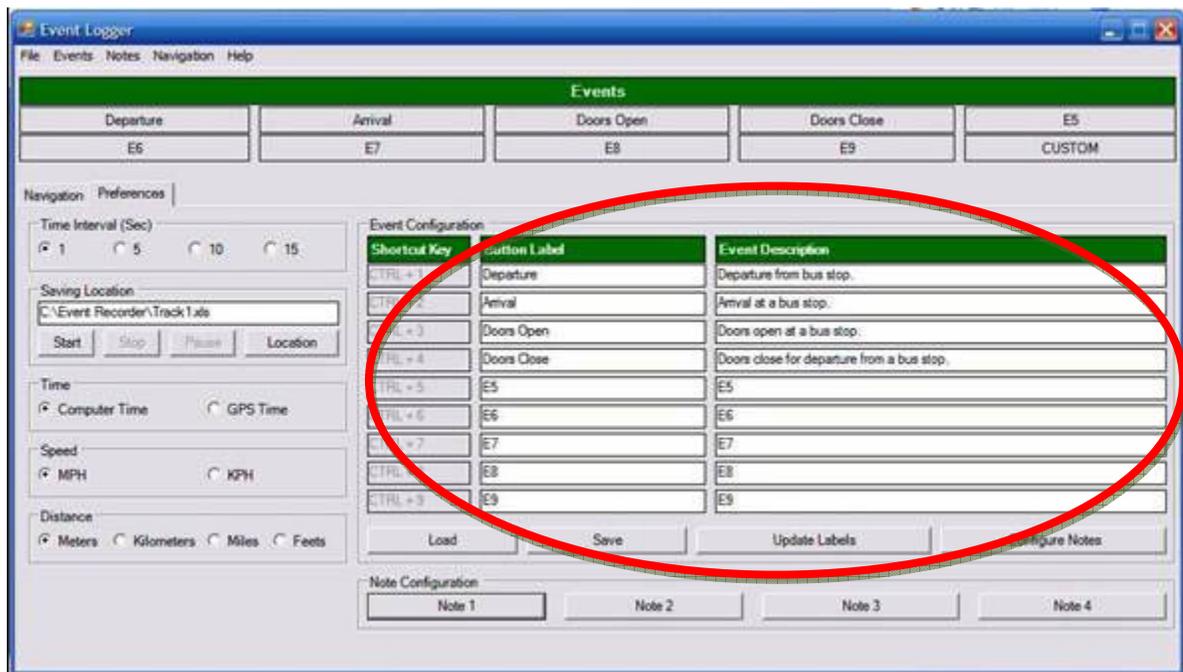


Figure 4.3 Event Configuration in Preferences tab

The three (3) columns in the Event Configuration table are very important and, as stated above, shall be carefully coordinated among all the members that will have access to the program during the study. Since each button will record a particular event along the bus route, clear and understandable names must be agreed for each label.

The first column indicates the command key on the laptop's keyboard that will be associated to the event. Since there are nine (9) event buttons, the short cut keys have been organized correspondingly from one (1) to nine (9). To activate any of these events using the laptop's keyboard, the User shall simultaneously press the Control (CTRL) key and the corresponding number.

The button labels have default values of E1 through E9 (nine event buttons). The User must provide names for each event button before beginning to use the program. Short names (one or two words) are highly recommended for the button labels; this will facilitate the program's use.

The third column of the Event Configuration table has been labeled Event Description. Every cell in this column allows the User to give a description of the button labeled next to it. Since the buttons' labels are short (as recommended above), the User can type a description of the use intended for each.

For example, in Figure 4.3, the first button has been labeled "Departure", whereas the second button was labeled "Arrival" and the ninth button could be named "Bus Acceleration". The "Departure" button has been described as a "departure from a bus stop", meaning that this button shall be pressed every time the bus departs from a bus stop during the route. Pressing this button will record an event in which the bus was leaving a determined bus stop, and will be stored with the exact time and location in which it happened.

Once all labels have been named, the User can press the "Update Labels" button (located at the bottom of the Event Configuration table). This will cause the buttons at the top of the screen to be automatically renamed according to the User's labels.

4.5 Note Configuration

The last step in the configuration of the User's Preferences of the program is to configure the notes that apply to the study. Notes are also a very important feature in the program, since the User will have to associate these with every event button, described later in this chapter.

The notes in the program represent important data that the User has to add during the study. For example, the number of passengers boarding or de-boarding a bus at any bus stop will be added using the notes in the program.

As shown in Figure 4.4, the program has four (4) Notes buttons. These represent the four (4) possible data inputs that the User can add to the program while performing a study.

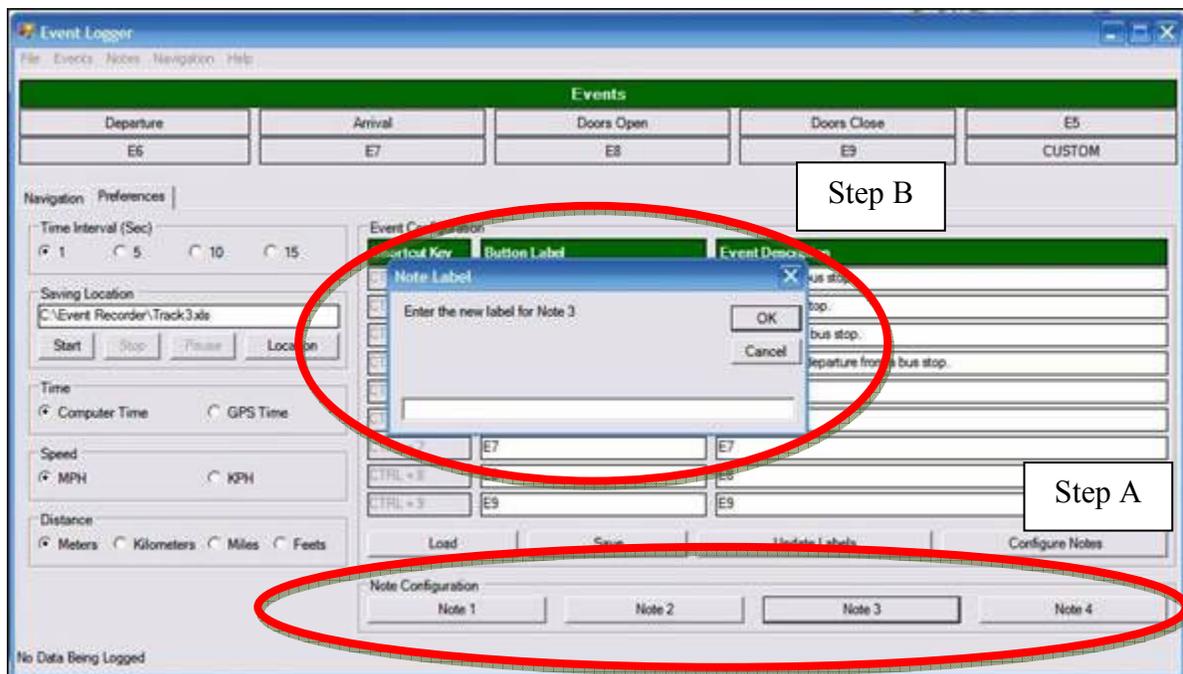


Figure 4.4 Note Configuration

Every time the User presses a Notes button, a pop-up window will appear requesting a new label for the selected note. Once again, the User is advised that a short label, consisting of no more than two words is chosen. After entering the note's label, a new pop-up window will appear requesting the message to be displayed when the note is pressed during the study. The User shall enter a message requesting the information that corresponds to the note.

For example, if Note 1 is labeled "Boarding Passengers", the message to be displayed should read: "Please enter the number of passengers boarding the bus." Likewise, if Note 2 is labeled "Alighting Passengers", the message to be displayed should read: "Please enter the number of passengers de-boarding the bus."

An example of how the program's main screen will look after all the Notes and Event buttons have been configured is shown in Figure 4.5. The User will be able to note the difference in the corresponding labels from the original default names that appeared when the program was originally opened.

Since each of the notes that were entered and described in the previous steps will be associated with an event that is logged by the User, these need to be configured so that every time an event is clicked, the appropriate note pops up and gathers the corresponding data. For instance, every time the bus reaches a bus stop, the User will click the event button named "Arrival", at which time the program shall request the number of passengers boarding and alighting the bus, which are both previously saved notes.

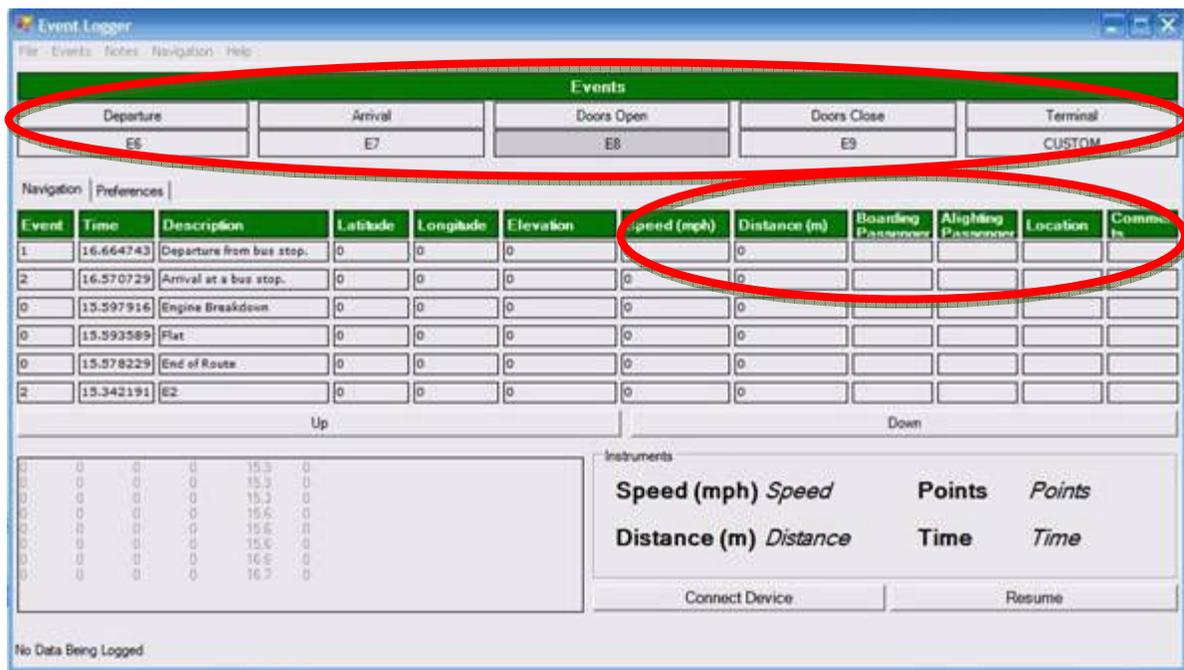


Figure 4.5 Main Screen after Event and Notes configuration

In the Preferences tab, click the “Configure Notes” button located on the lower right hand side, as shown in Figure 4.6.

After clicking the “Configure Notes” button, a pop-up window titled “Required Notes for Each Event” will appear in the User’s screen, as shown in Figure 4.7.

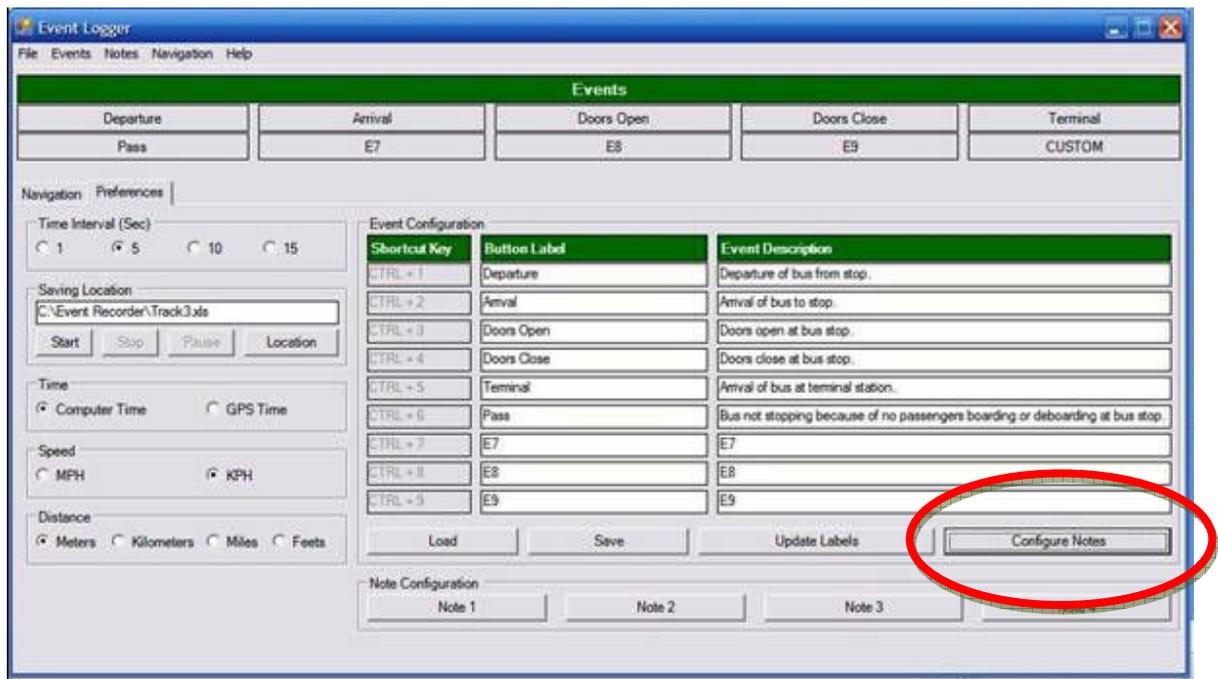


Figure 4.6 Configure Notes Window 1

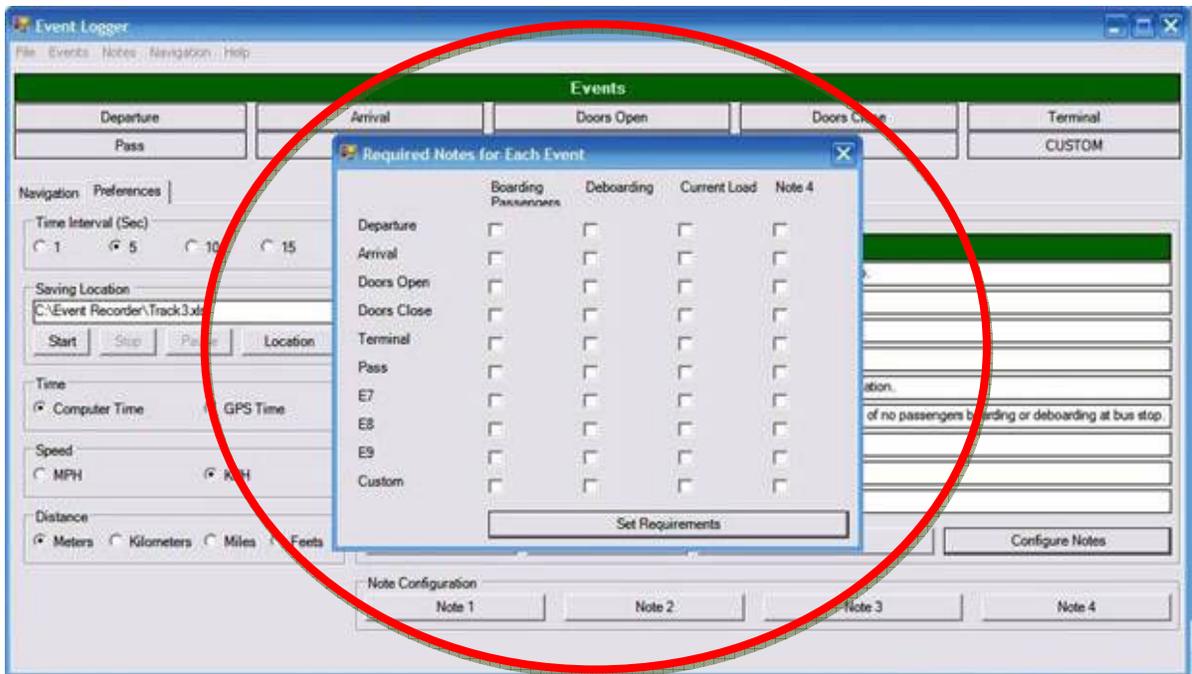


Figure 4.7 Configure Notes Window 2

The User shall click on the open boxes to create the corresponding associations between events and notes. Please note that each selection must be done carefully and according to the information needed for each event. The program will not limit the User on the number of relations made; in other words, all boxes can be checked by the User, in which case all notes will appear on every event logged during the route.

The “Configure Notes” procedure can also be done by clicking:

File \Rightarrow Configuration \Rightarrow Event-Notes.

Once the User has configured all notes with their corresponding events, the “Set Requirements” button at the bottom of the pop-up window must be clicked.

The final step in setting up the program prior to its use is to save all the User Preferences. In the Preferences tab, click the “Save” button located below the Event Configuration chart, as shown in Image 4.8.

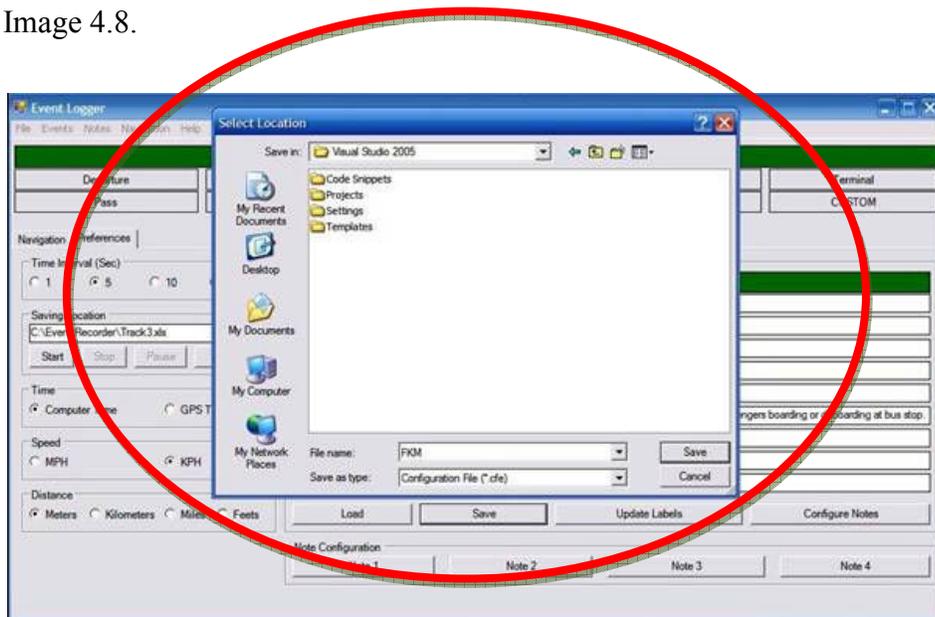


Figure 4.8 Saving User Preferences

A typical Windows pop-up requesting the location where the file wants to be saved will appear on the screen. The program's default location is the computer's My Documents file. Any other file can be selected by the User. A .cfe file will save all the settings made by the User in the Preferences tab. These preferences will be automatically set in the program by clicking the "Load" button in the Preferences tab, when the User returns to the program for a new study.

4.6 Data Gathering

Now that the Event Logger has been configured with all the User's preferences, it can be used to gather data for a bus route.

Once the User's Preferences have been loaded and / or updated in the Preferences tab, click the Navigation tab. The Event Logger resembles a spreadsheet in which the information that is being gathered is organized in rows and columns. All titles shown have the names given by the User and all measurements are shown in the units selected by the User as well.

The program's main screen (Navigation screen) with the User's preferences is shown in Figure 4.9.

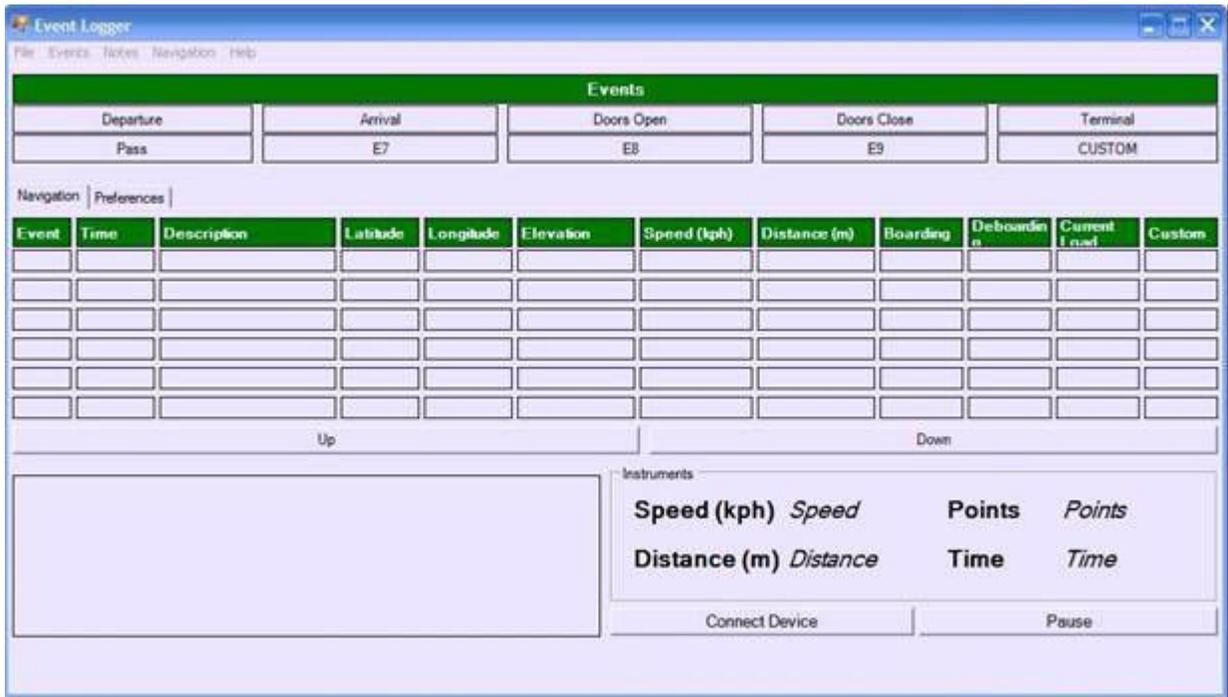


Figure 4.9 Navigation Screen

4.7 Connecting a GPS Device

The first step in using “*TEDR*” is connecting the program to a GPS in order for the program to be able to collect data points and record them in its data sheet.

Today’s most common GPS devices connect via Bluetooth technology. If the laptop computer or PDA that is being used does not have Bluetooth technology installed into its original hardware, a peripheral connector will be required. Bluetooth connectivity devices are available in the market; most commonly connecting via USB. Since most GPS devices

can be connected via Bluetooth, this guide has been prepared assuming that a Bluetooth connection is available.

Once the laptop or PDA has Bluetooth connectivity and the GPS device has been installed in the vehicle, the User can connect the device and the program by clicking File \Rightarrow Device and then Connect. The User can also opt for clicking the “Connect Device” button, located on the bottom right area of the program’s main window, as shown in Figure 4.10.

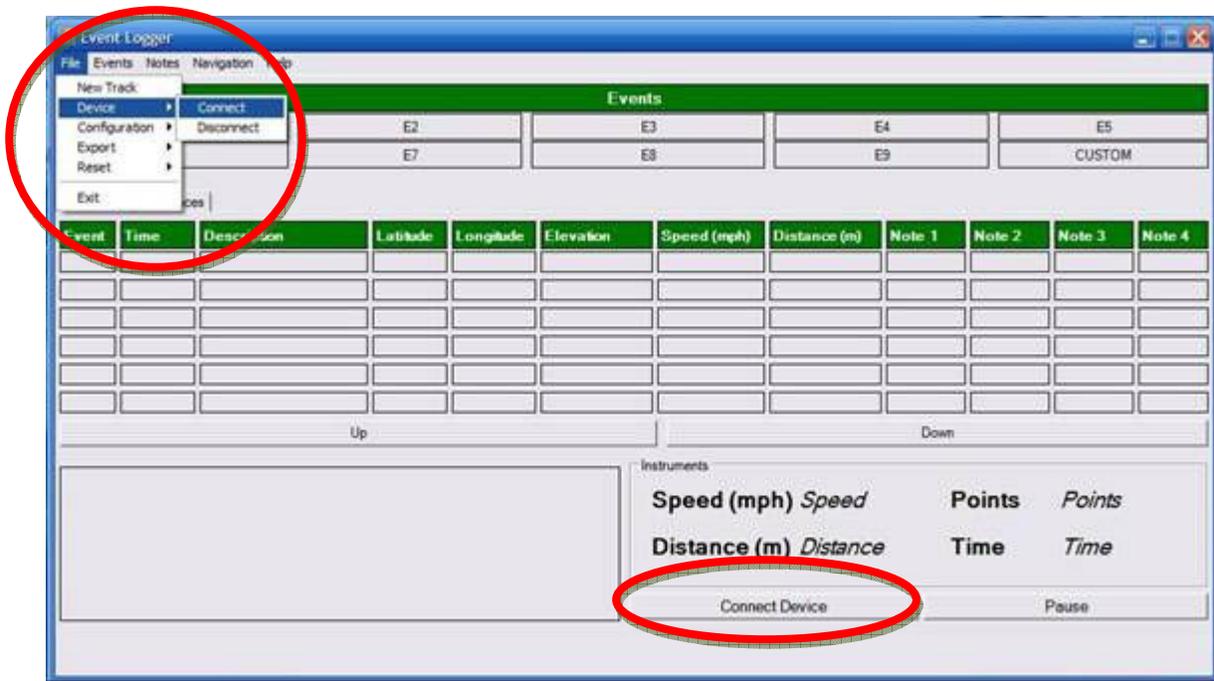


Figure 4.10 Connecting to a GPS Device

The program will inform the User if the connection to the GPS device has been successful or not. Once connected, the program will track and record points with data of the horizontal and vertical alignment of the route followed by the bus. The connection to the GPS device

will establish these coordinate points in sync with the computer's internal clock, so the User can later calculate speeds and other statistics for the route.

If the study is stopped at any given point, the "Pause" button must be clicked (the button is located right next to "Connect Device" button). This should be done in order for the program to stop gathering the same coordinate point at different time intervals.

4.8 Logging Events

The first step in logging events with the program is to start recording data. On the Preferences Tab, click "Start" on the "Saving Location" panel, located below the "Time Interval" selection panel.

The number on the .xls file will automatically increase. For example, if the last file seen in the "Saving Location" panel was Track 9.xls, once the User clicks "Start", Track 10.xls will appear instantly. If the User wants to name the file differently or choose a new saving location, click File \Leftrightarrow New Track, and the file's name will be highlighted for change.

The "Stop" and "Pause" buttons next to "Start" will also light up immediately after the latter is clicked. At any point in time that the User decides to temporarily interrupt the study, clicking the "Pause" button will do so. By doing so, the button's name will change from "Pause" to "Resume". By clicking "Resume", the program will continue recording events logged in the same .xls file.

If the “Stop” button is pressed, the “Start” button will turn back on, which means that future data that is logged will have to be recorded in a new .xls file.

Figure 4.11 below shows the “Saving Location” panel after clicking the “Start” button.

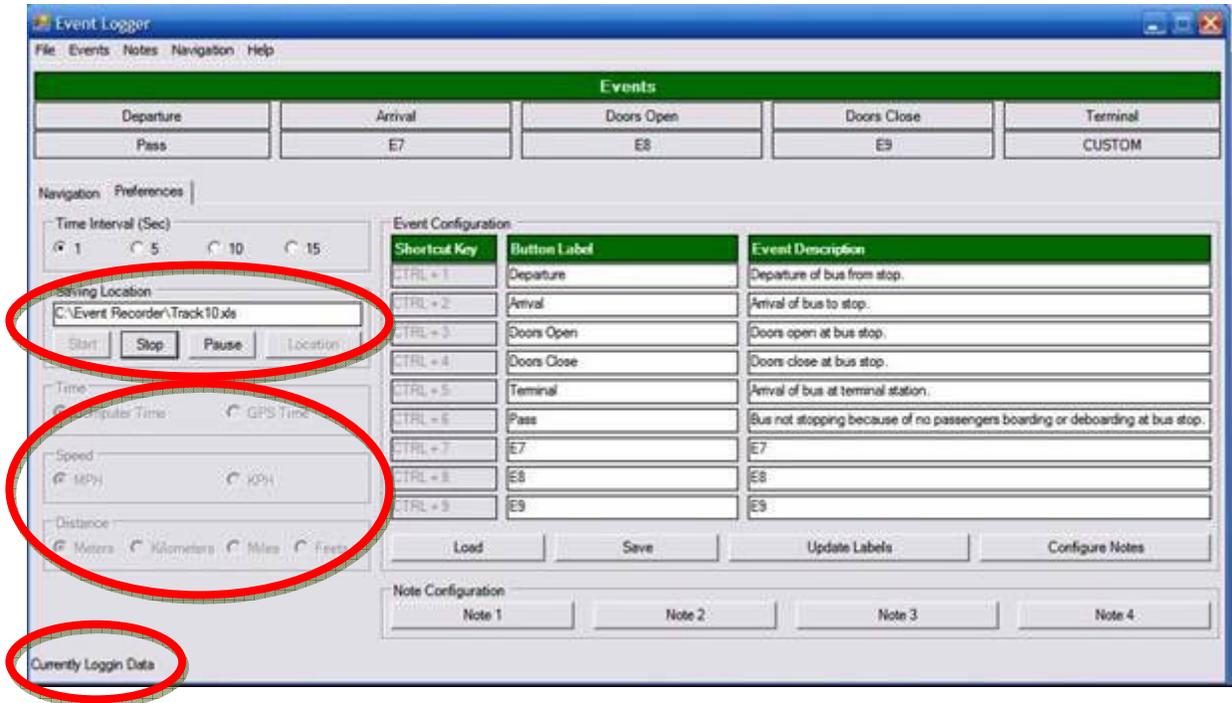


Figure 4.11 Starting Data Collection

Once the “Start” button is clicked, the “Time”, “Speed” and “Distance” panels will turn off, since these preferences cannot be modified once data begins to be recorded. However, the time interval can be changed along the route.

The User will be informed of the project’s data recording current status automatically. On the lower left corner of the screen, the program will show “Currently Logging Data” when recording events, “Data Logging Stopped” when recording is paused, or “No Data Being Logged” when the program is stopped.

While working with the program, the only buttons that will be used are those that were named for the different events. These appear under the Events header located at the upper central part of the screen, as shown in Figure 4.12.

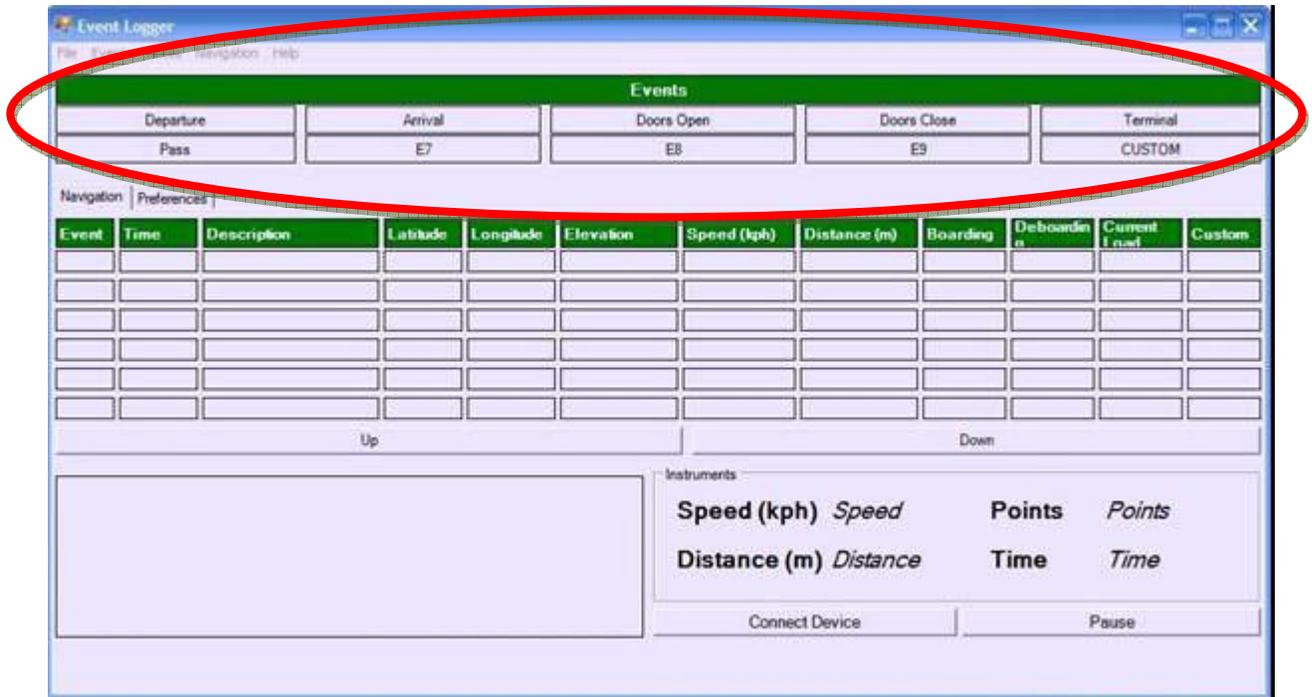


Figure 4.12 Events header

Every time an event is clicked by the User, the program will automatically register it in the events' log. The log will contain the event, its description, the time when it occurred, horizontal and vertical coordinate points, speed, distance traveled from the original departure point, and specific passenger data at the time of the event.

Events can also be logged using the “Events” menu located at the top of the screen. Figure 4.13 shows the “Events” menu after being clicked; all events are always shown with their default names (E1, E2, etc.), which means that the User will have to be careful when logging events this way. The User is strongly recommended to log events using the event buttons named in the Preferences tab.

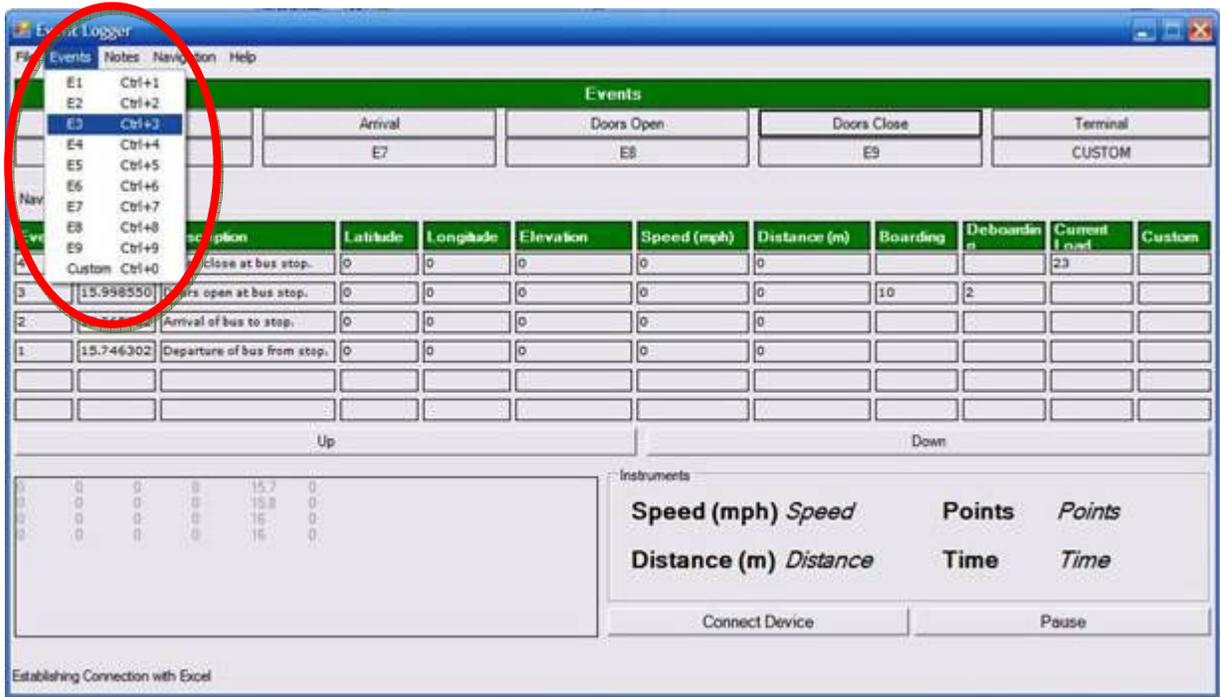


Figure 4.13 Navigation Screen with Events’ Menu

The Notes menu works the same way as the Events menu described above.

A sample of what the main screen will look during a route study is shown in Figure 4.14.

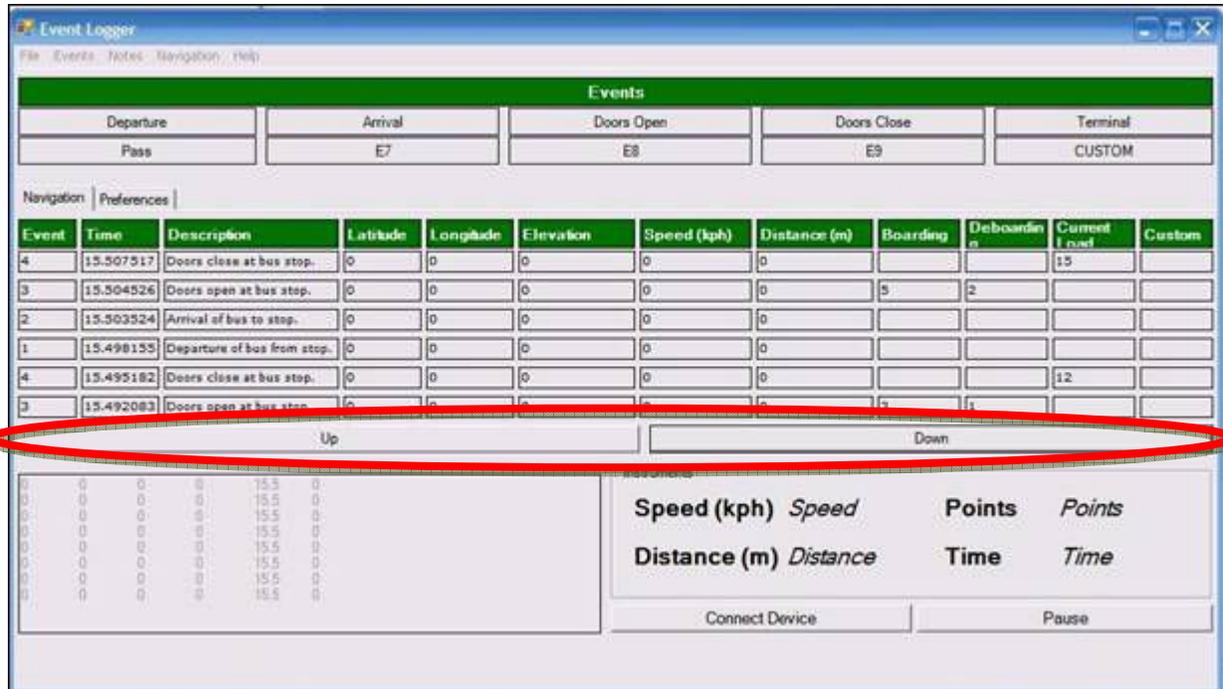


Figure 4.14 Navigation Screen with Events' Log

The most current event will appear at the top of the list. The User can scroll through all the events using the “Up” and “Down” buttons located below the events’ log. The number that appears on the column labeled “Event” refers to the event’s default settings, rather than the chronological order in which it happened. It is important for the User to bear this in mind, in order to avoid confusions.

The program can be reset at any time, if the User decides to do so. This means that all data that has been gathered up to that point will be erased from the file and the new data from that point on will be recorded.

To reset the Event Logger, click File ⇒ Reset ⇒ Events / Collected Data, as shown in Figure 4.15.

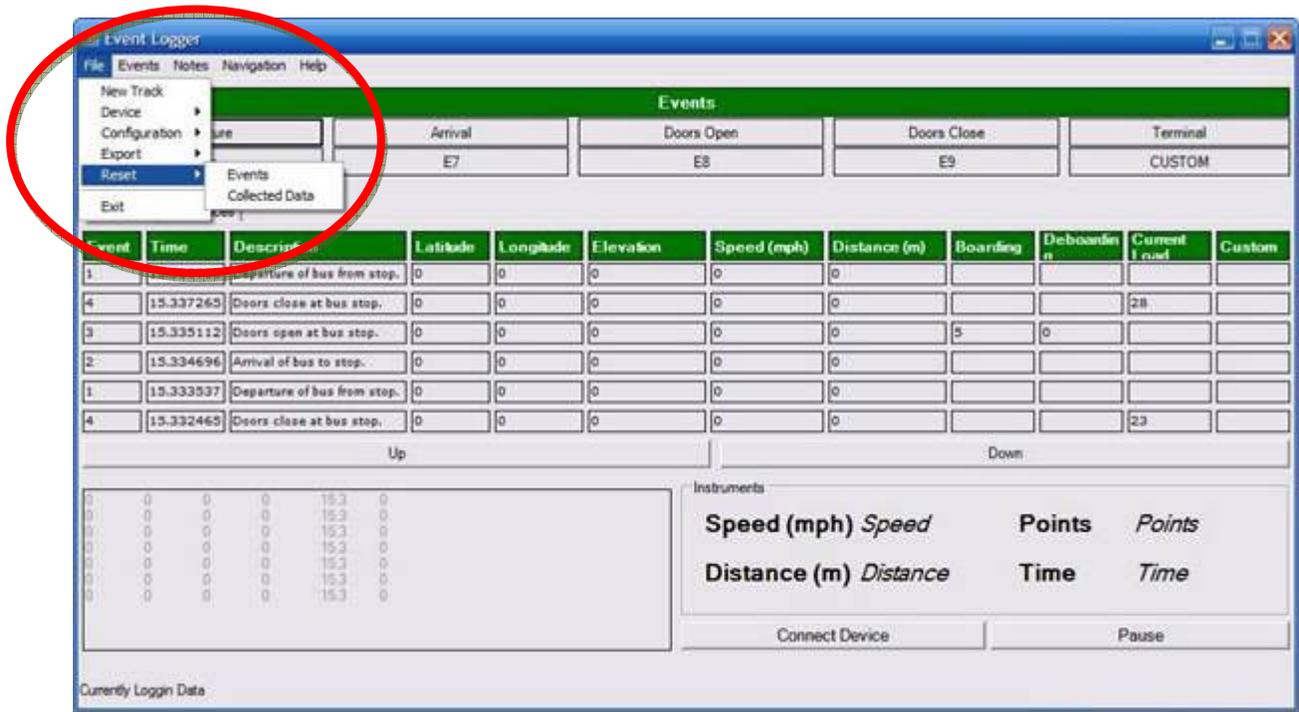


Figure 4.15 Resetting Events and Collected Data

By resetting the Events, the User will erase all events that are currently shown in the events' log. This will give the User a clean spreadsheet to continue working. However, the data that has been previously recorded will not be eliminated from the current .xls file where the collected data is being stored.

On the other hand, if the User chooses to reset the data that has been collected, all the data that has been recorded in the current file will be eliminated. This can be done when the User wants to eliminate data from a .xls file without having to create a new one.

The Time and Distance can also be reset during the route. By doing this, both of these elements in the “Instruments” panel (lower right corner of the Navigation screen) will return to zero (0), as shown in Figure 4.16.

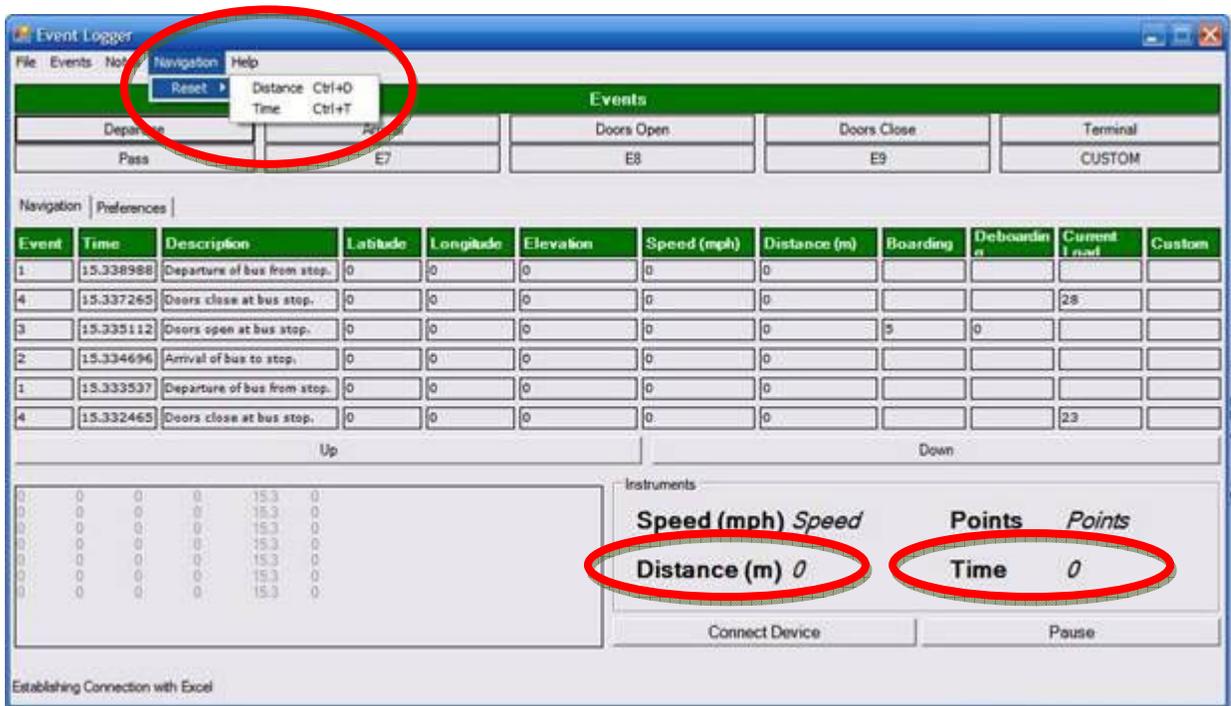


Figure 4.16 Resetting Time and Distance

The program’s internal tracking of the data is shown on the lower left corner of the screen. This record shows coordinate points and time in which the different events take place. Since it is the raw data used internally by the program, it can be retrieved by the User by opening the .xls file saved by the program.

The .xls file containing all the raw data gathered can be retrieved from the file where it was destined to be saved by the User (see User Preferences). This .xls file can be validated and used for further calculations to be made for any specific bus route that is studied.

4.9 Other Menu Commands

Some of the program's operations and components have been shown to be done directly in the Preferences or Navigation tabs, as well as on the program's menu. This section of the manual will focus on describing the remaining utilities that are available in the program.

Events logged in the program can be exported to a .txt file, which can be later exported to a spreadsheet. In order to do this, go to File \Rightarrow Export \Rightarrow Events, as shown in Figure 4.17.

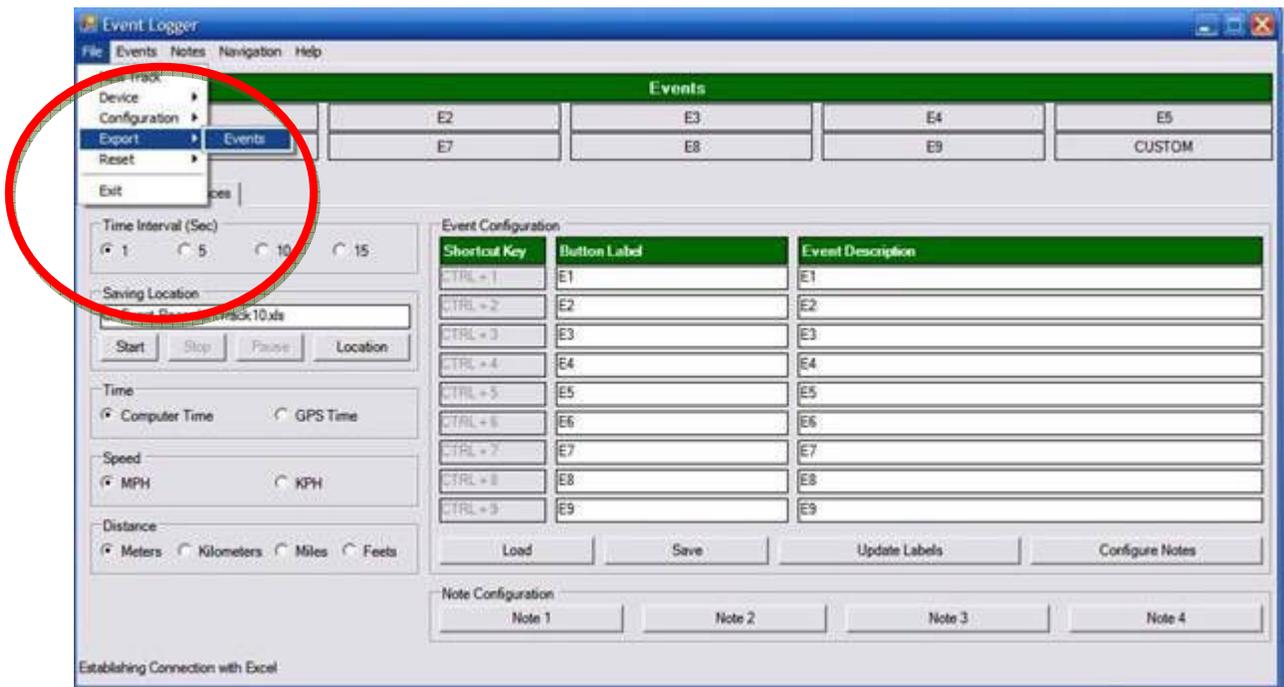


Figure 4.17 Exporting Events

The resulting .txt file will contain all the events gathered during the study. The reason why this information is exported into a .txt file is to ensure compatibility with other programs (like MS Excel) when updated versions are released.

Finally, the last command in the program that needs to be reviewed is the “Help” menu. When the User clicks “Help”, the only available sub-menu that will appear is: “About F1”. This sub-menu was created to present the User the basic information on the software.

This chapter summarized the major data logging processes developed as part of “*TEDR*”. In the following chapter, the application of “*TEDR*” in transportation data and event recording will be discussed.

5 CASE STUDY OF DATA COLLECTION APPLICATIONS

This chapter presents a case study performed during the months of December, 2008 through March, 2009 in which both the manual and automated methods of data gathering were alternately used to gather information of an existing bus route.

The main reason for this case study to analyze only one route was the limited resources that were available, since no funds from grants were awarded for the development of this project.

5.1 Route Description

The selected route to be analyzed for this case study was the Metrobus I Express route. This route is privately operated and runs from Old San Juan (OSJ) through the exclusive Metropolitan Bus Authority (MBA) right-of-way (ROW) of Puerta de Tierra, the Convention District, and the Muñoz Rivera Expressway, to reach Sagrado Corazón (SC) station of the Tren Urbano (TU), also known as Stop 26, from the train lines of the 19th and early to mid 20th centuries (see Figures 5.1 through 5.7).

The return route is identical, except for the exit taken by the bus in Hoare St., Miramar, to follow a segment of the Fernández Juncos Avenue in order to reach the Convention District. This modification is needed because there are no exits from the Muñoz Rivera Expressway to the Convention District.

5.1.1 Route Details

The maps and aerial photographs included in this chapter (Figures 5.1 through 5.7) show the areas covered by the new route traveled by Metrobus I Express route. Figure 5.1 is a map presented by the Metropolitan Bus Authority (MBA) for all the bus routes in the Metropolitan Area of San Juan, since most had changes during the months of November and December, 2008. Figure 5.2 is the map of the route available online on MBA's website.

Figure 5.3 is an aerial photograph obtained from Google Earth, showing the entire geographical area covered by the route. Figures 5.4 through 5.7 show close-ups of the different segments of the route.

The Metrobus I Express route departs Covadonga Terminal station in Old San Juan from Juan Antonio Corretjer Street, immediately taking Paseo Concepción de Gracia Avenue, which leads to MBA's exclusive right-of-way (ROW) in Puerta de Tierra (a.k.a. "Calle del Tren", from the train lines of the 19th and early to mid 20th centuries which it originally served).

After finishing the exclusive ROW, the route enters the Muñoz Rivera Expressway to cross the San Antonio Bridge and exit to State PR-16, thus entering the Convention District. The route turns into Lindbergh Street and continues to Saint John Boulevard, which takes the bus to the main entrance of the Puerto Rico Convention Center.

The route turns back to State Road PR-16, where it makes its last stop before it reaches the frontage road of the Muñoz Rivera Expressway, where it turns to enter the expressway. The

route exits the expressway at the new facilities of the Sports and Recreation Department, to reach the Sagrado Corazón Terminal.

The return trip is almost identical to the trip described above, in reverse form. The route departs de Sagrado Corazón terminal and enters directly to the Muñoz Rivera Expressway, exiting at Hoare St., in Miramar. The route turns into the existing exclusive bus lane on Fernández Juncos Ave. and continues into de Convention District, where it once again follows the loop formed by Lindbergh St. and Saint John Boulevard.

After turning back into State Road PR-16, the route temporarily enters the Muñoz Rivera Expressway again, in order to reach the exclusive Puerta de Tierra ROW. After completing the Puerta de Tierra segment, the route exits to Fernández Juncos Ave., which connects with Paseo Concepción de Gracia Ave., from which it accesses the Covadonga Terminal.

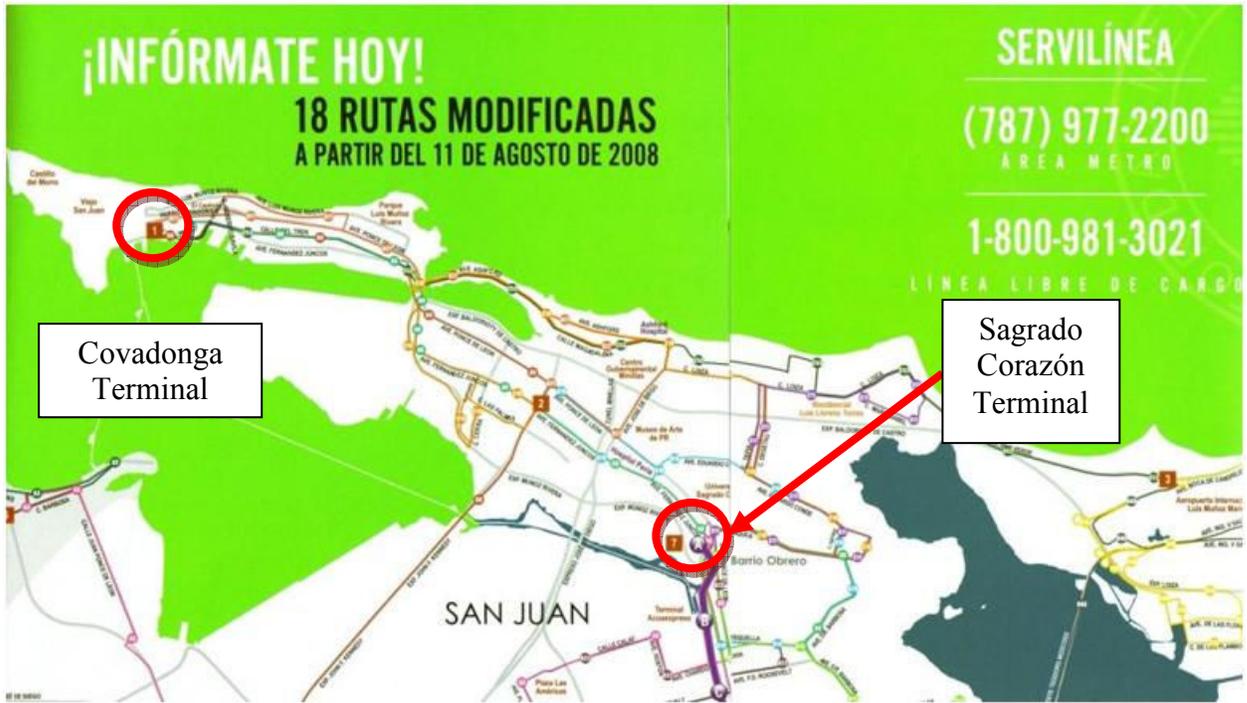


Figure 5.1 Revised MBA Bus Routes Printed Map

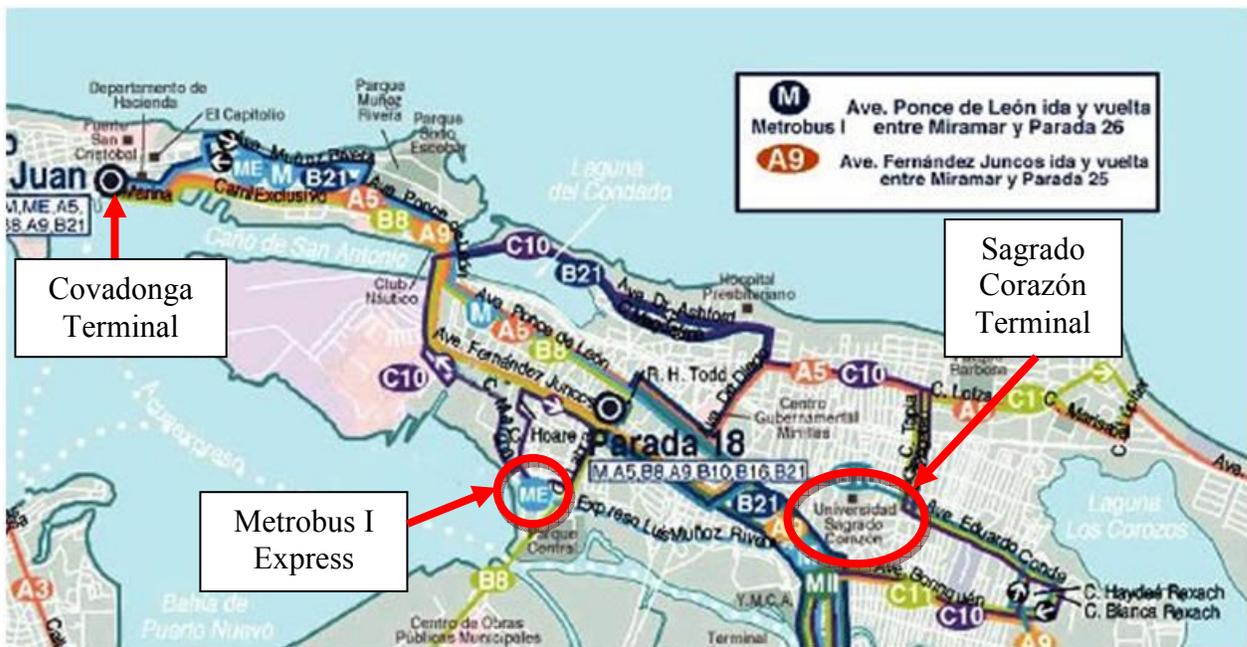


Figure 5.2 MBA Bus Routes Online Map



Figure 5.3 Aerial Photograph of the Main Locations Served by Metrobus I Express

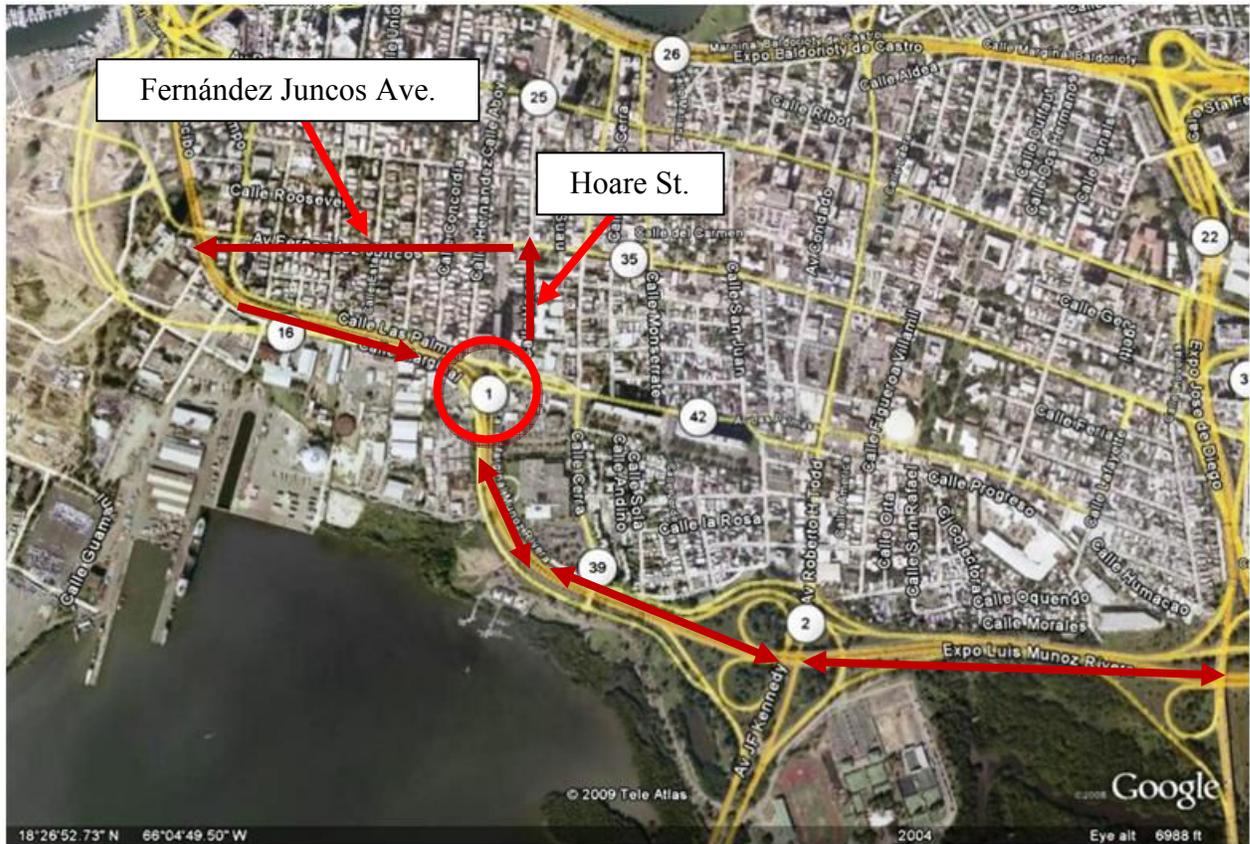


Figure 5.6 Aerial Photograph of the Muñoz Rivera Expressway and Surroundings

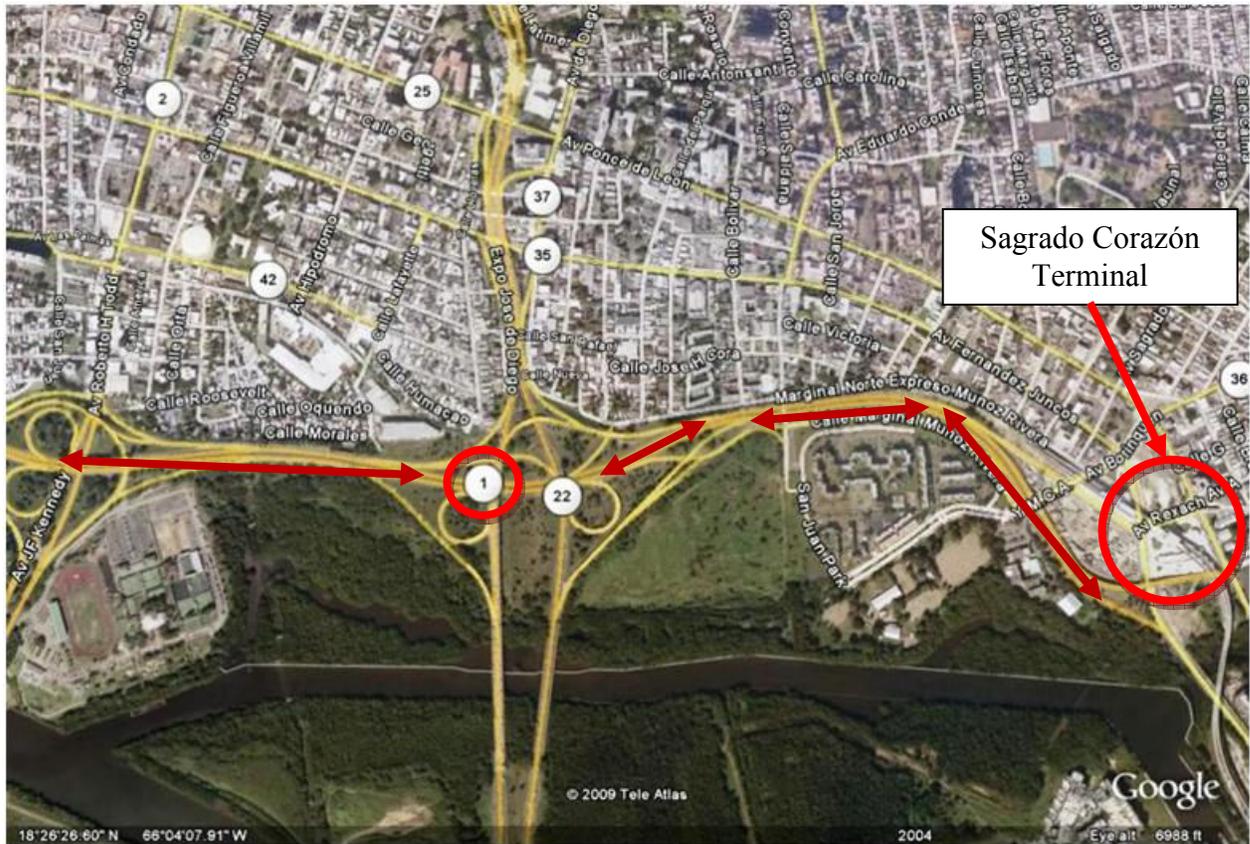


Figure 5.7 Aerial Photograph of the Sagrado Corazón Terminal and Surroundings

5.2 Identification of Bus Stops Along the Metrobus I Express Route

The location identification of all the bus stops along the route had to be done as part of the manual process of the ride check study. This process served two (2) purposes, namely to determine the distances between the different bus stops and to provide visual documentation of each stop and its existing conditions.

Since the most of this route is comprised of exclusive bus lanes, field work was done riding a bicycle. For personal safety reasons, the return segment of the route from Sagrado Corazón (SC) to Old San Juan (OSJ) that included the Muñoz Rivera Expressway was calculated using the odometer of a personal motor vehicle. A schematic description of the data collection process is shown in Figure 5.8.

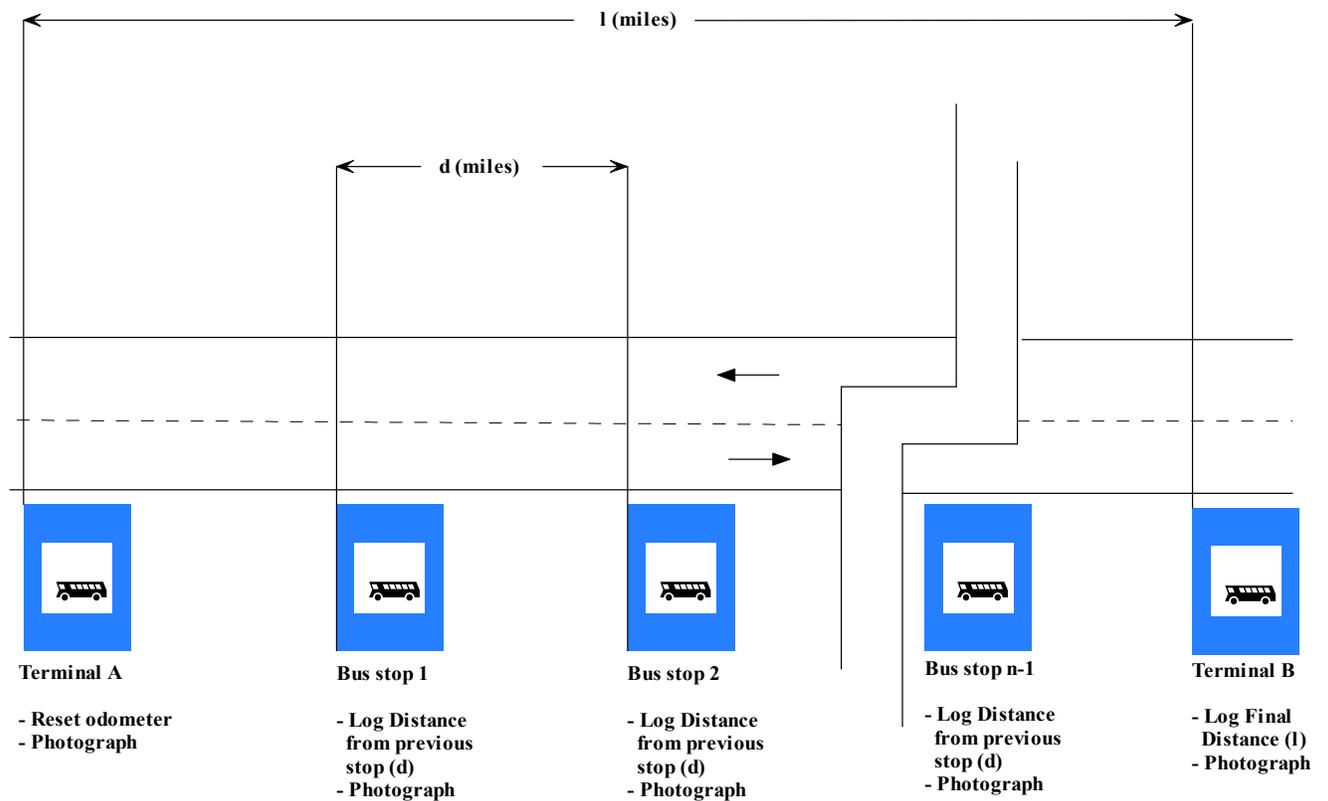


Figure 5.8 Schematic Representation of Bus Stop Location Identification

An alternative to this method for gathering distances between stops is to take note of the bus's odometer at each stop. However, the latter depends on the driver's cooperation and that the bus's odometer is working properly.

All pictures taken along the route can be found in Appendix D.

A *CATEYE VELO5* instrument was used during the bicycle reconnaissance ride, which measures the speed and the distance traveled by the bicycle with a precision of a hundredth of a mile. The bicycle ride was done in the afternoon of December 9, 2008 in approximately four (4) hours. As stated previously, a bicycle was used in lieu of a motor vehicle because of the exclusive ROW used by the route when it goes through Puerta de Tierra in Old San Juan.

The GPS and computer-aided ride checks were done using a Garmin GPS 10 and a Hewlett-Packard Pavilion dv500 personal laptop computer.

The two lane ROW is for the exclusive use of buses, but has signalized controls at the intersections of the local streets that cross it.

Tables 5.1 and 5.2 show the distances between the stops for each direction of the route.

5.3 Manual vs. GPS and Computer-Aided Data Gathering

Whereas performing the computer-aided data gathering process only required the coordination of the time and point of departure of the bus route to be studied, it can be clearly appreciated that the manual process required a substantial amount of additional work in order to be able to obtain all the necessary information of the route.

5.3.1 Data Precision

One of the most immediate differences that can be highlighted between the two (2) processes is the precision of the data that is obtained. Since work was limited to a single checker, cruising speeds for the buses could be obtained when using the program, whereas it was impossible to do while performing the study manually.

While the software presents distances to a ten-thousandth of a mile (or kilometer), the highest precision that could be obtained with the manual process was to a hundredth of a mile.

Similarly, the software presents the time with a precision of ten-thousandths of an hour, while manually the checker can only observe hours, minutes and seconds. Furthermore, time precision is enhanced by the software, since it instantly saves the time of an event based on its internal clock, while manually there is a gap between the moment the checker identifies that an event is happening, the time he or she observes the time-measuring device, and finally takes note of the time in the field sheet.

5.3.2 Available Data

The software can locate every point along the route, since it is connected to the GPS. This provides East – North coordinates and elevations, which can be used to analyze the route based on its horizontal and vertical alignments. This information cannot be obtained using the manual method without the use of surveying equipment.

TABLE 5.1 Bus Stops and Distances from Old San Juan to Sagrado Corazón

Old San Juan - Sagrado Corazón Station			
Bus Stop No.	Distance from Terminal (mi)	Distance from Previous Stop (mi)	Description
Covadonga Terminal	0	0	Old San Juan (OSJ) terminal station.
1	0.65	0.65	Entrance to Puerta de Tierra's exclusive Right-of-Way (ROW).
2	0.76	0.11	Puerta de Tierra
3	0.92	0.16	Puerta de Tierra
4	1.09	0.17	Puerta de Tierra
5	1.18	0.09	Puerta de Tierra
6	1.35	0.17	Puerta de Tierra / National Archives Building
7	1.62	0.27	Millennium Building
8	2.13	0.51	Entering the Convention District.
9	2.28	0.15	Convention District No. 1
10	2.62	0.34	Convention District No. 2
11	2.89	0.27	Convention District No. 3
12	3.02	0.13	Convention District No. 4
13	3.12	0.10	Baldorioty de Castro Boulevard (Muñoz Rivera Expressway frontage road).
Sagrado Corazón Station	5.67	2.55	Sagrado Corazón (SC) Terminal Station - Tren Urbano (TU).

TABLE 5.2 Bus Stops and Distances from Sagrado Corazón to Old San Juan

Sagrado Corazón Station - Old San Juan			
Bus Stop No.	Distance from Terminal (mi)	Distance from Previous Stop (mi)	Description
Sagrado Corazón Station	0	0	Sagrado Corazón (SC) Terminal Station - Tren Urbano (TU).
1	2.0	2.0	Hoare St. School.
2	2.1	0.1	Fernández Juncos Ave. No. 1
3	2.3	0.2	Fernández Juncos Ave. No. 2
4	2.6	0.3	Convention District No. 1
5	2.75	0.15	Convention District No. 2
6	3.09	0.34	Convention District No. 3
7	3.36	0.27	Convention District No. 4
8	3.49	0.13	Exit from Convention District
9	3.6	0.11	Underpass Muñoz Rivera Expressway.
10	3.95	0.35	Millennium Building - Entering Puerta de Tierra's Exclusive ROW.
11	4.11	0.16	Puerta de Tierra Entrance.
12	4.37	0.26	Puerta de Tierra / National Archives Building
13	4.51	0.14	Puerta de Tierra
14	4.62	0.11	Puerta de Tierra
15	4.84	0.22	Puerta de Tierra
16	4.93	0.09	Puerta de Tierra
17	5.03	0.10	Exit from Puerta de Tierra.
18	5.2	0.17	Entering Old San Juan - Capitol Building.
19	5.57	0.37	Hacienda - Muelles
Covadonga Terminal	5.69	0.12	Old San Juan (OSJ) terminal station.

Likewise, the software gathers bus speeds based on its location and distance traveled (using the GPS connection) and records it for future use. This cannot be easily done manually without the help of additional persons recording the information and the help of the driver.

5.3.3 Data Reliability

Minimizing errors is of the essence when gathering field data that will be used to analyze existing transportation systems or design new ones. Therefore, the more reliable the data, the more suitable it will be to the Designer.

In this context, there are two (2) key disadvantages to the manual method of collecting field data. First, the difficulty of writing and recording information while sitting inside a moving bus. The lack of support, constant movement of the vehicle, and sometimes being pressed against other passengers makes it very difficult to accommodate the writing pad for the field sheet, which can lead to mistakes or hard to interpret handwriting. A personal computer or PDA works directly from the checkers lap and avoids this inconvenience.

Second, after the process is done manually, the data that is gathered has to be transcribed in order to be used for the analysis and design. There is an inherent margin of error associated with this data entry process, which is completely avoided when using the computer-aided process, since the data are stored internally by the computer.

All data files can be accessed immediately after finishing the gathering process, instead of having to wait for the data to be entered into the system. Although all data recorded by the program result from the input of the user, including the passenger load of the bus, data can be

stored, and checked and analyzed for consistency sooner, for a faster delivery of the required reports or designs.

However, the above considerations have to be analyzed from the standpoint of the bus route that is being studied. In this case, passenger loads observed in the Metrobus I Express route were always low, which facilitated the comfortable setting of the checker's computer, as well as the GPS. Passenger counting by a single person was also possible, primarily because there were no obstructions from other standing passengers, and the number of persons boarding and de-boarding the bus was always manageable.

A bus route with heavier passenger loads, like the one shown in Figure 5.9, could only be studied with two (2) or three (3) checkers on board. This condition applies to both methods, manual and computer-aided.

The checker collecting the information on paper or into the computer needs help from additional personnel in order to complete a ride check successfully under these conditions. Otherwise, data reliability is seriously compromised, since a single checker cannot simultaneously count passengers boarding and alighting from the front and rear doors, while keeping track of the current passenger load, and recording the different events happening along the route.

Since both the .txt files that are created when exporting the events recorded during a field study and the .xls files with the raw data from the program have standardized fields, they can all be migrated to any selected data base, without having to modify them in any way.



Figure 5.9 Bus with Full Seating Capacity

5.3.4 Costs

The comparison of the manual and computer-aided methods for data collecting was performed by the writer without the assistance of any additional checkers. This was done intentionally, in order to be able to compare the amount and quality of the data a single checker could obtain using both methods.

As it can be observed in Appendixes A and B the amount of data that can be gathered by a single checker using the computer-aided system is substantially larger than those obtained by the same checker using the manual method.

Considering the previous statement and the summary of transit studies presented in Table 3.1, using the software is economically beneficial to the project, since the same cost per checker per vehicle – hr produces a substantial amount of additional information on the studied route.

For instance, the total cost for data collection during six (6) ride checks using the “*TEDR*” software will only consider the time spent by the checker riding the bus. In this case study, every roundtrip of the bus can be approximated to one (1) hour, which yields a total of six (6) hours of working time. Considering a minimum hourly wage of \$6.55, as previously in this document, the total cost adds up to \$39.30.

In order to obtain the same information using the manual method, there are additional time elements to be considered when determining the total cost of the study. At first, the time spent recognizing the bus stops along the route and the distances between them, which was previously estimated at four (4) hours.

In order to manually determine the cruising speed of the bus, markers would have to be set at different points of the route, at a specific distance from each other, so the checker could determine the time it takes the bus to traverse them. Using time and distance, the cruising speed of the bus could be calculated. This process can be estimated to take approximately five (5) hours.

Finally, there is the data entry process time to be considered, which can be estimated at four (4) hours, for a total time of thirteen (13) additional hours, which represent a cost increase of \$85.15, or more than 300% over the computer-aided method. Although the percentage of cost increase the initial set-up work that the manual method requires diminishes as the

number of rides increase, it still represents a fixed cost in the study that can be eliminated by using the software.

6 COMPARISON OF DATA COLLECTION METHODS AND GRAPHIC EXAMPLES

This chapter contains calculations made for the Metrobus I Express route, using both the data gathered manually and the one obtained using the program. The calculations made are some of the basic design components of a typical bus route, and they were obtained using both sets of data in order to establish a comparison between the results that could be reached using the two (2) methods of data gathering.

Some of the limitations of the manual system are evidenced immediately. For instance, the User will notice that the cruising speed of the bus cannot be calculated from the data obtained manually, whereas it is readily available in the raw data file resulting from the program.

Another important difference is the fact that the data obtained from the program differentiates the times when doors open and close, from the times when the bus reaches and departs a bus stop. Furthermore, it can obtain data for the point where a bus begins decelerating prior to reaching a bus stop, as well as the point where it stops accelerating after departing from one and reaches its cruising speed between stops.

Since time is obtained directly from the computer or GPS when using the program, it is automatically converted into a decimal number, facilitating calculations and minimizing errors that can occur while transforming time into a decimal number manually. This is yet another data entry process that has to be done when using the data that is obtained manually as shown in Table 6.1.

TABLE 6.1 Time Conversion for Data Obtained During a Manual Ride Check

<u>Bus Stop</u>	<u>Hr.</u>	<u>Min.</u>	<u>Sec.</u>	<u>Time Doors Open (Hr)</u>	<u>Hr.</u>	<u>Min.</u>	<u>Sec.</u>	<u>Time Doors Close (Hr)</u>
Covadonga	14	0.1333	0.0158	14.1492	14	0.1333	0.0158	14.1492
Entering Puerta de Tierra	14	0.1833	0.0053	14.1886	-	-	-	-
Puerta de Tierra 1	14	0.1833	0.0100	14.1933	-	-	-	-
Puerta de Tierra 2	14	0.2000	0.0006	14.2006	14	0.2000	0.0075	14.2075
Puerta de Tierra 3	14	0.2000	0.0022	14.2022	14	0.2167	0.0042	14.2208
Puerta de Tierra 4	14	0.2167	0.0108	14.2275	14	0.2167	0.0136	14.2303
Puerta de Tierra 5	14	0.2333	0.0047	14.2381	-	-	-	-
Millennium	14	0.2333	0.0128	14.2461	-	-	-	-
Entering Convention District	14	0.2500	0.0150	14.2650	-	-	-	-
Convention District 1	14	0.2667	0.0053	14.2719	-	-	-	-
Convention District 2	14	0.2833	0.0019	14.2853	-	-	-	-
Convention District 3	14	0.2833	0.0114	14.2947	-	-	-	-
Convention District 4	14	0.2833	0.0164	14.2997	-	-	-	-
Exiting Convention District	14	0.3000	0.0067	14.3067	-	-	-	-
Sagrado Corazón	14	0.4500	0.0000	14.4500	-	-	-	-

6.1.1 Path Diagrams

The following two (2) path diagrams (Figures 6.1 and 6.2), from the ride check studies performed on February 5, 2009 using the “TEDR” software can be immediately obtained by capturing the data that is gathered electronically. This data is automatically available when the study is over and there are no delays in using it for analysis due to the data entry process associated with manual data gathering.

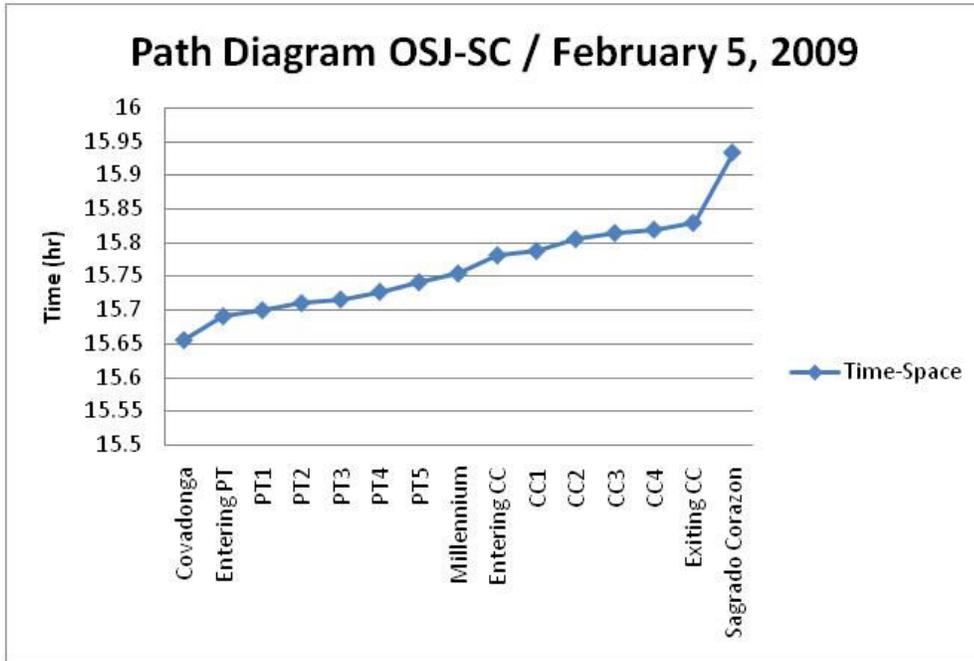


Figure 6.1 Path Diagram OSJ – SC, February 5, 2009, from Program Data

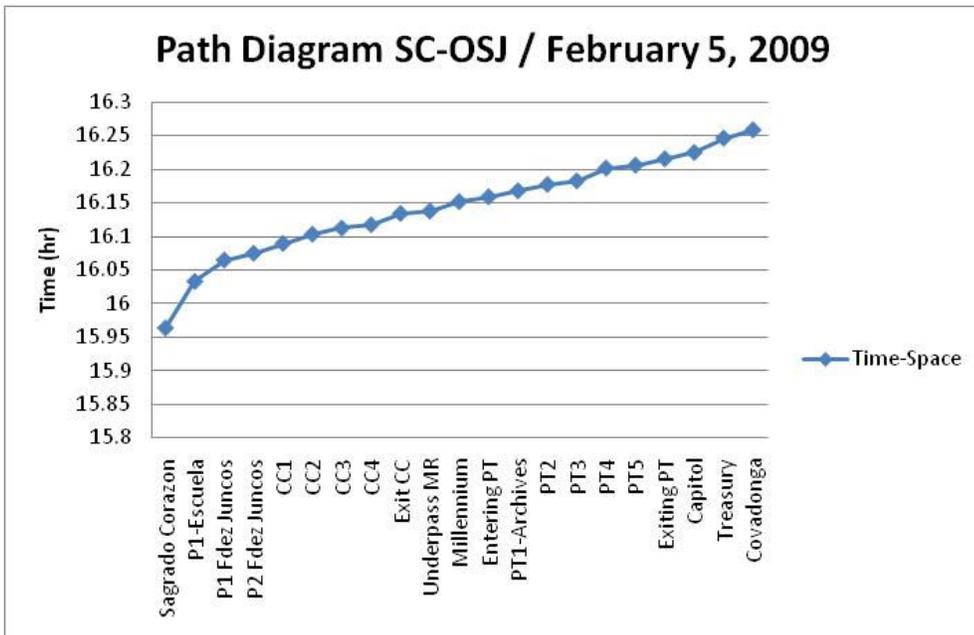


Figure 6.2 Path Diagram SC – OSJ, February 5, 2009, from Program Data

On the other hand, to be able to obtain the same diagrams from the manual data, the time has to be converted first into decimal numbers, as shown in Table 6.1, in order to be able to use the data for the corresponding graphs. Figure 6.3 below shows the Path Diagram for the ride check done manually from OSJ – SC on February 24, 2009 (data from Table 6.1).

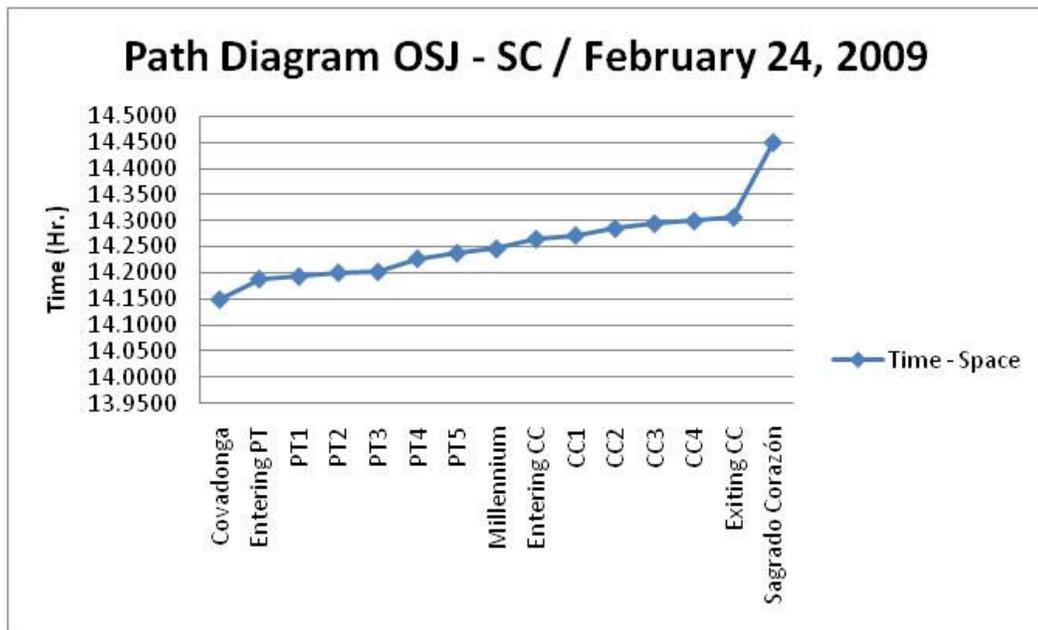


Figure 6.3 Path Diagram OSJ - SC, February 24, 2009, from Manual Data

6.1.2 Load Diagrams

Figures 6.4 and 6.5 below show the average passenger load for the OSJ – SC and SC – OSJ trips, calculated from the data obtained from the program during the ride checks performed on February 5, 25, 26, and March 2, 2009.

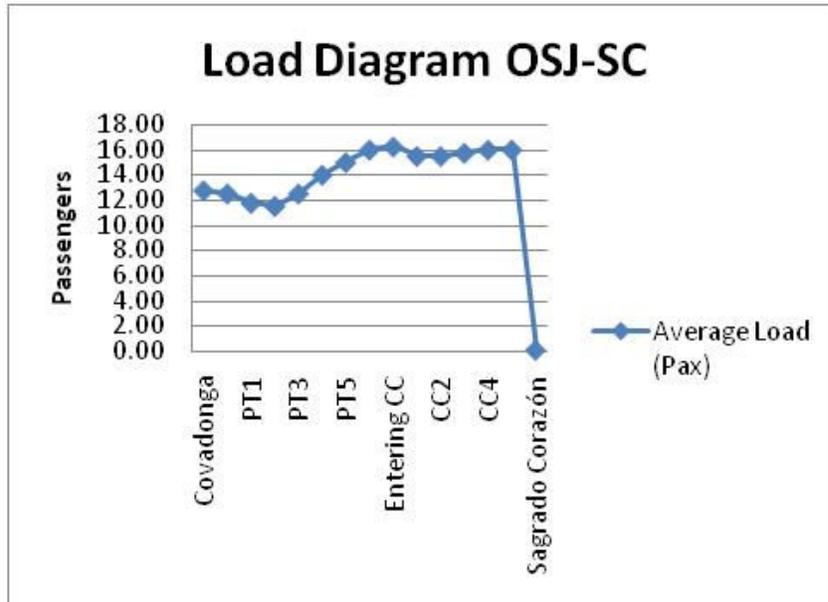


Figure 6.4 Average Passenger Load Diagram OSJ - SC

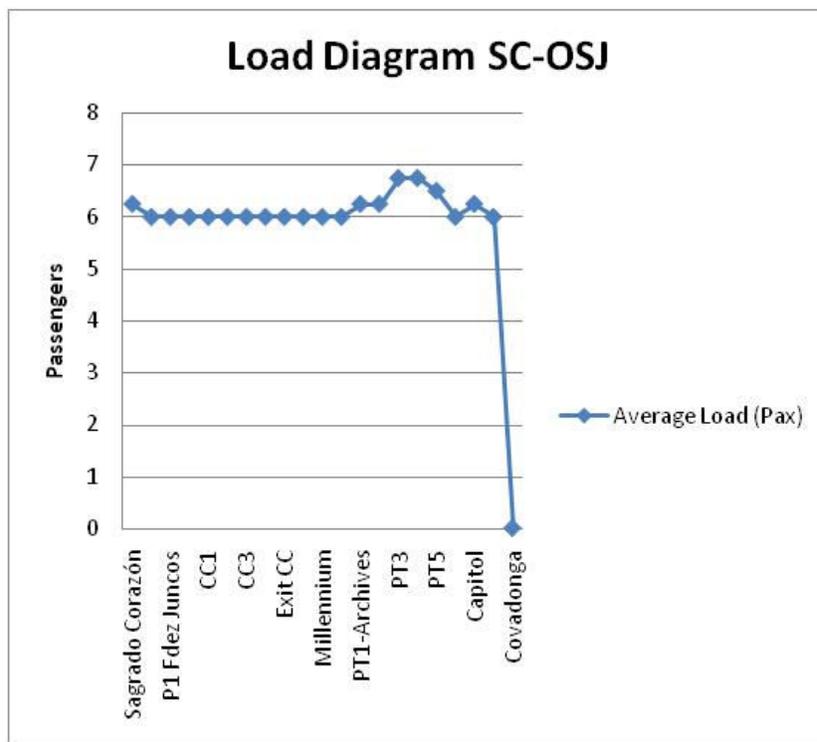


Figure 6.5 Average Passenger Load Diagram SC - OSJ

Once again, although these figures can be obtained from the data gathered manually, there is a data entry process that causes a delay in having them readily available for analysis. By using the program, the information is automatically stored in the computer's memory and can be accessed immediately.

These two (2) Average Passenger Load diagrams show that the current level of service (LOS) of the route, based only on comfort aboard the bus, being studied is A, since all passengers throughout the course of the trip have seats available in the bus.

Having all this information available is extremely useful to a Designer when having to determine changes in an existing bus route or when designing a new one. Also, being able to obtain all this information rapidly is fundamental at the early stages of implementation of a new or re-designed bus route, since it allows designers and operators to modify the route's parameters for a more efficient operation.

7 CONCLUDING REMARKS

Having thoroughly reviewed the different types of studies that can be done to obtain field data for the design of new or existing bus routes, it can be concluded that using technology such as computers and PDA's is extremely useful in making field work easier, more efficient and assuring better quality of the collected data.

Traditional manual field data-collection methods can now be replaced by GPS and computer-aided systems, in which data can be collected simultaneously and more accurately. Just as the data collection process is simplified, the validation process of the data will be easier because of the lesser amount of errors in the data that is collected.

Today's laptop computers and PDA's offer powerful and movable working platforms that can support numerous applications and have immense storage capacity. These systems can also connect to more than one peripheral device at the same time, offer remote internet connectivity, as well as wireless connection to peripherals such as Bluetooth, which is the most common technology available today.

GPS technology is readily available to everyone nowadays. Precise and accurate tracking can be achieved using GPS technology. Tracking information can be used to represent horizontal and vertical alignments of bus routes. This is very useful when designing a new bus route or improving an existing one, since an appropriate route design will be critical during its operational phase.

The Event Logger software developed by Santiago and González [2006] is a straightforward tool for field data gathering during ride check and point check studies. The software connects to a GPS device in order to record events during a transportation study. Every event is logged with the time when it happens, the N-E coordinates where it happens and the elevation. This information is necessary to determine horizontal and vertical alignments, as well as the bus's speed through the route.

Technology is a reliable tool that has to be used as extensively as possible in order to continue achieving more efficiency in engineering processes. “*TEDR*” is an example of such. The program significantly simplifies field work and data validation, thus resulting in better information during design work.

The use of technology not only simplifies these processes, but it also impacts them in economic terms. Reducing field work and data validation times during the study of a new or existing bus route means having less personnel involved and minimizing checker-hours spent on each process, which translates in a reduced payroll.

Administrative agencies, municipalities or private developers that have the responsibility to analyze and design new or existing bus routes can take advantage of a program that will benefit them with easier use, faster times and reduced economies. Smaller and more cohesive data collecting, validating and design teams can be formed when the appropriate technology is available for their use. This is the most important justification for modernizing field work and design processes.

The statistics presented in this report clearly show the need that most major U.S. cities have for efficient and extensive public transportation systems. Puerto Rico's situation is not a different one, but rather a critical example of the transportation problems facing most of the American society.

The program that was developed and presented in this report is a perfect example of the technology that needs to be implemented by public transportation authorities, such as the United States Department of Transportation (DOT), the Federal Transit Administration (FTA), the Puerto Rico Highway and Transportation Authority (PRHTA) and the Metropolitan Bus Authority (MAB), in order to have better designed and more flexible systems that can accommodate to the constantly changing needs and requirements of the traveling public.

Technological breakthrough is constantly expanding the boundaries of human capabilities to perform more and better work. New technologies allow operator and designers to have a larger amount of quality data more efficiently, which is why further research and investigation in this area should be promoted.

Some areas for future development should include, but not be limited to, continued analyzing of current GPS capabilities, remote data transmission, direct integration of collected data with Geographic Information Systems (GIS), as well as incorporating automated data gathering techniques to the development of Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) technologies.

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APPENDIX A. DATA COLLECTED DURING MANUAL RIDE CHECKS

Ride Check Data Gathering Sheet

Date: Tuesday, February 24, 2009
Time: 12:27:53 PM
Weather Conditions: Cloudy
Bus Route Number: Metrobus I Express
Bus Identification Number: 99-123
To: Sagrado Corazón
From: Covadonga Terminal - Old San Juan
Comments: Arrivals and departures from stops are considered when doors open and close, respectively. "Pass" means the bus did not stop because there were no boarding or deboarding passengers.
Page (? Of ?): 1 of 1

Bus Stop	Time Doors Open	Time Doors Close	Mileage	Boarding Passengers	Deboarding Passengers	Current Passenger Load	Comments
Covadonga	-	12:27:53 PM		9	-	9	Terminal Station
Entering Puerta de Tierra	12:30:34 PM	-		0	0	9	Pass
Puerta de Tierra 1	12:31:07 PM	12:31:13 PM		1	0	10	
Puerta de Tierra 2	12:31:50 PM	12:31:56 PM		0	1	9	
Puerta de Tierra 3	12:32:34 PM	-		0	0	9	Pass
Puerta de Tierra 4	12:33:02 PM	12:33:16 PM		3	1	11	
Puerta de Tierra 5	12:34:07 PM	12:34:12 PM		1	0	12	
Millennium	12:35:01 PM	12:35:09 PM		1	0	13	
Entering Convention District	12:36:27 PM	-		0	0	13	Pass
Convention District 1	12:36:57 PM	-		0	0	13	Pass
Convention District 2	12:37:47 PM	-		0	0	13	Pass
Convention District 3	12:38:22 PM	-		0	0	13	Pass
Convention District 4	12:38:40 PM	-		0	0	13	Pass
Exiting Convention District	12:39:00 PM	-		0	0	13	Pass
Sagrado Corazón	12:47:09 PM	-		0	0	13	Terminal Station

Figure A.1 Ride Check No. 1 from OSJ – SC, February 24, 2009

Ride Check Data Gathering Sheet

Date: _____ Tuesday, February 24, 2009 _____

Time: _____ 2:08:57 PM _____

Weather Conditions: _____ Cloudy _____

Bus Route Number: _____ Metrobus I Express _____

Bus Identification Number: _____ 99-123 _____

To: _____ Sagrado Corazón _____

From: _____ Covadonga Terminal - Old San Juan _____

Comments: _____ Arrivals and departures from stops are considered when doors open and close, respectively. "Pass" means the bus did not stop because there were no boarding or deboarding passengers. _____

Page (? Of ?): _____ 1 of 1 _____

Bus Stop	Time Doors Open	Time Doors Close	Mileage	Boarding Passengers	Deboarding Passengers	Current Passenger Load	Comments
Covadonga	-	2:08:57 PM		3	-	3	Terminal Station
Entering Puerta de Tierra	2:11:19 PM	-		0	0	3	Pass
Puerta de Tierra 1	2:11:36 PM	-		0	0	3	Pass
Puerta de Tierra 2	2:12:02 PM	2:12:27 PM		1	1	3	
Puerta de Tierra 3	2:12:08 PM	2:13:15 PM		2	0	5	
Puerta de Tierra 4	2:13:39 PM	2:13:49 PM		2	0	7	
Puerta de Tierra 5	2:14:17 PM	-		0	0	7	Pass
Millennium	2:14:46 PM	-		0	0	7	Pass
Entering Convention District	2:15:54 PM	-		0	0	7	Pass
Convention District 1	2:16:19 PM	-		0	0	7	Pass
Convention District 2	2:17:07 PM	-		0	0	7	Pass
Convention District 3	2:17:41 PM	-		0	0	7	Pass
Convention District 4	2:17:59 PM	-		0	0	7	Pass
Exiting Convention District	2:18:24 PM	-		0	0	7	Pass
Sagrado Corazón	2:27:00 PM	-		0	7	0	Terminal Station

Figure A.2 Ride Check No. 2 from OSJ – SC, February 24, 2009

Ride Check Data Gathering Sheet

Date: _____ Wednesday, February 25, 2009 _____

Time: _____ 10:34:44 AM _____

Weather Conditions: _____ Sunny _____

Bus Route Number: _____ Metrobus I Express _____

Bus Identification Number: _____ 99-116 _____

To: _____ Sagrado Corazón _____

From: _____ Covadonga Terminal - Old San Juan _____

Comments: Arrivals and departures from stops are considered when doors open and close, respectively. "Pass" means the bus did not stop because there were no boarding or deboarding passengers.

Page (? Of ?): _____ 1 of 1 _____

Bus Stop	Time Doors Open	Time Doors Close	Mileage	Boarding Passengers	Deboarding Passengers	Current Passenger Load	Comments
Covadonga	-	10:34:44 AM		9	-	9	Terminal Station
Entering Puerta de Tierra	10:37:44 AM	-		0	0	9	Pass
Puerta de Tierra 1	10:38:00 AM	-		0	0	9	Pass
Puerta de Tierra 2	10:38:29 AM	10:38:34 AM		1	0	10	
Puerta de Tierra 3	10:39:12 AM	-		0	0	10	Pass
Puerta de Tierra 4	10:39:31 AM	-		0	0	10	Pass
Puerta de Tierra 5	10:39:55 AM	-		0	0	10	Pass
Millennium	10:40:44 AM	-		0	0	10	Pass
Entering Convention District	10:42:05 AM	-		0	0	10	Pass
Convention District 1	10:42:28 AM	-		0	0	10	Pass
Convention District 2	10:43:17 AM	-		0	0	10	Pass
Convention District 3	10:44:01 AM	-		0	0	10	Pass
Convention District 4	10:44:21 AM	-		0	0	10	Pass
Exiting Convention District	10:44:43 AM	-		0	0	10	Pass
Sagrado Corazón	10:51:57 AM	-		0	10	0	Terminal Station

Figure A.3 Ride Check from OSJ – SC, February 25, 2009

Ride Check Data Gathering Sheet

Date: Thursday, February 26, 2009

Time: 11:09:39 AM

Weather Conditions: Sunny

Bus Route Number: Metrobus I Express

Bus Identification Number: 8333

To: Sagrado Corazón

From: Covadonga Terminal - Old San Juan

Comments: Arrivals and departures from stops are considered when doors open and close, respectively. "Pass" means the bus did not stop because there were no boarding or deboarding passengers.

Page (? Of ?): 1 of 1

<u>Bus Stop</u>	<u>Time Doors Open</u>	<u>Time Doors Close</u>	<u>Mileage</u>	<u>Boarding Passengers</u>	<u>Deboarding Passengers</u>	<u>Current Passenger Load</u>	<u>Comments</u>
Covadonga	-	11:09:39 AM		1	-	1	Terminal Station
Entering Puerta de Tierra	11:12:48 AM	-		0	0	1	Pass
Puerta de Tierra 1	11:13:10 AM	11:13:17 AM		1	0	2	
Puerta de Tierra 2	11:13:51 AM	-		0	0	2	Pass
Puerta de Tierra 3	11:14:29 AM	-		0	0	2	Pass - Red Light Passenger did not Board Bus.
Puerta de Tierra 4	11:14:59 AM	11:15:17 AM		0	0	2	Pass
Puerta de Tierra 5	11:16:03 AM	11:16:09 AM		1	0	3	
Millennium	11:17:02 AM	-		0	0	3	Pass
Entering Convention District	11:18:25 AM	-		0	0	3	Pass
Convention District 1	11:18:53 AM	-		0	0	3	Pass
Convention District 2	11:19:43 AM	-		0	0	3	Pass
Convention District 3	11:20:25 AM	-		0	0	3	Pass
Convention District 4	11:10:46 AM	-		0	0	3	Pass
Exiting Convention District	11:21:44 AM	-		0	0	3	Pass
Sagrado Corazón	11:30:14 AM	-		0	3	0	Terminal Station

Figure A.4 Ride Check from OSJ – SC, February 26, 2009

Ride Check Data Gathering Sheet

Date: Monday, March 02, 2009

Time: 12:37:12 PM

Weather Conditions: Sunny

Bus Route Number: Metrobus I Express

Bus Identification Number: 8331

To: Sagrado Corazón

From: Covadonga Terminal - Old San Juan

Comments: Arrivals and departures from stops are considered when doors open and close, respectively. "Pass" means the bus did not stop because there were no boarding or deboarding passengers.

Page (? Of ?): 1 of 1

<u>Bus Stop</u>	<u>Time Doors Open</u>	<u>Time Doors Close</u>	<u>Mileage</u>	<u>Boarding Passengers</u>	<u>Deboarding Passengers</u>	<u>Current Passenger Load</u>	<u>Comments</u>
Covadonga	-	12:37:12 PM		7	-	7	Terminal Station
Entering Puerta de Tierra	12:39:50 PM	-		0	0	7	Pass
Puerta de Tierra 1	12:40:32 PM	-		0	0	7	Pass
Puerta de Tierra 2	12:41:16 PM	-		0	0	7	Pass
Puerta de Tierra 3	12:41:45 PM	-		0	0	7	Pass
Puerta de Tierra 4	12:42:01 PM	12:42:08 PM		1	0	8	
Puerta de Tierra 5	12:42:38 PM	12:42:53 PM		0	0	8	Bus stopped but no passenger boarded.
Millennium	12:43:26 PM	-		0	0	8	Pass
Entering Convention District	12:44:29 PM	-		0	0	8	Pass
Convention District 1	12:44:52 PM	-		0	0	8	Pass
Convention District 2	12:45:33 PM	-		0	0	8	Pass
Convention District 3	12:46:05 PM	-		0	0	8	Pass
Convention District 4	12:46:23 PM	-		0	0	8	Pass
Exiting Convention District	12:46:44 PM	-		0	0	8	Pass
Sagrado Corazón	12:52:02 PM	-		0	8	0	Terminal Station

Figure A.5 Ride Check OSJ – SC, March 2, 2009

Ride Check Data Gathering Sheet

Date: _____ Tuesday, February 24, 2009 _____

Time: _____ 1:38:58 PM _____

Weather Conditions: _____ Cloudy _____

Bus Route Number: _____ Metrobus I Express _____

Bus Identification Number: _____ 99-123 _____

To: _____ Covadonga Terminal - Old San Juan _____

From: _____ Sagrado Corazón _____

Comments: Arrivals and departures from stops are considered when doors open and close, respectively. "Pass" means the bus did not stop because there were no boarding or deboarding passengers.

Page (? Of ?): _____ 1 of 1 _____

Bus Stop	Time Doors Open	Time Doors Close	Mileage	Boarding Passengers	Deboarding Passengers	Current Passenger Load	Comments
Sagrado Corazón	-	1:38:58 PM		14	-	14	Terminal Station
Hoare St.	1:43:02 PM	-		0	0	14	Pass
Fdez. Juncos 1	1:44:09 PM	-		0	0	14	Pass
Fdez. Juncos 2	1:44:47 PM	-		0	0	14	Pass
Convention District 1	1:46:36 PM	-		0	0	14	Pass
Convention District 2	1:47:31 PM	-		0	0	14	Pass
Convention District 3	1:48:06 PM	-		0	0	14	Pass
Convention District 4	1:48:24 PM	-		0	0	14	Pass
Exiting Convention District	1:49:22 PM	-		0	0	14	Pass
Underpass Muñoz Rivera Exp	1:49:36 PM	-		0	0	14	Pass
Millennium	1:50:27 PM	-		0	0	14	Pass
Entering Puerta de Tierra	1:50:52 PM	-		0	0	14	Pass
Puerta de Tierra 1	1:51:30 PM	-		0	0	14	Pass
Puerta de Tierra 2	1:51:48 PM	-		0	0	14	Pass
Puerta de Tierra 3	1:52:31 PM	-		0	0	14	Pass
Puerta de Tierra 4	1:53:08 PM	1:53:20 PM		2	0	16	
Puerta de Tierra 5	1:54:18 PM	1:54:23 PM		0	1	15	
Exiting Puerta de Tierra	1:54:42 PM	-		0	0	15	Pass
Capitol	1:55:19 PM	-		0	0	15	Pass
Hacienda	1:56:39 PM	1:56:45 PM		0	1	14	
Covadonga	1:57:27 PM	-		0	14	0	Terminal Station

Figure A.6 Ride Check No. 1 from SC - OSJ, February 24, 2009

Ride Check Data Gathering Sheet

Date: _____ Tuesday, February 24, 2009 _____

Time: _____ 2:28:01 PM _____

Weather Conditions: _____ Cloudy _____

Bus Route Number: _____ Metrobus I Express _____

Bus Identification Number: _____ 99-123 _____

To: _____ Covadonga Terminal - Old San Juan _____

From: _____ Sagrado Corazón _____

Comments: Arrivals and departures from stops are considered when doors open and close, respectively. "Pass" means the bus did not stop because there were no boarding or deboarding passengers.

Page (? Of ?): _____ 1 of 1 _____

Bus Stop	Time Doors Open	Time Doors Close	Mileage	Boarding Passengers	Deboarding Passengers	Current Passenger Load	Comments
Sagrado Corazón	-	2:28:01 PM		4	-	4	Terminal Station
Hoare St.	2:32:07 PM	-		0	0	4	Pass
Fdez. Juncos 1	2:33:41 PM	-		0	0	4	Pass
Fdez. Juncos 2	2:34:19 PM	2:34:27 PM		1	0	5	
Convention District 1	2:36:14 PM	-		0	0	5	Pass
Convention District 2	2:37:05 PM	-		0	0	5	Pass
Convention District 3	2:37:39 PM	-		0	0	5	Pass
Convention District 4	2:38:00 PM	2:38:05 PM		1	0	6	
Exiting Convention District	2:40:19 PM	-		0	0	6	Pass
Underpass Muñoz Rivera Exp	2:40:34 PM	-		0	0	6	Pass
Millennium	2:41:29 PM	-		0	0	6	Pass
Entering Puerta de Tierra	2:41:52 PM	-		0	0	6	Pass
Puerta de Tierra 1	2:42:29 PM	2:42:36 PM		1	0	7	
Puerta de Tierra 2	2:43:09 PM	2:43:15 PM		0	1	6	
Puerta de Tierra 3	2:43:40 PM	-		0	0	6	Pass
Puerta de Tierra 4	2:44:17 PM	-		0	0	6	Pass
Puerta de Tierra 5	2:44:54 PM	2:44:58 PM		0	1	5	
Exiting Puerta de Tierra	2:45:20 PM	-		0	0	5	Pass
Capitol	2:45:46 PM	-		0	0	5	Pass
Hacienda	2:46:59 PM	-		0	0	5	Pass
Covadonga	2:47:35 PM	-		0	5	0	Terminal Station

Figure A.7 Ride Check No. 2 from SC - OSJ, February 24, 2009

Ride Check Data Gathering Sheet

Date: Monday, March 02, 2009

Time: 1:36:56 PM

Weather Conditions: Sunny

Bus Route Number: Metrobus I Express

Bus Identification Number: 99-116

To: Covadonga Terminal - Old San Juan

From: Sagrado Corazón

Comments: Arrivals and departures from stops are considered when doors open and close, respectively. "Pass" means the bus did not stop because there were no boarding or deboarding passengers.

Page (? Of ?): 1 of 1

<u>Bus Stop</u>	<u>Time Doors Open</u>	<u>Time Doors Close</u>	<u>Mileage</u>	<u>Boarding Passengers</u>	<u>Deboarding Passengers</u>	<u>Current Passenger Load</u>	<u>Comments</u>
Sagrado Corazón	-	1:36:56 PM		2	-	2	Terminal Station
Hoare St.	1:41:23 PM	-		0	0	2	Pass
Fdez. Juncos 1	1:42:22 PM	-		0	0	2	Pass
Fdez. Juncos 2	1:43:11 PM	-		0	0	2	Pass
Convention District 1	1:44:27 PM	-		0	0	2	Pass
Convention District 2	1:45:20 PM	-		0	0	2	Pass
Convention District 3	1:46:06 PM	-		0	0	2	Pass
Convention District 4	1:46:29 PM	-		0	0	2	Pass
Exiting Convention District	1:47:29 PM	-		0	0	2	Pass
Underpass Muñoz Rivera Exp	1:47:46 PM	-		0	0	2	Pass
Millennium	1:48:53 PM	1:49:01 PM		1	0	3	
Entering Puerta de Tierra	1:49:35 PM	-		0	0	3	Pass
Puerta de Tierra 1	1:50:41 PM	-		0	0	3	Pass
Puerta de Tierra 2	1:51:02 PM	-		0	0	3	Pass
Puerta de Tierra 3	1:51:53 PM	-		0	0	3	Pass
Puerta de Tierra 4	1:52:32 PM	-		0	0	3	Pass
Puerta de Tierra 5	1:53:13 PM	-		0	0	3	Pass
Exiting Puerta de Tierra	1:53:30 PM	-		0	0	3	Pass
Capitol	1:53:59 PM	-		0	0	3	Pass
Hacienda	1:55:39 PM	-		0	0	3	Pass
Covadonga	1:56:19 PM	-		0	3	0	Terminal Station

Figure A.8 Ride Check from SC - OSJ, March 2, 2009

APPENDIX B DATA COLLECTED DURING COMPUTER-AIDED RIDE CHECKS

Events Recorded	Time	Description	Latitude	Longitude	Elevation	Speed	Distance	Boarding	Deboarding	Current Load	Bus Stop
Event	0	11:89200955 Ride Check 2-20-09	18.412805	-66.0976183	0	0	0				
	1	12:25625868 Bus departs from Terminal.	18.412805	-66.0976183	0	0	0				19 Covadonga bus no. 8312 m1 express
	5	12:31354167 Bus begins slowdown as it reaches bus stop.	18.412805	-66.0976183	0	0	0				
	1	12:31446181 Bus departs from Terminal.	18.412805	-66.0976183	0	0	0				19 p1pt
	7	12:31776042 Doors open at bus stop.	18.412805	-66.0976183	0	0	0	0	1		
	8	12:32051215 Doors close at bus stop.	18.412805	-66.0976183	0	0	0				
	3	12:32077691 Bus accelerates from stop.	18.412805	-66.0976183	0	0	0			18	
	4	12:32372396 Bus reaches cruising speed.	18.412805	-66.0976183	0	0	0				
	5	12:3275434 Bus begins slowdown as it reaches bus stop.	18.412805	-66.0976183	0	0	0				
	6	12:32819878 Bus reaches bus stop.	18.412805	-66.0976183	0	0	0				p2pt
	7	12:32983073 Doors open at bus stop.	18.412805	-66.0976183	0	0	0	1	2		
	8	12:33243056 Doors close at bus stop.	18.412805	-66.0976183	0	0	0				
	3	12:3330729 Bus accelerates from stop.	18.412805	-66.0976183	0	0	0				16
	4	12:33786458 Bus reaches cruising speed.	18.412805	-66.0976183	0	0	0				
	5	12:34191406 Bus begins slowdown as it reaches bus stop.	18.412805	-66.0976183	0	0	0				
	6	12:34265191 Bus reaches bus stop.	18.412805	-66.0976183	0	0	0				p2pt
	7	12:34422309 Doors open at bus stop.	18.412805	-66.0976183	0	0	0	2	0		
	8	12:34963542 Doors close at bus stop.	18.412805	-66.0976183	0	0	0				
	3	12:35133681 Bus accelerates from stop.	18.412805	-66.0976183	0	0	0			18	
	4	12:3538151 Bus reaches cruising speed.	18.412805	-66.0976183	0	0	0				
	5	12:36277344 Bus begins slowdown as it reaches bus stop.	18.412805	-66.0976183	0	0	0				
	6	12:36350694 Bus reaches bus stop.	18.412805	-66.0976183	0	0	0				n3pty
	7	12:36550781 Doors open at bus stop.	18.412805	-66.0976183	0	0	0	2	0		
	8	12:36768663 Doors close at bus stop.	18.412805	-66.0976183	0	0	0				
	3	12:3678342 Bus accelerates from stop.	18.412805	-66.0976183	0	0	0			20	
	4	12:36971354 Bus reaches cruising speed.	18.412805	-66.0976183	0	0	0				
	5	12:37252038 Bus begins slowdown as it reaches bus stop.	18.412805	-66.0976183	0	0	0				
	6	12:37348958 Bus reaches bus stop.	18.412805	-66.0976183	0	0	0				p4pt
	7	12:37483073 Doors open at bus stop.	18.412805	-66.0976183	0	0	0	1	0		
	8	12:37983941 Doors close at bus stop.	18.412805	-66.0976183	0	0	0				
	3	12:38076389 Bus accelerates from stop.	18.412805	-66.0976183	0	0	0			22	
	4	12:38313368 Bus reaches cruising speed.	18.412805	-66.0976183	0	0	0				
	0	12:38361545 2 passengers boarded in previous stop	18.412805	-66.0976183	0	0	0				
	9	12:3903776 Bus passes bus stop without stopping.	18.412805	-66.0976183	0	0	0				p5pt
	9	12:40718316 Bus passes bus stop without stopping.	18.412805	-66.0976183	0	0	0				millennium
	5	12:43494792 Bus begins slowdown as it reaches bus stop.	18.412805	-66.0976183	0	0	0				
	6	12:43544271 Bus reaches bus stop.	18.412805	-66.0976183	0	0	0				ent cc
	7	12:43674479 Doors open at bus stop.	18.412805	-66.0976183	0	0	0	1	0		
	8	12:43822483 Doors close at bus stop.	18.412805	-66.0976183	0	0	0				
	3	12:43884549 Bus accelerates from stop.	18.412805	-66.0976183	0	0	0			23	
	4	12:44052517 Bus reaches cruising speed.	18.412805	-66.0976183	0	0	0				
	9	12:45022569 Bus passes bus stop without stopping.	18.412805	-66.0976183	0	0	0				p1cc
	9	12:46666667 Bus passes bus stop without stopping.	18.412805	-66.0976183	0	0	0				p2cc
	5	12:48050781 Bus begins slowdown as it reaches bus stop.	18.412805	-66.0976183	0	0	0				
	6	12:4818353 Bus reaches bus stop.	18.412805	-66.0976183	0	0	0				p3cc
	7	12:4834635 Doors open at bus stop.	18.412805	-66.0976183	0	0	0	1	0		
	8	12:48512153 Doors close at bus stop.	18.412805	-66.0976183	0	0	0				
	3	12:48547309 Bus accelerates from stop.	18.412805	-66.0976183	0	0	0			24	
	4	12:48717014 Bus reaches cruising speed.	18.412805	-66.0976183	0	0	0				
	9	12:49340712 Bus passes bus stop without stopping.	18.412805	-66.0976183	0	0	0				p4cc
	9	12:50665365 Bus passes bus stop without stopping.	18.412805	-66.0976183	0	0	0				salida cc
	0	12:58327691 Minnoz Rivera Expressway	18.4417117	-66.0742667	12.9	33.832903	0.8836				
	0	12:58700087 GPS began collecting coordinates after entering the Expressway portion of the route.	18.4408183	-66.0726017	9.7	34.983682	1.0277				
	2	12:66185764 Bus arrives at Terminal.	18.436015	-66.0598023	-4	7.1348298	2.1593		4		Sagrado Corazon
	1	12:71401042 Bus departs from Terminal.	18.435805	-66.06011	-1	5.1785055	2.3252			35	Sagrado corazon

Figure B.1 Ride Check from OSJ – SC – OSJ, February 5, 2009

Events Recorded	Event	Time	Description	Latitude	Longitude	Elevation	Speed	Distance	Boarding	Deboarding	Current Load	Bus Stop
	1	15.65454861	Bus departs from Terminal.	18.4656183	-66.11116	0	0	0				18 Covadonga Bus No. 8322
	5	15.68794705	Bus begins slowdown as it reaches bus stop.	18.4656183	-66.11116	0	0	0				
	6	15.6900434	Bus reaches bus stop.	18.4656183	-66.11116	0	0	0				ent pt
	7	15.69132378	Doors open at bus stop.	18.4656183	-66.11116	0	0	0	1	0		
	8	15.69290799	Doors close at bus stop.	18.4656183	-66.11116	0	0	0				
	3	15.69325087	Bus accelerates from stop.	18.4656183	-66.11116	0	0	0				19
	4	15.69735243	Bus reaches cruising speed.	18.4656183	-66.11116	0	0	0				
	5	15.69825087	Bus begins slowdown as it reaches bus stop.	18.4656183	-66.11116	0	0	0				
	6	15.69903646	Bus reaches bus stop.	18.4656183	-66.11116	0	0	0				pt1
	7	15.70046875	Doors open at bus stop.	18.4656183	-66.11116	0	0	0	0	1		
	8	15.70217882	Doors close at bus stop.	18.4656183	-66.11116	0	0	0				
	3	15.70275174	Bus accelerates from stop.	18.4656183	-66.11116	0	0	0				18
	4	15.70531684	Bus reaches cruising speed.	18.4656183	-66.11116	0	0	0				
	9	15.70951823	Bus passes bus stop without stopping.	18.4656183	-66.11116	0	0	0				pt2
	5	15.71401476	Bus begins slowdown as it reaches bus stop.	18.4656183	-66.11116	0	0	0				
	6	15.71490885	Bus reaches bus stop.	18.4656183	-66.11116	0	0	0				pt3
	7	15.71618924	Doors open at bus stop.	18.4656183	-66.11116	0	0	0	1	0		
	8	15.71946615	Doors close at bus stop.	18.4656183	-66.11116	0	0	0				
	3	15.72071615	Bus accelerates from stop.	18.4656183	-66.11116	0	0	0				19
	4	15.72419705	Bus reaches cruising speed.	18.4656183	-66.11116	0	0	0				
	5	15.72565972	Bus begins slowdown as it reaches bus stop.	18.4656183	-66.11116	0	0	0				
	6	15.72628038	Bus reaches bus stop.	18.4656183	-66.11116	0	0	0				pt4
	7	15.72732205	Doors open at bus stop.	18.4656183	-66.11116	0	0	0	4	0		
	8	15.73208333	Doors close at bus stop.	18.4656183	-66.11116	0	0	0				
	3	15.73284288	Bus accelerates from stop.	18.4656183	-66.11116	0	0	0				23
	4	15.73763889	Bus reaches cruising speed.	18.4656183	-66.11116	0	0	0				
	9	15.74055599	Bus passes bus stop without stopping.	18.4656183	-66.11116	0	0	0				pt5
	5	15.75269097	Bus begins slowdown as it reaches bus stop.	18.4656183	-66.11116	0	0	0				
	6	15.75364149	Bus reaches bus stop.	18.4656183	-66.11116	0	0	0				mil;
	7	15.75490885	Doors open at bus stop.	18.4656183	-66.11116	0	0	0	2	0		
	8	15.75722222	Doors close at bus stop.	18.4656183	-66.11116	0	0	0				
	3	15.75764757	Bus accelerates from stop.	18.4656183	-66.11116	0	0	0				25
	6	15.77568142	Bus reaches bus stop.	18.4656183	-66.11116	0	0	0				error
	9	15.78042535	Bus passes bus stop without stopping.	18.4656183	-66.11116	0	0	0				ent ce
	5	15.78651042	Bus begins slowdown as it reaches bus stop.	18.4656183	-66.11116	0	0	0				
	6	15.78710069	Bus reaches bus stop.	18.4656183	-66.11116	0	0	0				p1cc
	7	15.7886849	Doors open at bus stop.	18.4656183	-66.11116	0	0	0	0	3		
	8	15.79116319	Doors close at bus stop.	18.4656183	-66.11116	0	0	0				
	3	15.79164063	Bus accelerates from stop.	18.4656183	-66.11116	0	0	0				22
	4	15.79716146	Bus reaches cruising speed.	18.4656183	-66.11116	0	0	0				
	9	15.80463542	Bus passes bus stop without stopping.	18.4656183	-66.11116	0	0	0				p2cc
	9	15.81362847	Bus passes bus stop without stopping.	18.4656183	-66.11116	0	0	0				p3cc
	6	15.81861545	Bus reaches bus stop.	18.4656183	-66.11116	0	0	0				p4cc
	7	15.81979601	Doors open at bus stop.	18.4656183	-66.11116	0	0	0	1	0		
	8	15.82105035	Doors close at bus stop.	18.4656183	-66.11116	0	0	0				
	3	15.82142795	Bus accelerates from stop.	18.4656183	-66.11116	0	0	0				23
	4	15.82400174	Bus reaches cruising speed.	18.4656183	-66.11116	0	0	0				
	9	15.82866753	Bus passes bus stop without stopping.	18.4656183	-66.11116	0	0	0				salida cc
	2	15.93311632	Bus arrives at Terminal.	18.4656183	-66.11116	0	0	0		22		sagrado corazon
	1	15.96422743	Bus departs from Terminal.	18.4656183	-66.11116	0	0	0				sagrado corazon
	6	16.03359809	Bus reaches bus stop.	18.4508883	-66.0816233	6.499999998	8.2856088	1.6883				pescuera
	7	16.03522569	Doors open at bus stop.	18.4510783	-66.081555	6.499999998	8.2856088	1.7001	0	1		
	8	16.03632378	Doors close at bus stop.	18.4512033	-66.0815	7.399999997	8.1705309	1.7119				
	3	16.0368316	Bus accelerates from stop.	18.451265	-66.0814767	7.499999997	8.1705309	1.7119				2
	4	16.03797939	Bus reaches cruising speed.	18.45138	-66.0814233	7.699999997	8.4006867	1.7237				
	9	16.06536892	Bus passes bus stop without stopping.	18.452445	-66.082993	14.499999999	26.122683	1.825				p1fc
	9	16.07544705	Bus passes bus stop without stopping.	18.45374	-66.0866983	16.099999999	24.971904	2.1164				p2ff
	9	16.08998698	Bus passes bus stop without stopping.	18.4568833	-66.0893833	-8.9	24.396513	2.4867				p1cc
	9	16.10375868	Bus passes bus stop without stopping.	18.4565183	-66.0938733	-4.7	9.3213099	2.8229				p2cc
	9	16.11281684	Bus passes bus stop without stopping.	18.4534083	-66.0910517	-6.5	29.690098	3.0814				p3cc
	9	16.11776042	Bus passes bus stop without stopping.	18.4527333	-66.0896883	-11	24.281437	3.2162				p4cc
	9	16.1346441	Bus passes bus stop without stopping.	18.4565033	-66.0882983	4.499999998	31.416267	3.5163				salida cc
	9	16.13810764	Bus passes bus stop without stopping.	18.457535	-66.086875	8.499999997	27.503618	3.6102				underpass mr
	9	16.15226997	Bus passes bus stop without stopping.	18.4616917	-66.0878267	-1.4	22.670346	4.0004				mill
	9	16.159375	Bus passes bus stop without stopping.	18.4623333	-66.0901617	-1.4	24.856826	4.1831				ent pt
	5	16.16719618	Bus begins slowdown as it reaches bus stop.	18.463655	-66.0934117	-2.9	30.725799	4.3894				
	6	16.16830295	Bus reaches bus stop.	18.4638283	-66.0938067	-3.7	17.491841	4.431				p1pt
	7	16.16978299	Doors open at bus stop.	18.4638817	-66.0939633	-4.1	0	4.4596	1	0		
	8	16.17095486	Doors close at bus stop.	18.4638783	-66.0939617	-4.2	0	4.4596				
	3	16.1722309	Bus accelerates from stop.	18.4638767	-66.09396	-4.2	2.7618696	4.4596				3
	4	16.17516927	Bus reaches cruising speed.	18.4638917	-66.09447	-4.2	15.650594	4.4801				
	9	16.17763889	Bus passes bus stop without stopping.	18.4639367	-66.095295	-4.2	18.64262	4.5323				p2pt
	5	16.18123264	Bus begins slowdown as it reaches bus stop.	18.4638967	-66.09632	-4.2	18.64262	4.5888				
	6	16.18304253	Bus reaches bus stop.	18.4638783	-66.0967933	-4.2	18.64262	4.641				p3pt
	7	16.18453993	Doors open at bus stop.	18.4638783	-66.0972017	-5.4	0	4.6671	1	1		
	8	16.18817274	Doors close at bus stop.	18.46388	-66.097185	-8.7	0	4.6727				
	3	16.19040799	Bus accelerates from stop.	18.4638933	-66.0971883	-8.9	0	4.6727				3
	4	16.19612413	Bus reaches cruising speed.	18.463905	-66.0972067	-8.9	0	4.6727				
	9	16.20191406	Bus passes bus stop without stopping.	18.4633817	-66.0999467	-10	26.352839	4.7591				p4pt
	5	16.2047309	Bus begins slowdown as it reaches bus stop.	18.46407	-66.1012483	-10.8	25.086982	4.9275				
	6	16.20628038	Bus reaches bus stop.	18.4641783	-66.1017417	-10.8	15.650594	4.9654				p5pt
	7	16.20730035	Doors open at bus stop.	18.464195	-66.102005	-10.8	15.650594	4.9915	1	0		
	8	16.20907552	Doors close at bus stop.	18.4642683	-66.101955	-10.3	1.150779	5.0083				
	3	16.2103559	Bus accelerates from stop.	18.4642883	-66.1019683	-10.7	1.150779	5.0138				4
	4	16.21356337	Bus reaches cruising speed.	18.46429	-66.1022433	-11.1	20.944178	5.0306				
	9	16.21586806	Bus passes bus stop without stopping.	18.464495	-66.1030233	-11.1	15.535517	5.0598				salida pt
	9	16.22519097	Bus passes bus stop without stopping.	18.465195	-66.1054833	-12.7	27.848852	5.2338				capitolio
	9	16.2465408	Bus passes bus stop without stopping.	18.4640367	-66.1094933	-11.1	28.079008	5.7881				hacienda
	2	16.2587934	Bus arrives at Terminal.	18.46485	-66.1108	-12.3	8.5157646	6.0783		4		covadonga

Figure B.2 Ride Check from OSJ – SC, February 20, 2009

Events Recorded	Time	Description	Latitude	Longitude	Elevation	Speed	Distance	Boarding	Deboarding	Current Load	Bus Stop
0	10.85309462	recreacion y deportes	18.4542933	-66.0889983	0	0	0				
2	10.89823785	Bus arrives at Terminal.	18.4366283	-66.0602417	32.49999999	15.075205	2.3407		10		sc
1	10.92186632	Bus departs from Terminal.	18.436285	-66.0602467	4.199999998	0	2.3792			1	sc
0	10.92402778	sc-osj 2-25-09 bus id no. 99-106	18.436285	-66.0602467	4.199999998	0	2.3792				
0	10.94735243	munoz rivera xpressway	18.4403783	-66.0692133	3.299999999	39.701876	3.0621				
9	10.9968099	Bus passes bus stop without stopping.	18.450895	-66.0812517	11.3	14.729971	4.4366				p1 escuela
9	11.01463108	Bus passes bus stop without stopping.	18.4521417	-66.0828733	16.79999999	26.122683	4.61				p1 fdez juncos
9	11.02414497	Bus passes bus stop without stopping.	18.453645	-66.08648	17.19999999	26.928229	4.8765				p2 fdez juncos
9	11.0556033	Bus passes bus stop without stopping.	18.4568667	-66.0894083	-0.3	22.785424	5.1978				cc1
9	11.06855903	Bus passes bus stop without stopping.	18.4561667	-66.0938433	-6.7	18.182308	5.5221				cc2
9	11.07798611	Bus passes bus stop without stopping.	18.4533767	-66.091255	-5	26.122683	5.7862				cc3
9	11.08291233	Bus passes bus stop without stopping.	18.4527233	-66.0895917	-2.3	26.928229	5.8937				cc4
9	11.09567708	Bus passes bus stop without stopping.	18.45655	-66.0882617	1.3	32.682124	6.228				salida cc
9	11.09934028	Bus passes bus stop without stopping.	18.4575517	-66.086875	-0.1	23.245736	6.3249				underpass MR
9	11.12220052	Bus passes bus stop without stopping.	18.4615733	-66.0878317	-5.1	20.368788	6.6841				millennium
9	11.12945313	Bus passes bus stop without stopping.	18.4624783	-66.08998	-3.6	18.182308	6.8345				ent pt
9	11.14345052	Bus passes bus stop without stopping.	18.46365	-66.093455	1.899999999	24.281437	7.0656				pt1 archivo
9	11.14845486	Bus passes bus stop without stopping.	18.4637467	-66.0959717	0.2	20.023555	7.2477				pt2
9	11.15390625	Bus passes bus stop without stopping.	18.4639083	-66.0975367	0.8	11.968102	7.3328				pt3
9	11.16354601	Bus passes bus stop without stopping.	18.4640833	-66.1003683	-0.1	25.892528	7.5086				pt4
9	11.17016493	Bus passes bus stop without stopping.	18.4642183	-66.1017633	-1.3	16.801373	7.6143				pt5
5	11.17280382	Bus begins slowdown as it reaches bus stop.	18.4642983	-66.1026017	-1	26.007605	7.664				
6	11.17443142	Bus reaches bus stop.	18.464465	-66.10308	0.3	10.702245	7.6988				salida pt
7	11.17611111	Doors open at bus stop.	18.4644783	-66.1031167	1.599999999	0	7.7137	1	0		
8	11.17735677	Doors close at bus stop.	18.4645083	-66.1031983	2.199999999	9.4363878	7.7137				
3	11.17762587	Bus accelerates from stop.	18.4645167	-66.103235	2.199999999	11.392712	7.7218				2
4	11.17936632	Bus reaches cruising speed.	18.4646117	-66.1036683	1.3	26.698073	7.7435				
9	11.18431424	Bus passes bus stop without stopping.	18.4659083	-66.1050483	46.199999998	34.638448	7.8753				capitol
9	11.20507378	Bus passes bus stop without stopping.	18.4640117	-66.10941	21.99999999	20.483866	8.3015				hacienda
2	11.2156901	Bus arrives at Terminal.	18.4647183	-66.1109917	16.39999999	11.853024	8.4482		2		covadonga

Figure B.3 Ride Check from SC – OSJ, February 25, 2009

Events Recorded	Time	Description	Latitude	Longitude	Elevation	Speed	Distance	Boarding	Deboarding	Current Load	Bus Stop
9	12.18329861	Bus passes bus stop without stopping.	18.4508833	-66.081375	-6.1	12.198257	0.0199				p1 escuela
0	12.18476563	m1 express sc-osj bus id no. 8331	18.4511533	-66.0812617	-6.4	9.6665436	0.0373				
9	12.21413628	Bus passes bus stop without stopping.	18.45217	-66.0829517	-4.2	24.626671	0.179				p1 fdez juncos
0	12.21644965	14 pax from terminal	18.452385	-66.0838783	-4.2	24.741749	0.2485				
9	12.22359809	Bus passes bus stop without stopping.	18.4530217	-66.0864133	-4.2	24.856826	0.4207				p2 fdez juncos
9	12.25141927	Bus passes bus stop without stopping.	18.4569067	-66.0894367	-3.7	25.432216	0.8239				cc1
9	12.2643316	Bus passes bus stop without stopping.	18.4561883	-66.093935	-8.7	16.801373	1.1601				cc2
5	12.27355903	Bus begins slowdown as it reaches bus stop.	18.453565	-66.0914	-8.5	26.352839	1.4136				
6	12.275	Bus reaches bus stop.	18.453285	-66.09104	-9	9.6665436	1.4497				cc3
7	12.27607205	Doors open at bus stop.	18.4532683	-66.091015	-8.7	0	1.4497	0	0		
8	12.2771875	Doors close at bus stop.	18.45326	-66.0909667	-9	4.2578823	1.4497				
3	12.27757813	Bus accelerates from stop.	18.4532233	-66.090945	-7.9	8.1705309	1.4528			14	
4	12.28039497	Bus reaches cruising speed.	18.4527733	-66.0903883	-8.7	23.01558	1.4975				
9	12.28317708	Bus passes bus stop without stopping.	18.4526567	-66.0895833	-8.4	23.821125	1.5553				cc4
0	12.28426649	bus stopped at cc3 but pax did not board	18.4528333	-66.089225	-8.4	21.979879	1.5553				
9	12.29655816	Bus passes bus stop without stopping.	18.4565517	-66.08817	-9	31.186111	1.8417				salida cc
9	12.30010417	Bus passes bus stop without stopping.	18.4575967	-66.0869417	-8.5	24.511593	1.9722				underpass mr
9	12.32046007	Bus passes bus stop without stopping.	18.4616217	-66.0876567	-4.7	22.210035	2.2929				millennium
9	12.32672743	Bus passes bus stop without stopping.	18.4622583	-66.09013	-5	24.281437	2.4743				ent pt
9	12.33542969	Bus passes bus stop without stopping.	18.4635983	-66.093655	0.9	27.733774	2.7104				pt1 archivo
9	12.34102431	Bus passes bus stop without stopping.	18.463905	-66.0958267	0.1	20.8291	2.8658				pt2
0	12.34215712	red light	18.4639133	-66.0959083	0.3	1.150779	2.8943				
5	12.34992622	Bus begins slowdown as it reaches bus stop.	18.4639683	-66.096917	2.799999999	10.587167	2.9621				
6	12.35166667	Bus reaches bus stop.	18.4639783	-66.0972033	2.099999999	7.7102193	2.9764				pt3
7	12.35246094	Doors open at bus stop.	18.46398	-66.097245	1.899999999	1.0357011	2.9838	2	0		
8	12.35534288	Doors close at bus stop.	18.46397	-66.0972383	2.899999999	0	2.9838				
3	12.35638455	Bus accelerates from stop.	18.4639683	-66.0972383	3.599999999	0	2.9838			16	
4	12.35962674	Bus reaches cruising speed.	18.4639633	-66.0975617	5.199999998	21.634645	3				
9	12.36652778	Bus passes bus stop without stopping.	18.4641083	-66.100195	4.399999998	29.344865	3.1702				pt4
5	12.36827257	Bus begins slowdown as it reaches bus stop.	18.46415	-66.1009317	3.599999999	25.20206	3.2119				
0	12.37471788	bus stopped because of red light	18.4642067	-66.1013017	-1.6	0	3.2454				
6	12.37803385	Bus reaches bus stop.	18.4642483	-66.1016583	1.599999999	13.579192	3.261				pt4
7	12.37983941	Doors open at bus stop.	18.4642667	-66.10194	1.999999999	0	3.2802	0	2		
8	12.38144531	Doors close at bus stop.	18.4642683	-66.1019383	3.699999999	0	3.2802				
3	12.38203559	Bus accelerates from stop.	18.4642683	-66.1019367	4.499999998	0	3.2802			14	
5	12.38631944	Bus begins slowdown as it reaches bus stop.	18.4643767	-66.1028333	3.999999998	22.900502	3.3268				
6	12.38749566	Bus reaches bus stop.	18.4645	-66.10317	3.599999999	16.916451	3.3579				salida pt
7	12.38859375	Doors open at bus stop.	18.46453	-66.1032367	3.999999998	0	3.3579	0	2		
8	12.39036024	Doors close at bus stop.	18.46453	-66.1032267	3.999999998	0	3.3579				
3	12.39082031	Bus accelerates from stop.	18.46453	-66.103225	4.299999998	0	3.3579			12	
0	12.39391927	bus stopped to board one additional passenger	18.464535	-66.1032133	4.799999998	0	3.3591				
0	12.39726997	current load 13	18.4645383	-66.1032833	4.999999998	0	3.361				
3	12.40060676	Bus accelerates from stop.	18.4645983	-66.10351	5.399999998	15.305361	3.3691				13
4	12.40101563	Bus reaches cruising speed.	18.4646533	-66.1037083	4.699999998	18.64262	3.3691				
9	12.40597222	Bus passes bus stop without stopping.	18.4651383	-66.105565	5.799999998	27.733774	3.494				capitol
9	12.42706597	Bus passes bus stop without stopping.	18.4639483	-66.109605	4.699999998	15.305361	3.8662				hacienda
7	12.42960503	Doors open at bus stop.	18.4639667	-66.1097483	6.399999998	0	3.8904	0	1		
8	12.43089844	Doors close at bus stop.	18.4639683	-66.1097617	6.799999997	2.7618696	3.8904				
3	12.43114149	Bus accelerates from stop.	18.4639717	-66.10979	6.799999997	6.5594403	3.8904				12
0	12.43226997	passenger called to stop after passing stop	18.4639783	-66.1099567	7.199999997	13.118881	3.8954				
2	12.44339844	Bus arrives at Terminal.	18.46476	-66.1108233	4.499999998	19.333087	3.9824		12		covadonga

Figure B.4 Ride Check from SC – OSJ, February 26, 2009

Events Recorded	Time	Hour	Minute	Seconds	Description	Latitude	Longitude	Elevation	Speed	Distance	Boarding	Deboarding	Current Load	Bus Stop
1	12 92710069	12	55	42	Bus departs from Terminal	18.4365883	-66.06089	-5.5	0	0.0721				7 SC-OSJ Bus id no. 8333
0	12 94391493	12	56	23	M1 Express - Sunny Day	18.440535	-66.0658467	-5.5	40.3923429	0.4623				
9	12 98493056	12	59	29	Bus passes bus stop without stopping	18.449695	-66.081745	-0.2	5.6388171	2.0673				P1-Escuela
9	13 0115885	13	0	6	Bus passes bus stop without stopping	18.4517867	-66.081195	16.99999999	3.1071033	2.0984				P1 Fdez Juncos
9	13 01902778	13	11	54	Bus passes bus stop without stopping	18.4519083	-66.0812583	16.99999999	0	2.1077				P2 Fdez Juncos
9	13 02388628	13	11	17	Bus passes bus stop without stopping	18.45641	-66.0892633	19.79999999	21.0592557	2.7073				CC1
5	13 0440625	13	2	24	Bus begins slowdown as it reaches bus stop	18.4563067	-66.0940533	15.99999999	12.8887248	3.0578				
6	13 04480469	13	2	28	Bus reaches bus stop	18.4561467	-66.0939917	15.79999999	14.3847375	3.0714				cc2
7	13 04581163	13	2	34	Doors open at bus stop	18.456025	-66.0939033	15.79999999	0	3.0913	0	0		
8	13 0472526	13	2	43	Doors close at bus stop	18.4560267	-66.0938667	15.59999999	1.150779	3.0913				
3	13 04747396	13	2	44	Bus accelerates from stop	18.45603	-66.0938633	15.59999999	1.150779	3.0913				7
4	13 05067708	13	3	4	Bus reaches cruising speed	18.45558	-66.0935817	15.79999999	23.3608137	3.1131				
9	13 05846788	13	3	50	Bus passes bus stop without stopping	18.4533033	-66.0911583	13.29999999	25.3421359	3.3399				cc3
9	13 06362413	13	3	21	Bus passes bus stop without stopping	18.452445	-66.0894883	15.49999999	24.3965148	3.4797				cc4
9	13 07786458	13	4	47	Bus passes bus stop without stopping	18.4563767	-66.088055	13.49999999	25.7774496	3.7891				salida cc
9	13 08213976	13	4	12	Bus passes bus stop without stopping	18.4572617	-66.086885	18.49999999	19.7933988	3.8916				underpass mr
9	13 10156684	13	6	9	Bus passes bus stop without stopping	18.4614467	-66.08759	10.7	18.6426198	4.2371				millenium
9	13 1087934	13	6	52	Bus passes bus stop without stopping	18.4626017	-66.0892517	10.7	17.9521524	4.367				ent pt
9	13 11953559	13	7	57	Bus passes bus stop without stopping	18.4641583	-66.0920033	10.3	19.7933988	4.5758				pt1 archivo
9	13 12437066	13	7	26	Bus passes bus stop without stopping	18.46397	-66.09562	10.3	25.7774496	4.7951				pt2
9	13 12963542	13	7	57	Bus passes bus stop without stopping	18.464003	-66.0972255	10.3	17.8370745	4.9213				pt3
9	13 14024306	13	8	1	Bus passes bus stop without stopping	18.4641633	-66.1001283	4.99999998	31.5313446	5.1172				pt4
9	13 14359575	13	8	21	Bus passes bus stop without stopping	18.4642667	-66.1016533	1.99999999	26.467917	5.2058				pt5
5	13 14595052	13	8	35	Bus begins slowdown as it reaches bus stop	18.46436	-66.1026317	0.7	25.317138	5.2717				
6	13 14753906	13	8	45	Bus reaches bus stop	18.4644633	-66.1032617	0.8	24.9719043	5.3133				salida pt
7	13 14875	13	8	52	Doors open at bus stop	18.4645183	-66.103525	0.6	8.2856088	5.3425	0	1		
8	13 14985243	13	8	59	Doors close at bus stop	18.4645433	-66.10357	0.5	0	5.3425				
3	13 15113713	13	9	6	Bus accelerates from stop	18.4645433	-66.1035633	0.4	0	5.3425				6
4	13 1534592	13	9	20	Bus reaches cruising speed	18.464543	-66.1035567	0.4	0	5.3425				
0	13 15377604	13	9	23	Bus had to stop at red light after departing from stop	18.464543	-66.1035567	0.4	0	5.3425				
3	13 16292969	13	9	17	Bus accelerates from stop	18.464645	-66.103495	-0.1	0	5.3425				6
4	13 16729601	13	10	43	Bus reaches cruising speed	18.4646633	-66.1034833	1.2	0	5.3425				
9	13 17013455	13	10	0	Bus passes bus stop without stopping	18.4653133	-66.1056467	1.2	26.467917	5.3686				capitol
9	13 1896545	13	11	59	Bus passes bus stop without stopping	18.4640417	-66.1096117	0.6	19.6783209	5.8135				hacienda
2	13 20067274	13	12	4	Bus arrives at Terminal	18.46439	-66.11124	-0.1	3.5674149	5.9683	6			covadonga
1	13 31388455	13	18	23	Bus departs from Terminal	18.4646133	-66.1106433	-0.1	0	5.99				7 covadonga
0	13 31959635	13	19	57	M1 Express OSJ-SC B us id no. 99-116	18.4646133	-66.1106433	-0.1	0	5.99				
9	13 35311632	13	21	18	Bus passes bus stop without stopping	18.4646483	-66.1036033	-1.8	19.1029314	6.5323				ent pt
5	13 36097656	13	21	5	Bus begins slowdown as it reaches bus stop	18.4643283	-66.1025083	-1.3	23.2457358	6.6052				
6	13 3624349	13	21	14	Bus reaches bus stop	18.4642567	-66.10205	0.8	20.0235546	6.6356				pt1
7	13 36359809	13	21	21	Doors open at bus stop	18.4642117	-66.1017633	-0.5	1.8146701	6.6549	0	3		
8	13 36598958	13	21	35	Doors close at bus stop	18.4642183	-66.101777	3.09999999	0	6.6549				
3	13 36641927	13	21	38	Bus accelerates from stop	18.46422	-66.1017717	3.89999999	0	6.6549				
4	13 36917101	13	22	55	Bus reaches cruising speed	18.4642083	-66.101285	5.79999998	20.9441778	6.6866				4
9	13 37338108	13	22	20	Bus passes bus stop without stopping	18.4640933	-66.0996417	1.99999997	29.4599424	6.7953				pt2
5	13 38057292	13	22	3	Bus begins slowdown as it reaches bus stop	18.4639683	-66.0974833	3.99999998	20.8290999	6.932				
6	13 38133247	13	22	7	Bus reaches bus stop	18.4639667	-66.09731	3.69999999	20.1386325	6.932				pt3
7	13 38234375	13	22	14	Doors open at bus stop	18.4639467	-66.0970883	3.59999999	5.2935834	6.9544	1	0		
8	13 38394097	13	23	25	Doors close at bus stop	18.463945	-66.0970883	4.09999998	0	6.9544				
3	13 38471354	13	23	28	Bus accelerates from stop	18.4639433	-66.09709	4.39999998	1.0357011	6.9544				5
4	13 38721354	13	23	43	Bus reaches cruising speed	18.4639083	-66.096805	5.59999998	18.412464	6.9736				
5	13 38887587	13	23	53	Bus begins slowdown as it reaches bus stop	18.463885	-66.096315	5.89999998	20.5989441	7.0004				
6	13 38992622	13	23	59	Bus reaches bus stop	18.46387	-66.0960583	5.69999998	16.801374	7.0004				pt4
7	13 39097656	13	23	3	Doors open at bus stop	18.4638467	-66.0958467	5.89999998	2.6467917	7.0277	1	1		
8	13 3959809	13	23	23	Doors close at bus stop	18.4638233	-66.0958417	3.69999999	0	7.0277				
3	13 39641927	13	23	38	Bus accelerates from stop	18.4638217	-66.09584	3.69999999	1.0357011	7.0277				5
4	13 39907986	13	23	54	Bus reaches cruising speed	18.463785	-66.0953833	2.09999999	19.4481651	7.0482				
5	13 40436354	13	24	20	Bus begins slowdown as it reaches bus stop	18.4637117	-66.09368	2.59999999	26.1226833	7.1483				
6	13 40414063	13	24	24	Bus reaches bus stop	18.4636083	-66.0934533	2.29999999	15.535165	7.1818				pt5
7	13 40483073	13	24	28	Doors open at bus stop	18.4635767	-66.09338	2.09999999	6.6745182	7.1818	2	0		
8	13 40835938	13	24	50	Doors close at bus stop	18.46354	-66.0933267	3.79999999	0	7.1818				
3	13 40950521	13	24	57	Bus accelerates from stop	18.46353	-66.0933267	3.99999998	0	7.1818				7
4	13 41239583	13	24	14	Bus reaches cruising speed	18.4634467	-66.0930267	3.69999999	19.3330872	7.2054				
5	13 4223507	13	25	14	Bus begins slowdown as it reaches bus stop	18.46212	-66.08996	0.2	18.7576977	7.4186				
6	13 42389497	13	25	17	Bus reaches bus stop	18.4620683	-66.0898217	0.5	16.4561397	7.4186				mill
2	13 42393663	13	25	23	Bus arrives at Terminal	18.4620033	-66.0896333	0.4	9.4363878	7.4415				
7	13 42532118	13	25	31	Doors open at bus stop	18.4619933	-66.0895967	0.8	0	7.4415	2	0		
8	13 4268316	13	25	40	Doors close at bus stop	18.461995	-66.0895917	1.49999999	0	7.4415				
3	13 4272222	13	25	43	Bus accelerates from stop	18.4619867	-66.0895767	1	1.7261685	7.4415				9
4	13 42974826	13	25	58	Bus reaches cruising speed	18.4618483	-66.0891133	1	20.5989441	7.4596				
9	13 44785156	13	26	47	Bus passes bus stop without stopping	18.4572083	-66.087755	1.59999999	26.0076054	7.8983				ent cc
9	13 45450955	13	27	27	Bus passes bus stop without stopping	18.4566183	-66.0893177	-0.8	23.8211253	8.0393				cc1
9	13 46897135	13	28	53	Bus passes bus stop without stopping	18.4561283	-66.0937017	0.6	19.7933988	8.3593				cc2
9	13 48039497	13	28	2	Bus passes bus stop without stopping	18.453415	-66.091145	1.1	19.563243	8.6327				cc3
9	13 48580729	13	29	34	Bus passes bus stop without stopping	18.4527783	-66.089625	2.29999999	22.785424	8.752				cc4
9	13 49238281	13	29	14	Bus passes bus stop without stopping	18.452645	-66.08839	4.79999998	18.412464	8.8359				salida cc
0	13 5234158	13	31	20	frontage road MR Expwy	18.4500617	-66.0833667	5.09999998	7.4800635	9.2218				
2	13 62214844	13	37	12	Bus arrives at Terminal	18.								

APPENDIX C EXAMPLE OF COMPUTER-AIDED AND MANUAL DATA COLLECTION AND CALCULATIONS FOR BUS PERFORMANCE PARAMETERS: METROBUS I EXPRESS

Data Collected Using the Program									
Date	TV OSJ-SC (hr)	TV SC-OSJ (hr)	TC (hr)	S SC-OSJ (mi)	S OSJ-SC (mi)	V Com (mph)	V Oper OSJ - SC (mph)	V Oper SC - OSJ (mph)	V Cruz (mph)
2/5/2009	0.2786	0.2946	0.7398	5.8962	5.2736	15.0984	18.9311	20.0166	22.5073
2/20/2009	0.4578	-	-	5.8962	5.2736	-	11.5207	-	20.2825
2/25/2009	-	0.2938	-	5.8962	5.2736	-	-	20.0671	21.5860
2/26/2009	-	0.3254	-	5.8962	5.2736	-	-	18.1204	19.5192
3/2/2009	0.3083	0.2736	0.7485	5.8962	5.2736	14.9229	17.1074	21.5526	21.8166
<i>Average</i>	<i>0.3482</i>	<i>0.2968</i>	<i>0.7442</i>	<i>-</i>	<i>-</i>	<i>15.0106</i>	<i>15.8531</i>	<i>19.9392</i>	<i>21.1423</i>
<i>St. Dev.</i>	<i>0.0960</i>	<i>0.0214</i>	<i>0.0062</i>	<i>-</i>	<i>-</i>	<i>0.1241</i>	<i>3.2144</i>	<i>1.4064</i>	<i>1.2133</i>

Figure C.1 Descriptive Statistics for Time and Speed Using the Computer-Aided Data

Data Collected Manually									
Date	TV OSJ-SC (hr)	TV SC-OSJ (hr)	TC (hr)	S SC-OSJ (mi)	S OSJ-SC (mi)	V Com (mph)	V Oper OSJ - SC (mph)	V Oper SC - OSJ (mph)	V Cruz (mph)
2/24/2009	0.3211	0.3081	0.7959	5.6900	5.6700	14.2737	17.6574	18.4707	N/A
2/24/2009	0.3008	0.3261	0.7936	5.6900	5.6700	14.3137	18.8476	17.4480	N/A
2/25/2009	0.2869	-	-	5.6900	5.6700	-	19.7599	-	N/A
2/26/2009	0.3431	-	-	5.6900	5.6700	-	16.5279	-	N/A
3/2/2009	0.2472	0.3231	0.7485	5.6900	5.6700	14.9229	17.1074	21.5526	N/A
<i>Average</i>	<i>0.2998</i>	<i>0.3191</i>	<i>0.7793</i>	<i>-</i>	<i>-</i>	<i>14.5034</i>	<i>17.9801</i>	<i>19.1571</i>	<i>N/A</i>
<i>St. Dev.</i>	<i>0.0362</i>	<i>0.0097</i>	<i>0.0267</i>	<i>-</i>	<i>-</i>	<i>0.3638</i>	<i>1.3129</i>	<i>2.1367</i>	<i>N/A</i>

Figure C.2 Descriptive Statistics for Time and Speed Using Manual Data Collection

APPENDIX D PICTURES OF BUS STOPS ALONG THE METROBUS I EXPRESS ROUTE



Figure D.1 Covadonga Bus Stop, Old San Juan



Figure D.2 Covadonga Bus Terminal Building, Old San Juan



Figure D.3 Bus Stop No. 1 (OSJ – SC), Puerta de Tierra



Figure D.4 Bus Stop No. 2 (OSJ – SC), Puerta de Tierra



Figure D.5 Bus Stop No. 3 (OSJ – SC), Puerta de Tierra



Figure D.6 Bus Stop No. 4 (OSJ – SC), Puerta de Tierra



Figure D.7 Bus Stop No. 5 (OSJ – SC), Puerta de Tierra



Figure D.8 Bus Stop No. 6 (OSJ – SC), Puerta de Tierra



Figure D.9 Bus Stop No. 7 (OSJ – SC), Millennium Building



Figure D.10 Bus Stop No. 8 (OSJ – SC), Convention District



Figure D.11 Bus Stop No. 9 (OSJ – SC), Convention District



Figure D.12 Bus Stop No. 10 (OSJ – SC), Convention District



Figure D.13 Bus Stop No. 11 (OSJ – SC), Convention District



Figure D.14 Bus Stop No. 12 (OSJ – SC), Convention District



Figure D.15 Bus Stop No. 13 (OSJ – SC), State Road PR-16



Figure D.16 Terminal Stop (OSJ – SC) Sign at Sagrado Corazón Station



Figure D.17 Terminal Stop (OSJ – SC) at Sagrado Corazón Station



Figure D.18 Boarding Terminal (SC – OSJ) at Sagrado Corazón Station



Figure D.19 Boarding Terminal (SC – OSJ) Sign at Sagrado Corazón Station



Figure D.20 Bus Stop No. 1 (SC – OSJ), Hoare Street in Santurce



Figure D.21 Bus Stop No. 2 (SC – OSJ), Fernández Juncos Avenue



Figure D.22 Bus Stop No. 3 (SC – OSJ), Fernández Juncos Avenue

After bus stop no. 3, the route enters the Convention District and serves the same stops as in the opposite direction (Figures 5.18 through 5.21).



Figure D.23 Bus Stop No. 8 (SC – OSJ), Exiting the Convention District



Figure D.24 Bus Stop No. 9 (SC – OSJ), Underpass of the Muñoz Rivera Expressway



Figure D.25 Bus Stop No. 10 (SC – OSJ), Millennium Building



Figure D.26 Bus Stop No. 11 (SC – OSJ), Entering Puerta de Tierra



Figure D.27 Bus Stop No. 12 (SC – OSJ), Puerta de Tierra



Figure D.28 Bus Stop No. 13 (SC – OSJ), Puerta de Tierra



Figure D.29 Bus Stop No. 14 (SC – OSJ), Puerta de Tierra



Figure D.30 Bus Stop No. 15 (SC – OSJ), Puerta de Tierra



Figure D.31 Bus Stop No. 16 (SC – OSJ), Puerta de Tierra



Figure D.32 Bus Stop No. 17 (SC – OSJ), Exiting Puerta de Tierra



Figure D.33 Bus Stop No. 18 (SC – OSJ), Capitol Building



Figure D.34 Bus Stop No. 19 (SC – OSJ), Department of the Treasury



Figure D.35 Covadonga Terminal Station (SC – OSJ), Old San Juan