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ANALYSIS AND EVALUATION OF WEIGH-IN-MOTION DATA

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ABSTRACT

One of the most critical parameters in the structural analysis and design of new and rehabilitated pavements is the characterization of truck traffic. The technology of Weigh-in-Motion (WIM) has been implemented in many countries in order to measure the weight of individual axles and gross vehicle weight, while at the same time classifying vehicles at high speeds. In Puerto Rico, eleven WIM stations have been programmed for installation, ten of which were installed during 1997. These stations are located in the primary highway network to gather data that can be useful to evaluate the effect of representative types of trucks in the performance of in-service pavements.

The main activities of this investigation consisted of characterizing the flow of trucks in the WIM stations and identifying typical trucks and possible patterns. Also, a methodology was developed for the construction of weight probability distribution and truck factors for Puerto Rico. Such curves could be used in highways with conditions similar to those of the WIM stations but lacking such equipment. Another task was the creation of a preprocessor, which among other things could rearrange the raw data to be used in a spreadsheet. Using Microsoft Excel, worksheets were prepared with formulas to identify errors found in the data. Another part of this study was to revise the land use adjacent to the WIM stations in order to see if those variables affect the behavior of the truck traffic in the area.

This investigation focused on the evaluation of Weigh-in-Motion equipment installed in Puerto Rico, and the possible analyses that could be carried out with the data. The analysis provides a basis for research possibilities in a short and long term, in order to improve the acquisition of data and reduce the deterioration of the pavements. Although the acquired data had errors, once filtered it was of great utility.

The WIM equipment should be installed in flat surfaces and far from intersections or vehicle exits, which could affect the data upon crossing lanes above the detectors. The typical trucks encountered in Puerto Rico are the class 5 or 2A, the class 6 or 3A, and the class 9 or 3-S2. A better calibration of the stations using a variety of trucks could improve the quality of the data. In the future, enforcement could be made using existent equipment, and future stations could be located in strategic places like toll booths, entrance and exit of port zones, and distribution centers. Finally, the development of a computer program is recommended to filter the data, calculate typical variables for the analysis, and create a database to improve the designs of new and rehabilitated pavements.

RESUMEN

Uno de los parámetros más críticos en el análisis estructural y diseño de pavimentos nuevos y rehabilitados es la caracterización del tráfico de camiones. La tecnología de Pesaje de Camiones en Movimiento (WIM, por sus siglas en inglés), ha sido implantada en muchos países para poder medir pesos de ejes individuales y peso bruto de los vehículos y a su vez, clasificar vehículos a altas velocidades. En Puerto Rico han sido programadas once estaciones de WIM para su instalación, de las cuales, diez fueron instaladas durante 1997. Estas estaciones están localizadas en la red primaria de carreteras para recopilar datos que puedan ser útiles para evaluar el efecto de tipos de camiones representativos en el desempeño de pavimentos en servicio.

Las actividades principales de esta investigación consistieron en caracterizar el flujo de camiones en las estaciones de WIM e identificar camiones típicos y posibles patrones. Además se desarrolló una metodología para la construcción de curvas de probabilidad de distribución de peso y factores de camión para Puerto Rico. Dichas curvas podrían ser utilizadas en carreteras con condiciones similares a las estaciones de WIM, pero que carezcan de dicho equipo. Otra tarea fue la creación de un preprocesador, que entre otras cosas pueda arreglar la data cruda para ser utilizada por una hoja de cálculo. Utilizando "Microsoft Excel", fueron creadas diversas hojas de cálculo con fórmulas para identificar errores encontrados en la data. Otra parte del estudio fue revisar el uso de terrenos adyacentes a las estaciones de WIM para ver si ésta variable afecta el comportamiento del tráfico de camiones en el área.

Esta investigación brindó la oportunidad de evaluar el equipo de Pesaje de Camiones en Movimiento instalado en Puerto Rico y los posibles análisis que se pueden realizar con los datos. El análisis provee una base para posibilidades de investigaciones a corto y largo plazo, para poder mejorar la adquisición de datos y reducir el deterioro de los pavimentos. Aunque los datos adquiridos tenían errores, una vez depurados son de gran utilidad.

El equipo de WIM debe ser instalado en superficies planas y lejos de intersecciones o salidas de vehículos, los cuales pueden afectar los datos al cruzar carriles sobre los detectores. Los camiones típicos encontrados en Puerto Rico son el clase 5 ó 2A, el clase 6 ó 3A y el clase 9 ó 3-S2. Una mejor calibración de las estaciones utilizando una variedad de camiones podría mejorar la calidad de los datos. En el futuro, podrían implantarse penalidades por pesos excesivos utilizando el equipo existente y futuras estaciones podrían instalarse en lugares estratégicos, como plazas de peaje, entradas y salidas de las zonas portuarias y centros de distribución. Por último, se recomienda el desarrollo de un programa de computadora capaz de depurar los datos, calcular variables típicas de análisis y crear una base de datos para mejorar los diseños de pavimentos nuevos y rehabilitados.

DEDICATION

I would like to dedicate this thesis to my brother Dennis Omar, whose innocence and unconditional love is an inspiration to me. Also, to my family and wife for all the support given.

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LIST OF ACRONYMS

AADT – Annual Average Daily Traffic

AASHO - American Association of State Highway Officials

AASHTO - American Association of State Highway and Transportation Officials

ADT – Average Daily Traffic

AI - Asphalt Institute

ASCII – American Standard Code for Information Interchange

ASTM - American Society for Testing and Materials

AVC – Automatic Vehicle Classification

CIRC - Civil Infrastructure Research Center

DTT – Daily Truck Traffic

EAL - Equivalent Axle Load

ESAL – Equivalent Single Axle Load

$ESAL_{18}$ - Equivalent Single Axle Load of 18,000 pounds

FHWA - Federal Highway Administration

GVM – Gross Vehicle Mass

GVW – Gross Vehicle Weight

HMA - Hot Mix Asphalt

HPMS - Highway Performance Monitoring System

HSWIM – High Speed Weigh-in-Motion

IMG – Image

ISTEA - Intermodal Surface Transportation Efficiency Act

LIST OF ACRONYMS (cont.)

Km – Kilometer

LSWIM – Low Speed Weigh-in-Motion

LTPP – Long Term Pavement Performance

LB - Pounds

PCC - Portland Cement Concrete

PCCP – Portland Cement Concrete Pavement

PDF - Probability Density Function

PMS - Pavement Management Systems

PRHTA – Puerto Rico Highway and Transportation Authority

PSI - Present Serviceability Index

psi – Pound Per Square Inch

SHRP – Strategic Highway Research Program

T_f – Truck Factor

TEL – Traffic Event Logger

TRRL - Transport and Road Research Laboratory

UPR - University of Puerto Rico

UTRC – University Transportation Research Center

WIM – Weigh-in-Motion

XTX - Extended Text Format

CHAPTER ONE

INTRODUCTION

1.1 Historical Background

The first paved road in the world is believed to have been built in about 2500 BC in Egypt as an aid to the construction of the Great Pyramids. The Assyrian Empire of western Asia did the first organized road building. The most famous road builders, however, were the Romans. From about 300 BC to about 200 AD they built roads for military and trade use throughout Europe and Britain. In Puerto Rico, Spaniards built the first roads (along existing Indians trails).

The Commonwealth of Puerto Rico has an area of 3,515 square miles (9,104 square kilometers), 110 miles (180 kilometers) from east to west and 35 miles (56 kilometers) from north to south. Puerto Rico's topography consists primarily of a central mountain range which covers approximately 70 percent of the Island and approximately 30 percent is considered level, located mostly in the coastal plains. The Island has a diverse climate. North of the mountainous interior it is wet, with annual rainfall between 80 and 120 inches (203.2 and 304.8 centimeters), and south of the mountain backbone it is relatively dry, with annual rainfall ranging between 40 and 50 inches per year (101.6 and 127.0 centimeters). The coastal plains are affected by floods, which affect the highway system due to quick saturation of the soil, poor drainage, and heavy truckloads.

The economy in the Island is highly dependent upon high tech industry rather than agriculture, and it is often referred to as a model for Caribbean development. The basis of industrial development was the decline of agriculture in the 1950's and 1960's, followed by industrial incentives provided by Puerto Rico's government to the industries in the United States to establish in Puerto Rico, with local tax exemption from 10 to 30 years. By 1980, rapid structural changes and economic reform resulted in more than 2,000 factories producing goods and commodities for the United States. The pharmaceutical industry, for example, produces 17 percent of all pharmaceuticals marketed in the world. The United States is the chief trading partner, accounting for 84 percent of Puerto Rico's exports and 64 percent of its imports. Puerto Rico's road network expanded rapidly to coincide with the increase industrial development throughout the Island. More than 3,700 miles (6,000 kilometers) of roads connect centers of economic activity and the island's cities and towns (1996, Compton).

Another important characteristic of Puerto Rico is the lack of a rail system to transport freight and other heavy loads to and from the major ports of the island located in Ponce, Mayagüez, and San Juan. Due to the lack of a cargo rail system, all goods and commodities have to be transported through the primary highway system. Trucks are often overloaded in order to compensate for the lack of a rail system. Until 1994, enforcement of load limits in the highway system was rare, due to the fact that there was no other means of freight transportation in the Island, and a truck strike will cause economic development to stop and chaos in economic activities. The lack of truck weight enforcement has resulted in premature structural failure of pavements in the primary highway system.

In Puerto Rico, and in many other countries, more than 80 percent of all passenger travel is on roads and streets. Almost all of the country's food and other goods are transported all or part of the way from the farm or factory to the store by way of roads and streets. There are about 120 million miles (193 million kilometers) of roads in the world. The United States has the largest road network: more than 4 million miles (6 million kilometers) of roads and streets. Puerto Rico has about 22,000 miles of paved roads. Other modern road networks serve Europe, Asia, South America, Australia, and parts of Africa. The smallest national road network is that of Monaco, which has about 29 miles (47 kilometers) of roads.

With the economic development of Puerto Rico, the demand for better roads was great. Transportation from the metropolitan areas to the central part of Puerto Rico was important for the economic development of the island as a whole. At present, the road system is a vital element of the Puerto Rican economy. Adequate transportation of goods such as food, cattle, and pharmaceutical products is essential to the economic activity of the island. All postal services, gas, electricity, telephone, food delivery, etc. depend on the use of the primary highway system. Although early roads were mainly unpaved, modern roads are generally paved, especially in the highway system. Without proper maintenance, road conditions will deteriorate with the continuing traffic growth.

The analysis and design of new and rehabilitated pavement structures relies on accurate traffic data to provide long-lasting pavements in a cost-effective manner. The design methodologies adopted by the American Association of State Highway and Transportation Officials (AASHTO) and the Asphalt Institute (AI) provide analytical procedures for traffic analysis based on Equivalent Single Axle Load (ESAL) and Truck Factor (T_f).

Historically, the planning departments of state highway agencies have had the responsibility of collecting traffic data for a variety of purposes. At the planning stage, manual traffic volume and classification counts have been used along with traffic pneumatic tubes, for developing Average Daily Traffic (ADT) flow maps, establishing growth rates for traffic forecasting and for meeting federal requirements such as those stipulated in the Highway Performance and Monitoring System, HPMS (FHWA, 1994). In addition, in Puerto Rico truck weighing stations have been established throughout the island's primary highway network to statically weigh axle loads. The resulting information is used for planning purposes to estimate equivalent single axle load of 18,000 lbs. This static truck weight data, although available, "is not by any means complete and lacks of a true representation of loads and traffic in the highway system" due to the fact that a significant number of trucks bypass the weighing stations. It has been demonstrated that if a weighing station is operating in a location, truck drivers are warned by others, and they take another route to bypass the weighing station and avoid the hassle of stopping, and probably getting a fine.

The Puerto Rico Highway and Transportation Authority (PRHTA) conducted a study for establishing truck size and weight limits on the island network and, as part of that study, a database of historical truck weight data was developed. A computer program called PESAJE was developed to compute descriptive statistics as well as design-related variables such as equivalent axle truck per truck (ESAL/truck), axle load distribution by station, and graphical capabilities to show the effect of ESAL/truck throughout the years. Santoni (1993) and Colucci (1994) demonstrated that "there is a strong need for calibrating traffic data for design and enforcement".

1.2 Nature of the Problem

New technologies such as the WIM equipment can be used to collect traffic data and classify all vehicle types for planning and enforcement. WIM equipment has the capability of measuring the axle loads, type and velocity of trucks.

PRHTA awarded a contract to Santa Fé Technologies Inc., in 1996 for the acquisition, installation, placing and maintenance of Automatic Vehicle Axle Classification (AVC) and Weigh-in-Motion (WIM) equipment in selected sites in the island, primarily to meet Strategic Highway Research Program Long-Term Pavement Performance (SHRP-LTPP) needs. A typical WIM/AVC set-up is exhibited in Figure 1.2.1.

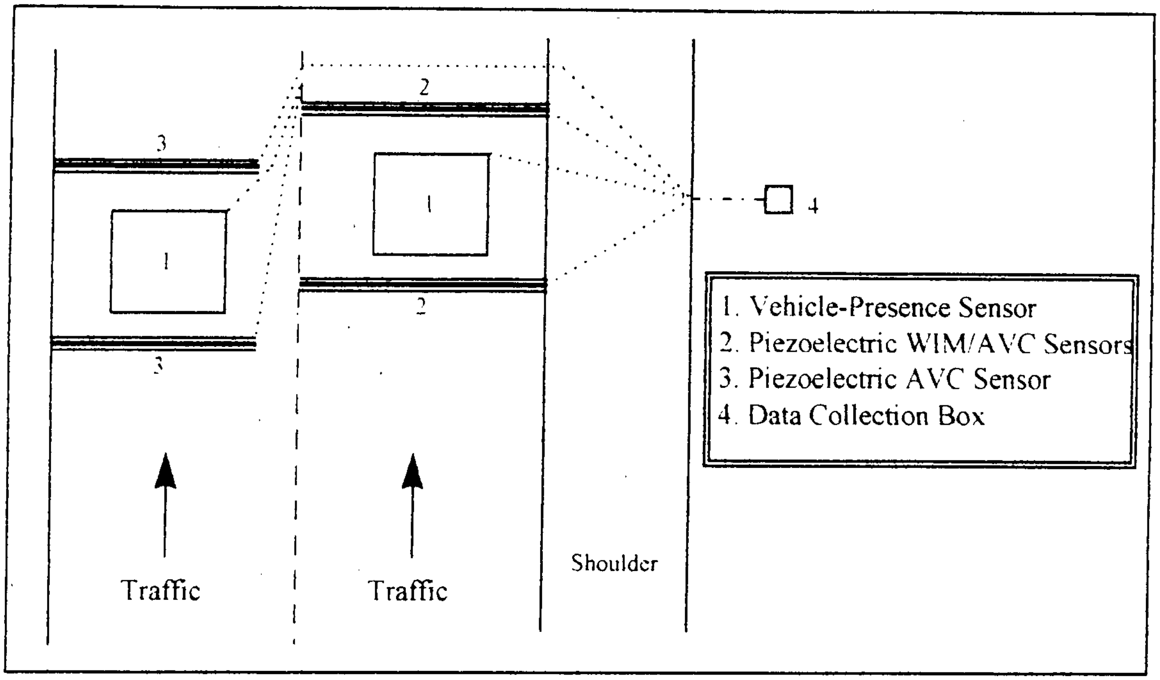
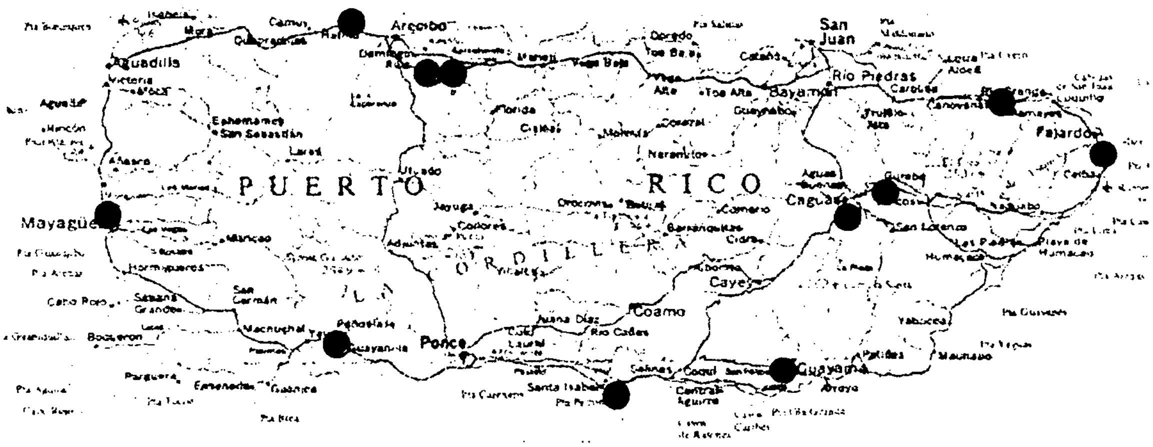


Figure 1.2.1 Typical WIM/AVC set-up.

Using the WIM techniques, wheels and axle can be weighed on the road without stopping the vehicles or disturbing the traffic. The WIM technology is currently the most reliable mechanism to collect traffic data that can be used to perform sound statistical analysis on real traffic parameters, including axle and vehicle loads, speeds, vehicle class, and others. These data can be used to calibrate historical static traffic data as well as to develop regression models to estimate the cumulative equivalent single axle load (ESAL) for different types of highways based on functional classification, climate, pavement types, and other factors.

Eleven WIM/AVC stations have been installed in the primary highway network in Puerto Rico. Figure 1.2.2 and Table 1.2.1 shows the municipalities and location of such stations.



● = WIM/AVC Station

Figure 1.2.2 Location of WIM/AVC Stations

Table 1.2.1 Location of WIM/AVC Stations

STATION	MUNICIPALITY	LOCATION
001	Arecibo	PR-22 Km. 69.8
002	Arecibo	PR-22 Km. 71.75
003	Caguas	PR-52 Km. 6.7
004	Hatillo	PR-2 Km. 84.6
005	Gurabo	PR-30 Km. 9.4
006	Mayagüez	PR-2 Km. 147.8
007	Rio Grande	PR-3 Km. 26.8
008	Peñuelas	PR-2 Km. 213.8
009	Guayama	PR-53 Km. 88.7
010	Salinas	PR-52 Km. 70.3
011	Ceiba	PR-53 Km. 1.1

There is a need for developing models to assist in traffic forecasting for the design of new and rehabilitated pavements. Methods for predicting performance should not be selected arbitrarily since an incorrect methodology makes optimal pavement design impossible. Regression models will assist in developing performance curves, which are the basis for pavement design, primarily in calibrating the reliability and overall standard deviation parameters required in the AASHTO Methodology. The cumulative ESAL is a fundamental variable that must be estimated in order to develop performance and survivor curves. Therefore, there is a need to develop weigh probability distribution for each weighing station, region, and primary functional classification using Weigh-in-Motion data to estimate the cumulative ESAL to support the analysis and design of new and rehabilitated pavement structures.

1.3 Objectives

The main purpose of this research is to develop a methodology to analyze and evaluate weigh-in-motion data collected at representative WIM sites in the primary highway network in Puerto Rico, taking into consideration all the parameters available for each station analyzed, supported by current land use, climatic, and pavement distress data. The specific objectives of this research are the following:

- identify homogeneous regions in Puerto Rico characterized by having similar climatic variables, traffic flow, and road infrastructure
- characterize truck traffic and land use for each station analyzed

- characterize errors that may be encountered in WIM data, and compare among stations and vehicles
- estimate the truck factors for each WIM station and compare them with truck factors obtained with historical static truck weight data
- use the WIM data currently being collected to validate historical truck factors collected with static measurements
- derive the weight probability distribution for each region and for Puerto Rico
- develop land use models to help establish new WIM stations
- develop mathematical equations for the purpose of predicting $\sum ESAL_{18}$ for different functional classification of roads
- establish guidelines for the implementation of the mathematical models as part of the pavement management efforts currently being implemented by the Puerto Rico Highway and Transportation Authority.

1.4 Expected Benefits

This research is based on the hypothesis that the WIM equipment can gather accurate and reliable weight data and that the data gathered by the equipment is a true reflection of the actual traffic condition of each station. It should be noted that the Puerto Rico Highway and Transportation Authority is learning to use WIM equipment and that errors are expected to arise throughout the process. But the important benefits are the methodologies that will be developed for the analysis, calibration, and selection of new WIM sites and the flagging of the different sources of errors and the corresponding countermeasure. The expected benefits of the research also include the development of generic weight probability distributions and truck factors for each climatic zone of Puerto Rico. A methodology for developing the first generation of these curves is described in this thesis. This approach can be fine tuned for use in future investigations due to the fact that WIM data is expected to be gathered for a long period of time after this research is completed.

1.5 Scope

This study has been performed using weigh-in-motion data gathered by Santa Fé Technologies for the Puerto Rico Highway and Transportation Authority (PRHTA), and made available to the researchers through their Pavement Management Office. WIM data included in this report corresponds to the data available from the stations illustrated in Figure 1.2.2 and Table 1.2.1 for the period of October 1996 through July 1997.

This research includes statistical analysis of the data obtained with the WIM/AVC equipment installed by Santa Fé Technologies at those stations.

1.6 Thesis Organization

Chapter one provides general background describing the importance of the highway system to the economy of Puerto Rico, and the need to collect reliable data to enhance the design methodologies and rehabilitation techniques. The objectives, the expected benefits and the scope are also presented in this chapter. Chapter two reviews the literature on pavement types, weighing equipment, WIM technologies, data gathering equipment, weight regulations, truck geometric configuration, and truck tire pressure. Also included in this chapter is a comprehensive review of previous WIM studies.

Chapter three deals with the process of data gathering at WIM/AVC stations, the installation, calibration, and operation of WIM/AVC equipment, and provides an overview of the reports generated by the software. Finally, the land use is analyzed and other pertinent data associated with the WIM/AVC stations evaluated. Chapter four presents the preliminary analysis performed in the first part of the research, along with the problems encountered and actions taken. The different vehicles analyzed are also presented, along with the errors encountered during data processing.

In chapter five data verification is discussed, along with the land use models. Also in this chapter the weight probability distribution for different stations is shown, along with the methodology proposed. Chapter six summarizes the major findings and conclusions of this investigation and provides recommendations concerning the application of truck data for analysis and design of pavements and for developing guidelines for the identification of future WIM stations. The overall organization of this thesis is illustrated in Figure 1.6.1

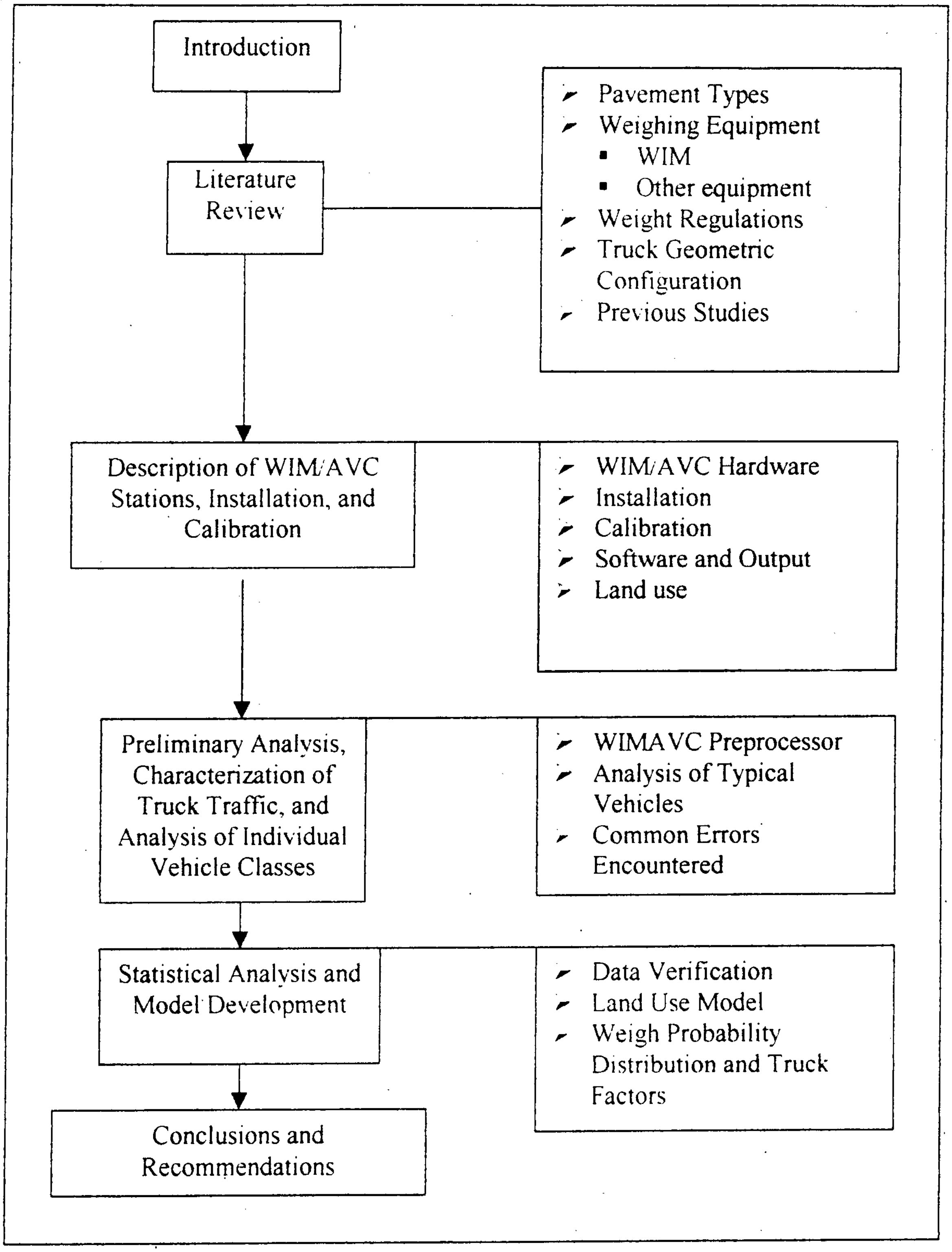


Figure 1.6.1 Thesis Organization

1.7 Methodology

Weigh-in-Motion is a new technology that is being implemented in Puerto Rico for the first time. As such, the first step in this research was to review the literature on the technology in order to understand the different uses that WIM/AVC data has. A preliminary analysis of the WIM data followed the literature review. During this preliminary analysis, the data being gathered was examined and the different outputs of the WIM/AVC software were reviewed. From this preliminary analysis, the ESAL and Truck Factors were evaluated among stations to determine the critical day of the week, the day with the highest volume of traffic. After preliminary analysis was done, site visits were made to all the WIM/AVC stations to see geometric differences and land use. Site visits were also made during calibration of the Arecibo WIM station, and installation of Mayagüez WIM station. Concurrent with various site visits, statistical analyses, characterization of traffic, and analysis of typical vehicles, were performed. The characterization of traffic and analysis of typical vehicles was done using the records for each vehicle. Due to the magnitude of data being processed by the equipment, a preprocessor had to be created called WIMAVC. WIMAVC has the capability of processing the records for the entire vehicle stream and arranging the data by vehicle class. Then basic parameters such as speed, length, GVM, etc. were calculated. In the analysis of the raw data some errors surfaced and a process for filtering the data was determined, in other words a calibration of the data was performed. Due to the magnitude of some errors encountered, a verification of the data was performed using video camera at the Mayagüez WIM/AVC station. Finally, guidelines were developed for installation of future WIM/AVC stations and future research. Figure 1.7.1, demonstrates a flowchart indicating the methodology used for the research.

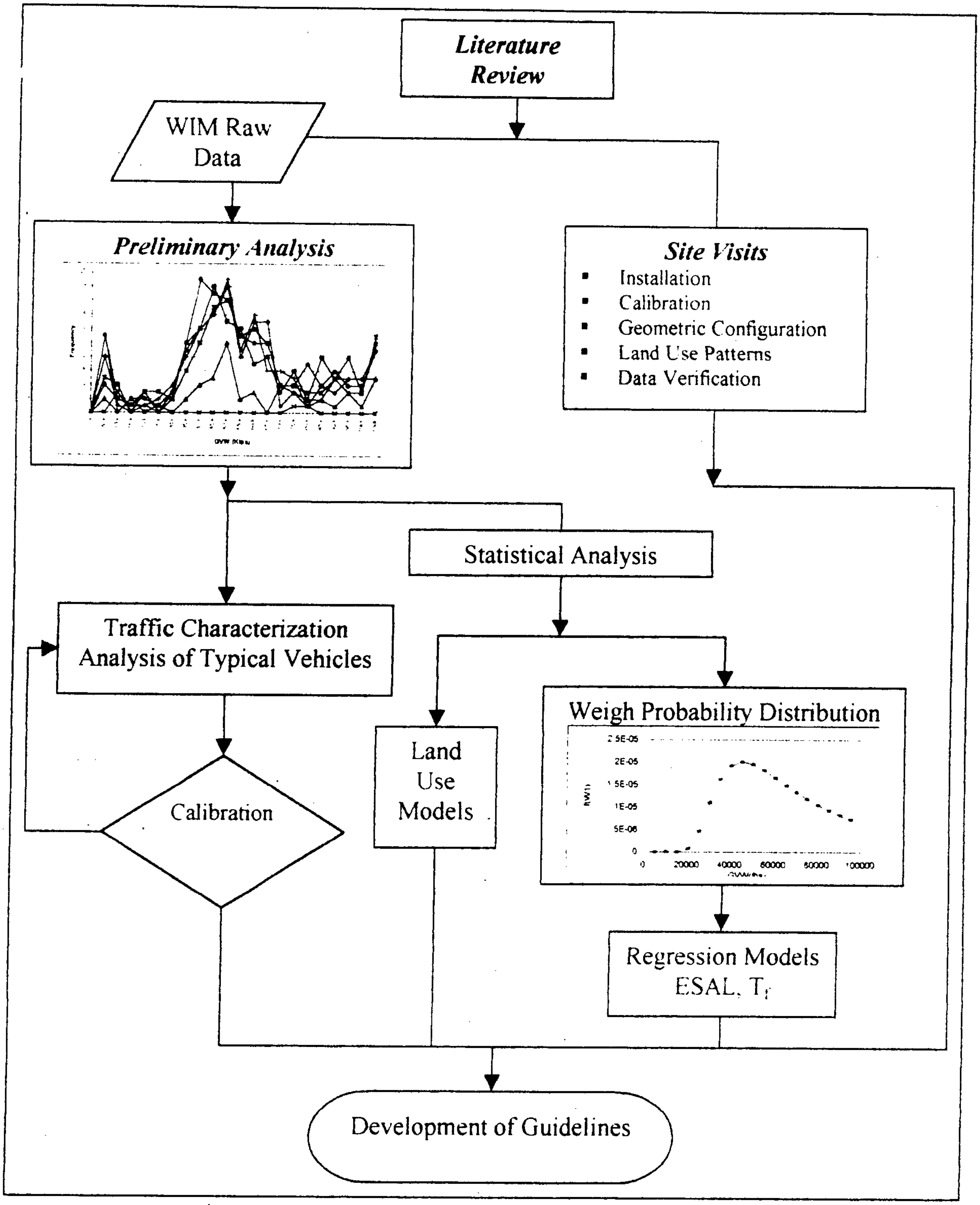


Figure 1.7.1 Methodology Used in the Research

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

A literature review has been conducted to assess the current state-of-the-art in WIM technology, traffic data, weighing equipment, and truck geometric configuration. The current truck size and weight regulation of Puerto Rico and other states was also studied.

2.2 Definition of WIM and Pavement Types

The design of pavements involves characteristics such as, expected traffic volume, frequency, vehicle weight and speed. Reliable data and a historical database are important for maintaining and designing new facilities which will sustain truck loads and maintain the quality and comfort for the driver. These data can be obtained in whole or part using **W**eigh-**In**-**M**otion (WIM). Weigh-in-Motion is the process of measuring the dynamic tire forces of a moving vehicle and estimating the corresponding tire loads of the static vehicle (ASTM, 1993). A WIM system consists of a set of sensors and supporting instruments which measures the presence of a moving vehicle and the related dynamic tire force at specified locations with respect to time (ASTM, 1993).

In order to provide the basis for understanding the relationship of pavement structures with WIM equipment, the following paragraphs describe the major types of pavements used.

A pavement structure is a combination of one or more subbase courses, base course, and a surface course placed on a compacted subgrade to support the expected traffic load over the design period and distributed uniformly over the roadbed. Different types of pavement structures in existence today are classified into two broad categories, namely flexible and rigid pavements; composite pavements are a third type which is a combination of the two and is mainly used in the rehabilitation of pavements.

Flexible pavements are constructed of bituminous and granular materials. This type of pavement structure maintains intimate contact with and distributes loads to the subgrade and depends upon aggregate interlock, particle friction and cohesion for stability. The two principal types of distress associated with flexible pavement are fatigue cracking and rutting. Fatigue cracking is based on the critical horizontal tensile strain at the bottom of the hot mix asphalt (HMA) caused by the repetition of heavy loads. Rutting is associated with the permanent deformation on top of the subgrade and is reflected as a longitudinal depression or rut depth along the wheelpath. Both distresses are load related, and WIM data can be useful for developing regression models to predict the critical threshold for these distresses.

Two major types of construction processes have been used for flexible pavements: conventional flexible pavement, and full-depth asphalt pavement. Conventional flexible pavements are layered systems with high quality materials on the top layers where the stress concentration is higher and inferior materials at the bottom where the stress intensity is low. Flexible pavements are usually made of three or more layers, but there can be fewer depending up on the traffic characteristics and the functional classification of the road.

Rigid pavement structures consist of one course of portland cement concrete slab of relatively high bending resistance that distributes the load over a wider area on top of the subgrade. Rigid pavements are usually eight to twelve inches thick with transverse joints every 20 feet, with load transfer devices such as 18-inch dowels spaced 12 inch apart. Rigid pavements may or may not be reinforced; such reinforcements would only add to the elongation of the distance between transverse joints and keep transverse cracks tight if developed. Rigid pavements may or may not have a base or subbase course, although state-of-the-art practice recommends the use of non-erodable bases to prevent pumping on heavily trafficked roads. Figure 2.2.1 demonstrates typical schemes of flexible and rigid pavements.

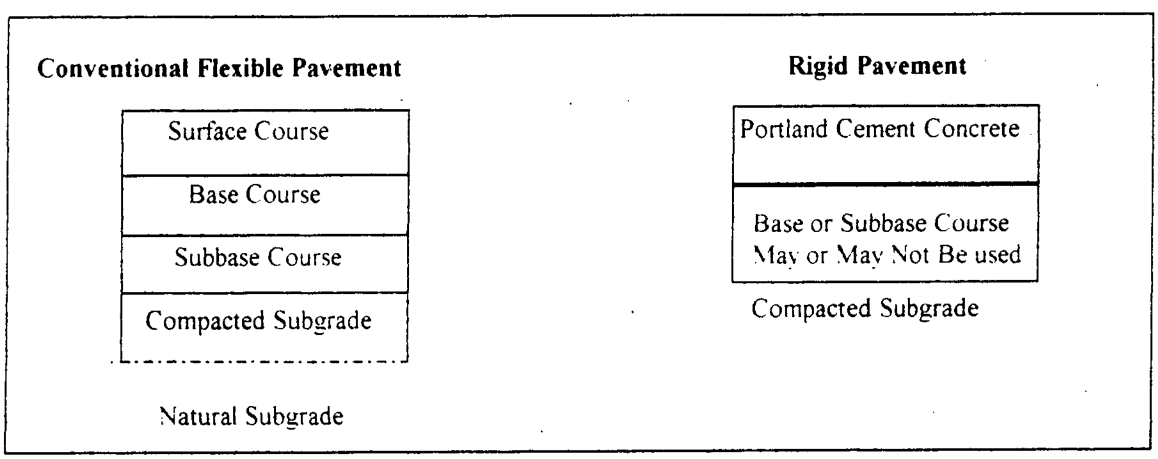


Figure 2.2.1 Schematic of Flexible and Rigid Pavements

The design of flexible as well as rigid pavements involves determination of the required layer thickness. The design involves parameters such as expected traffic over the design period, axle load type (single, tandem, tridem, quadem), frequency, lane, and direction distribution factors among others. These parameters can be obtained using WIM equipment.

2.3 Static Weigh vs. Weigh-in-Motion

Different types of weighing equipment are available today, basically divided into two types; static weigh and weigh-in-motion. Truck weights can be gathered by the use of a vehicle scale, an axle load scale or a wheel load scale. A static or stationary scale is commonly used to measure the weight of trucks mainly for the purpose of enforcement of legal weight loads. An advantage of this type of weighing is that information on drivers and truckload can be obtained through interviews. A disadvantage of this type of weighing is that it is time consuming, requires trained personnel, and the data gathered may not be realistic because after starting the process overweight trucks are warned by others to bypass the inspection site. Weigh-in-motion, on the other hand, provides traffic data 24 hours a day, 7 days a week, in an unobtrusive manner, which does not distract the driver.

More than 2000 traffic lanes in the United States have been equipped with weigh-in-motion scales (Hajek et al., 1994). Because of their unobtrusiveness and continuous operation, WIM systems provide statistically reliable data. WIM can determine truck exposure rates and evaluation of vehicle speed and headway distributions as a function of highway facility, vehicle type, daytime and nighttime, and truck load. WIM data is useful for a wide range of transportation planning and decision making purposes including:

1. planning and programming of transportation facilities
2. pavement design and rehabilitation
3. apportionment of pavement damage
4. compliance with vehicle weight regulations
5. development of geometric design standards
6. compliance and regulatory policy development of truck dimensions
7. safety analysis
8. traffic operation and control
9. analysis related to highway bridges.

WIM systems are specified to meet the needs of the user for the intended application. WIM systems are classified by type according to speed of the vehicle to be monitored and portability of the equipment. Currently, the ASTM E 1318-94 classifies WIM systems into four types as presented in Table 2.3.1.

Table 2.3.1 WIM Systems Classification

Type	Installation	Speed (mph)	For each vehicle processed, the system shall produce:
I	Up to 4 lanes in a traffic data-collection site	10 – 70	All data items shown in Table 2.3.2
II	Traffic data collection site	10 – 70	All data items shown in Table 2.3.2 except Item 1. All other features and options of Type II are identical to Type I
III	One or two lanes at a weight enforcement station	15 – 50	All data items shown in Table 2.3.2 except Items 7, 12, 13, and shall also estimate acceleration.
IV	Weight enforcement station to detect weight limit or load limit violations	0 – 10	All data items shown in Table 2.3.2 except Item 7, 9, 12, and 13. Shall also estimate acceleration.

Type I and II WIM systems accomplish vehicle classification according to axle arrangement. The vendor incorporates software within Type I and II WIM systems for using the available WIM system axle-count and axle-spacing information for estimating the Federal Highway Administration (FHWA) Vehicles Types (ASTM, 1993).

Table 2.3.2 Data Items Generated by a WIM System (after ASTM E 1318-94)

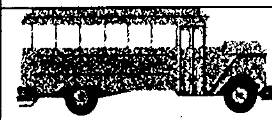
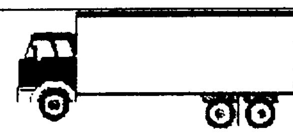
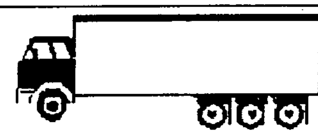
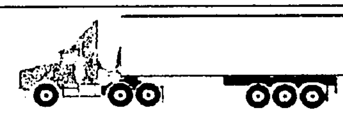
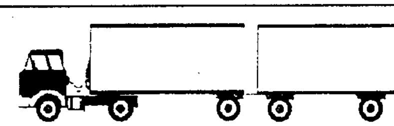
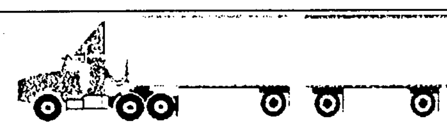
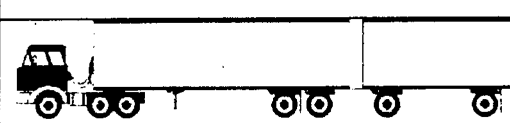
ID	Description
1	Wheel Load
2	Axle Load
3	Axle-Group Load
4	Gross-Vehicle Weight
5	Speed
6	Center-to-Center Spacing Between Axles
7	Vehicle Class (via axle arrangement)
8	Site Identification Code
9	Lane and Direction of Travel
10	Date and Time of Passage
11	Sequential Vehicle Record Number
12	Wheelbase (frontmost to rearmost axle)
13	Equivalent Single Axle Load
14	Violation Code

Each type of WIM system is capable of performing the indicated functions within the accuracy shown in Table 2.3.3. Field calibration of the WIM system used in Puerto Rico to perform within the limits shown in Table 2.3.3 are discussed in Chapter 3, Section 3.4. The Federal Highway Administration classification scheme used in WIM equipment classifies by a two-digit code as shown in Table 2.3.4.

Table 2.3.3 Functional Performance Requirements for a WIM System (after ASTM E 1318-94)

Function	Tolerance for 95% Probability of Conformity				
	Type I	Type II	Type III	Type IV	
				Value > lb.	± lb.
Wheel Load	± 25%		± 20	5,000	250
Axle Load	± 20%	± 30%	± 15	12,000	500
Axle-Group Load	± 15%	± 20%	± 10	25,000	1,200
Gross-Vehicle Weight	± 10%	± 15%	± 6	60,000	2,500
Speed	± 1 mph				
Axle Spacing	± 0.5 ft				

Table 2.3.4 FHWA Classification Scheme

Code	Description	Sketch
01	Motorcycles	
02	Passengers cars	
03	Other two-axle, four-tire single-unit vehicles	
04	Buses	
05	Two-axle, six tire, single-unit truck	
06	Three axle, single-unit truck	
07	Four or more axle single-unit truck	
08	Four or less axle single-unit trailer truck	
09	Five-axle single-trailer truck	
10	Six or more axle single-trailer truck	
11	Five or less axle multi-trailer truck	
12	Six-axle multi-trailer truck	
13	Seven or more axle multi-trailer truck	

2.4 WIM Technologies

Different types of technologies are or have been in use in WIM systems. Table 2.4.1 presents information on function, installation, cost, and advantages & disadvantages of five of the most common WIM systems, including piezoelectric, fiber optic, bending plates, load cells, and capacitive strip.

Table 2.4.1 WIM Technologies

WIM Technology	Function	Installation	Cost $	Advantages/ Disadvantages
Piezoelectric	Weigh/ Classify	At the surface of the pavement, easy to install	1,500 ea.	Precision and minimal traffic congestion
Bending Plate	Weigh	A frame supports the plate in a trench 2-in deep	Low cost	Simplicity and Precision
Load Cell	Weigh	A piston has to be installed in a trench with a weighing platform in each wheelpath	150,000 per installation	Higher cost due to installation difficulty
Fiber Optic	Weigh	Easy to install	-	Low cost in general
Capacitive Strip	Weigh	Minimal installation is required	-	Low cost due to the installation

Piezoelectric - Consist of encapsulated devices in a rubber-like carrier which register forces as electrical charges of opposite polarity at the parallel faces of a crystalline material. The piezoelectric cables are installed in a narrow slot across the traffic lane. Piezoelectric devices are capable of weighing as well as classifying vehicles.

The installation is typically made at the surface of the pavement. The cost of a piezoelectric sensor is between $1,200 to $1,500 US dollars.

Fiber Optic – Consists of a silicone rubber cover that compresses the fiber optic sensors when weight is applied. The intensity of light transmitted through each fiber varies with the magnitude of weight applied. This type of equipment is easy to mount, making it less costly.

Bending Plate – Typically consist of a high strength steel plate 5/8in. thick, instrumented with strain gages. Plates are mounted across a traffic lane normally covering both wheel paths. Bending of the plate, under vehicle loads, is measured by strain gages located on the underside of the plate. A frame supports the plate in a trench 2 inches deep, minimizing the installation cost. The entire plate has a protective covering of vulcanized synthetic rubber for environmental protection. Reading from the strain gages are recorded by microcomputer that can be interfaced with data transmission equipment. Low cost of installation, simplicity, and precision are some of the advantages of this technology (Santoni, 1993).

Load Cell – Consist of applied load to weighing platforms in each wheel path resting on a common concrete foundation produces vertical movement in a centrally located oil-filled piston, which acts as a load cell. The load cell system is costly with an approximate cost of $150,000 per installation.

Capacitive Strip – Consist of a thin aluminum extrusion, with an inner air gap, which is closed slightly when an axle passes over it. Compression of the capacitive strip under load produces an increase in capacitance which is interpreted as a weight by an attached microprocessor data base collection system.

2.5 Automatic Vehicle Classification

Weigh-in-Motion systems are combined with automatic vehicle classification (AVC) to optimize the data gathered. A WIM/AVC station can be made up of several of the technologies mentioned above, combined with other equipment used in data acquisition such as an inductive loop detector, infrared light sensor beam, video image processing, microwave (radar) and laser.

An inductive loop detector consists of one or more turns of insulated wire placed in a shallow slot which is then sealed by a sealant material that will resist climatic condition as well as the passage of vehicles.

An Infrared light beam senses the thermal energy of the vehicle and provides presence output. A wide detection zone is possible; the only problem is that the equipment or device is susceptible to climatic conditions such as snow, fog and heavy rain. Cost varies from low to medium.

Video image processing is a new technology for detecting vehicles with a wide variety of potential uses. It can be used jointly with WIM for plate reading when a vehicle is overweight. Other uses are for scene assessment and vehicle traffic studies.

Microwave (Radar) is an off-road vehicle detector that transmits electro-magnetic energy, typically in the 24 GHz band, and listens for a return echo. Vehicle presence and speed can be measured. Generally this equipment is insensitive to weather effects.

Laser is a vehicle detector similar to off-road microwave detectors, except that it operates at a shorter wavelength, in the visible and infrared spectrum. Heavy rain and poor visibility can affect it.

2.6 Truck Weight Regulations

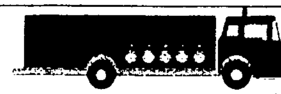
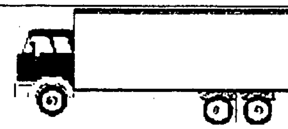
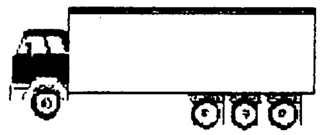
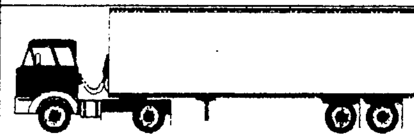
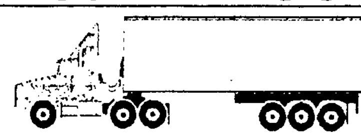
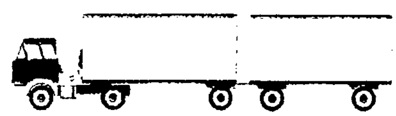
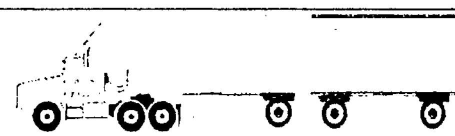
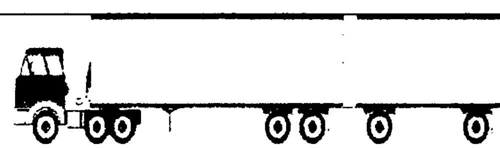
Truck weight regulations are different among countries in North America. The national laws regarding commercial vehicle operation include vehicle size, safety standards, and weight regulations. A comparison of heavy vehicle weight regulation among Puerto Rico, United States, Mexico, and Canada, with special interest in Puerto Rico is presented. The truck weight regulation in Puerto Rico of September 1994 is called "Reglamento de Dimensiones y Pesos de Vehículos que Transitan por las Vías Públicas". In the United States truck weight regulations vary depending the state of operation and the road type. A similar situation occurs in Canadian Providences and Mexican states, but all have federal laws governing them.

Table 2.6.1 Truck Weight Regulations

Weight Classification		Canada	USA	Mexico	Puerto Rico
Axle Load		(pounds)			
Steering		12,150		12,150	12,000
Single		20,050	20,000	22,050	22,000
Tandem		37,500	34,000	39,700	42,000
Tridem (various spacing)					
	8 ft	46,300	42,000	49,600	60,000
	10 ft	50,700	43,500	49,600	60,000
	12 ft	52,900	45,000	49,600	60,000
GVW (lbs.)		87,100	80,000	91,550	110,000

Table 2.6.2 shows the maximum weight allowed for each truck in FHWA categories, along with a representative vehicle drawing. It should be clarified that Table 2.6.2 has calculated the maximum weight for the specific vehicle showed. Some classifications might have more than one truck, for example a class 8 truck can be a four axle semi-trailer truck or a three axle semi-trailer truck. To calculate the maximum gross vehicle weight allowed for any vehicle, one can use Table 2.6.1. The allowable GVW can be computed by adding the individual axles of the vehicle in consideration.

Table 2.6.2 Vehicle Schematic and Maximum Axle and Gross Vehicle Weight

Classification Code	Axle Load Limit Kips	Representative Vehicle Schematic
04	12 + 22 = 34	
05	12 + 22 = 34	
06	12 + 42 = 54	
07	12 + 60 = 72	
08	12 + 22 + 42 = 76	
09	12 + 42 + 42 = 96	
10	12 + 42 + 60 = 114 Maximum Limit = 110	
11	12 + 22 + 22 + 22 + 22 = 100	
12	12 + 42 + 22 + 22 + 22 = 120 Maximum Limit = 110	
13	12 + 42 + 42 + 22 + 22 = 140 Maximum Limit = 110	

2.7 Traffic Impact on Pavement

The deterioration of pavement is the product of multiple factors. Construction materials, roadbed soil, drainage, precipitation, and traffic have the most significant impact on pavement life. In this study the focus is mainly on the effect of the load on the pavement. The overload of the pavement can reduce significantly its performance life as shown in Figure 2.7.1.

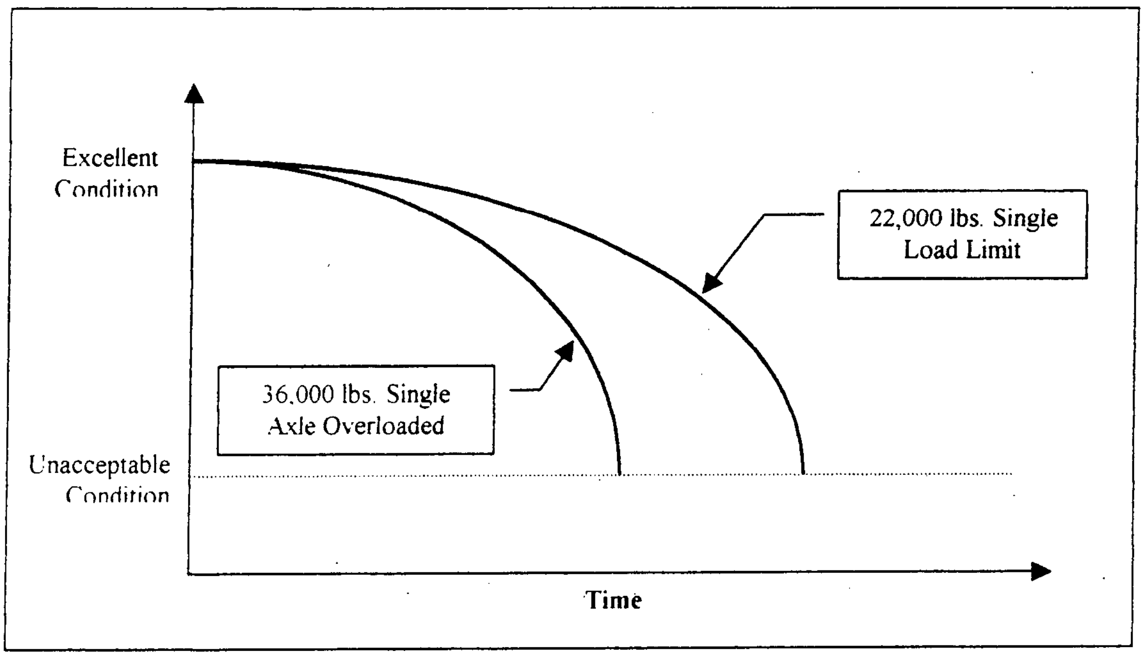


Figure 2.7.1 Effect of Overloading a Single Axle through Time

In 1958, the American Association of State Highway Officials (AASHO), today known as the American Association of State Highway and Transportation Officials (AASHTO), developed a large-scale road test to determine damaging effects of axle load passage on different pavement types. The AASHO road test converts the damage produced by application of any axle load application to the equivalent damage produced by an 18,000 pound single-dual tire axle load application. Under these conditions, an 18-kip single axle would produce a unit value of relative damage. This factor is known as equivalent single axle load or $ESAL_{18}$. An 18-kip ESAL of any load is determined by the ratio of the damage caused by the 18-kip single axle load application, (W_{t18}), against the damage caused by the selected axle load application (W_t). The general formula used to characterize traffic damage is given below:

$$(W_t): ESAL = \frac{W_{t18}}{W_t}$$

Where: W_{t18} = 18-kip single axle load application

W_t = t axle load application

The ESAL relationship was found to increase exponentially to the fourth power as load increases. So for a single axle the formula to calculate ESAL would be $(w_i/w_{18})^4$. In Figure 2.7.2 a comparison between the ESAL calculated for a single axle with the simple formula and the tables from the AASHTO Design Guide, is given. It should be noted that the damage effect is not for the load only; it is also a function of the tire pressure.

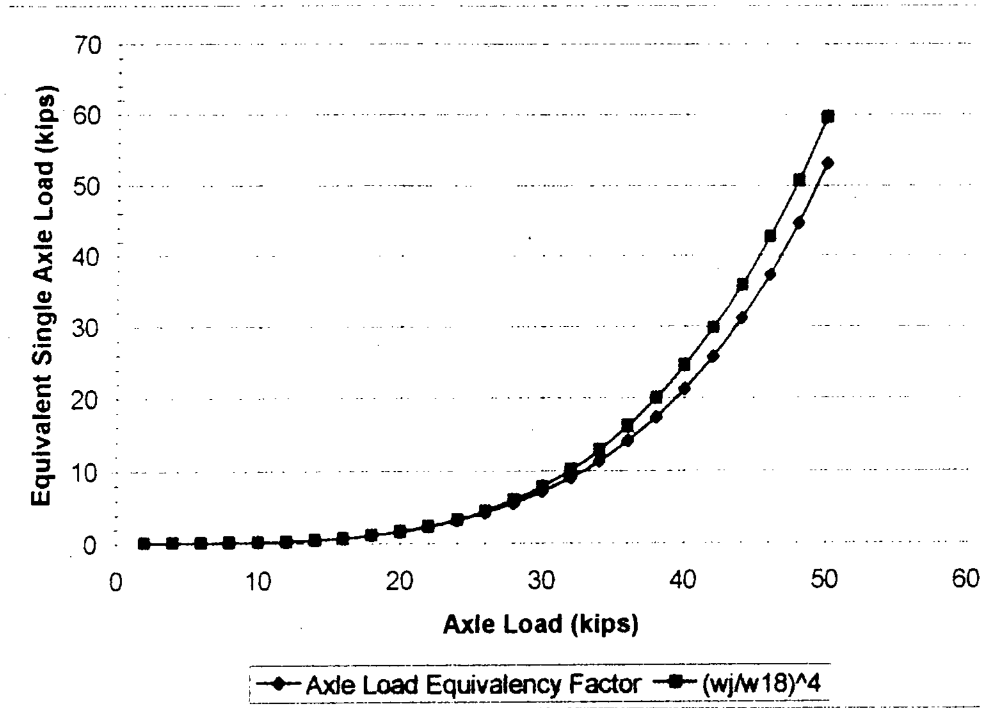


Figure 2.7.2 Comparison of Damage Factor for Different Scenarios

The thickness and type of pavement, roadbed characteristics, axle configuration, and expected pavement performance influence the load equivalence factor. The expected pavement performance is a measure of pavement structural and functional conditions. The structural part deals with the ability of the pavement to sustain loads while structural failure includes rutting, cracking, and faulting, among others.

Another result of the AASHO Road Test was the development of the pavement serviceability performance concept. The serviceability of the road is a parameter that can be used to estimate the pavement life and determine when rehabilitation is needed. Figure 2.7.3 shows how, as load increases over time, the serviceability index diminishes to an unacceptable level. At that point, rehabilitation is performed and the serviceability is increased again.

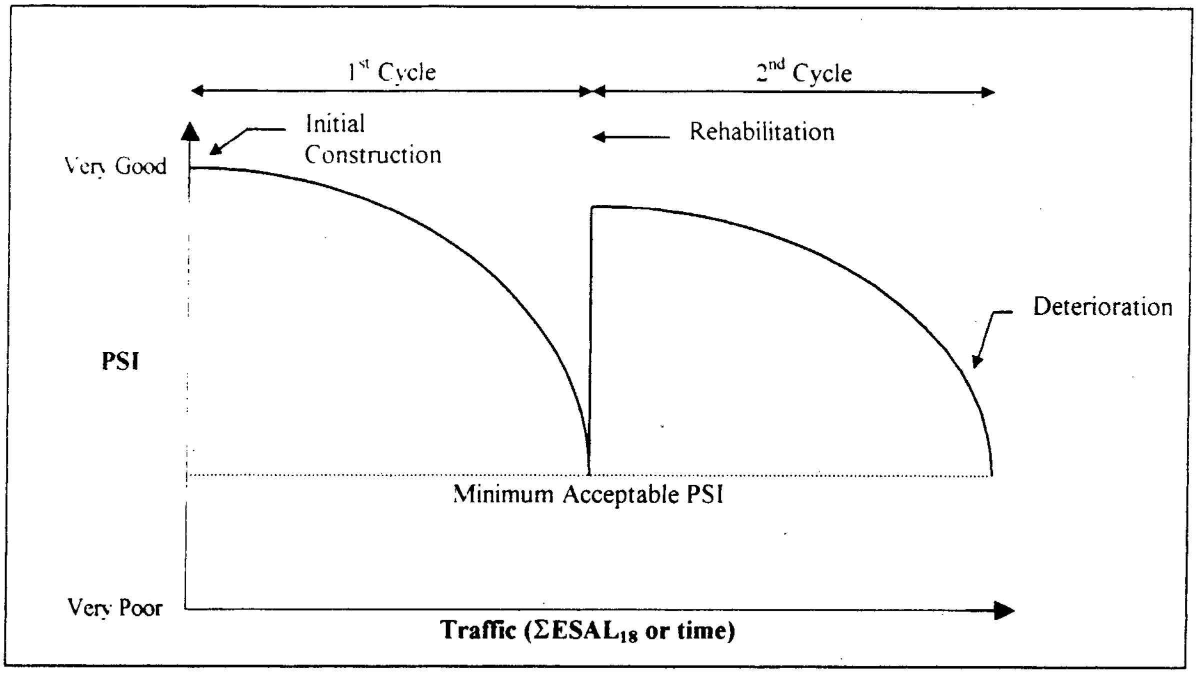


Figure 2.7.3 Schematic of Structural Capacity Loss Over Time and With Traffic

2.8 Truck Geometric Configurations

In this section the truck considered is the semi-trailer five-axle truck. This type of truck is usually used to move a lot of cargo, especially from the docks at the major ports of the island, namely San Juan, Ponce, and Mayagüez. In Puerto Rico the trailer comes in different lengths, which will be classify in two main categories: short, and normal trailer. A short trailer is 20 feet in length, while normal trailers are 40, 45, 48, and even 53 feet in length. The tractor part of the truck ranges from 20 to 22 feet in length. A typical spacing between axle in the tandem axle is four feet six inches. The spacing between the single and tandem axle ranges from 10'9" to 17'1' depending upon the length of the truck.

According to the regulations of Puerto Rico stated in the "Reglamento de Dimensiones y Pesos de Vehículos que Transitan por las Vías Públicas", unless granted a special permit, the following vehicles cannot transit public roads:

- single unit truck or bus with length greater than forty (40) feet
- semi-trailer trucks with length greater than fifty-three (53) feet
- any combination greater than three (3) vehicles
- any combination of vehicles with length greater than seventy-five (75) feet
- any vehicle or combination of vehicles whose load or devices used to sustain them extends more than three (3) feet to the front or six (6) feet to the back
- any vehicle wider than eight (8) feet - six (6) inches
- any vehicle that exceeds a height of thirteen (13) feet - six (6) inches

2.9 Truck Tire Pressure

Truck tires are important because they transfer the load to the pavement. Tire contact is calculated using the pressure of the tire. The normal pressure is supposed to be 60 psi (pound per square inch). Tire pressure is different for hot air pressure and cold air pressure. As travel time passes, the pressure increases from 8 to 10 psi. The pressure applied to the tires depend on the kind of tire and the load the truck is carrying. For example, in single tire configuration, a tire can sustain a recommended load of 7,030 lbs.

at a pressure of 120 psi cold; this same tire used in a dual arrangement with 6,170 lbs. uses 110 psi cold. The average pressure used in Puerto Rico ranges from 80 to 100 psi, which when hot will increase to 90 to 110 psi.

Trucks today usually use the so-called super single tires. The single unit dump truck, used to carry aggregates to construction sites, uses this type of tire quite often. This type of tire is known as Valum and the pressure ranges from 80 to 120 psi.

2.10 Previous Studies

WIM data can be very useful for both highway and bridge applications. Since the implementation of the Strategic Highway Research Program (SHRP), a 5-year $150 million research program to improve the performance and durability of U.S. roads and to make them safer for both motorist and highway workers, weigh-in-motion technology has been commonplace. It is estimated that more than 2,000 traffic lanes equipped with WIM devices have been installed in North America, with installations in virtually all states (Hajek et al., 1994).

New mechanistic-based pavement design procedures under development by various agencies will likely require the use of axle load distribution (Kim et al. 1998). Simple regression models can be fitted to the cumulative frequency curves for the axle load distribution. An example of this type of model for the North Central Region of the United States is the following (Kim et al, 1998):

- Single Axle ($0 \leq W < 37$ kN)
- Tandem Axle ($0 \leq W < 67$ kN)

- $CF = \alpha_1 W^3 + \alpha_2 W^2 + \alpha_3 W$

  Where: CF = Cumulative Frequency

  W = axle load

  α_i = regression constants

Another use for WIM data is to transform the axle load distribution to an equivalent single axle load of 18,000 pounds or, simply stated, $ESAL_{18}$. By doing this the traditional empirical pavement design can be used in the design of pavements.

WIM data has different uses. In the request for proposals prepared by the PRHTA (Castro, 1993), WIM data for pavement applications provides the basis:

- providing comprehensive and reliable axle load distribution, gross vehicle weight and related traffic data to assist in the pavement design and rehabilitation process
- complying with the data requirements of the Strategic Highway Research Program (SHRP) Long-Term Pavement Performance (LTPP) sections
- providing traffic estimates to assist in the development of performance models of in-service pavements that will assist in the priority setting and decision process for the network level Pavement Management System (PMS) as required by AASHTO, FHWA and documented in the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA)

- measuring and forecasting the traffic growth on highways and reporting highway statistics mandated by the Federal Highway Administration (FHWA) in the 1992 Traffic Monitoring Guide (FHWA, 1992).

In the following paragraphs a brief description is given for some of the literature reviewed for this research.

Some studies show the effect of the loading on the pavement. It has been demonstrated that increasing loading of trucks drastically increases 18-kip equivalent single axle load ($ESAL_{18}$). As a result, a shorter pavement life is expected for pavements that are subjected to this kind of loading. A pavement with an overweight/legal ratio of 5 to 1 can reduce its design life from 20 years to 4.2 years. (McElhaney, 1985).

Chira-Chavala et al. (1986) developed a data collection plan for truck weights using weigh-in-motion equipment for Texas. This plan, based on probability-sampling framework criteria for selecting preliminary locations for weighing stations, was also developed to capture maximum variability of truck weights and types.

Stoneman and Moore (1989) reported a trial of high-speed, weigh-in-motion (HSWIM) equipment conducted by the Transport and Road Research Laboratory (TRRL) in February, 1987. This trial provided information about the measurement accuracy of WIM equipment both commercially available and under development for a range of axle weights. Results obtained from the equipment trial indicate that piezoelectric transducer systems produced results as good as traditional TRRL equipment. It was found that weights obtained by the piezoelectric system and capacitive pads were within a few per cent of the static load.

Cole and Cebon (1992) developed a theory for the design of multiple capacitative strip sensor WIM systems to minimize the errors caused by the dynamic axle loads of heavy vehicles moving at highway speeds. The advent of low cost WIM sensors provides the possibility of using two or more sensors along the road in order to compensate for the effects of dynamic forces in the determination of static axle loads. Results showed that arrays with 3 or more evenly spaced sensor system are more robust to speed and frequency variations, than 2-sensor system. Three-sensor arrays are likely to give 1/3 to 1/2 of the errors for single-sensor system.

Santoni (1993) conducted a research project at UPR-Mayagüez that consisted primarily of the statistical evaluation of WIM data collected with the Golden River WIM equipment owned by PHRTA. Three highway segments with high traffic volumes were evaluated, namely PR-64 in Mayagüez, PR-14 in Ponce and PR-165 in Cataño, Puerto Rico. The study also documented a data calibration validation procedure and guidelines for similar weighing equipment. The study revealed that inadequate calibration of the equipment can contribute to the lack of accuracy and reliability of traffic data. The need to follow standard procedures and test methods for WIM data collection and analysis, such as those documented by ASTM E 1318, is critical for design and enforcement.

Dahlin and Novak (1994) compared weight data collected at weigh-in-motion systems at three different sites on the same route. One of the relevant findings was that in certain cases weight data collected at one site could be used with confidence at the other sites on that route. Also the directional patterns observed at these three sites were all such that it was possible to calibrate the WIM systems.

Chunhua Han et al. (1995) proposed a methodology to enhance the existing quality check program by monitoring data patterns. It corrects for calibration drift in distributions of gross vehicle weight of tractor semitrailer (loaded and unloaded). This method is labor-intensive, however. It is proposed that statistical process control be integrated with the existing quality check program.

Sánchez (1996) analyzed the truck traffic volume and composition, axle loads, and equivalent single axle load (ESALs) for trucks entering the USA at Laredo and El Paso, Texas. Sánchez found that the composition of truck traffic is different in Laredo and El Paso. At both locations, five-axle trucks constitute the major portion of the vehicles observed. Truck traffic at El Paso comprised about 82 percent, while in Laredo constituted about 62 percent. He found that the second most common type of truck observed in Laredo was the four-axle configuration, which made up approximately 20 percent of the total number that passed over the WIM system.

Najafi et al, (1997) developed a computer program to analyze Florida's Department of Transportation WIM data, using Microsoft Excel and Visual Basic, to calculate the number of trucks, maximum, minimum, and generate average truck damage factors for each truck classification. Damage factors were calculated based on the 18-kip Equivalent Single Axle Load. The program excluded bad data such as a "burp" in the system or any other spacing problems, such as a short container on a short trailer frame.

In summary, weigh-in-motion technology is being used all around the United States due to the fact that the data obtained is reliable and measures the full spectrum of vehicles currently on the roads. The resulting data can be used for planning of transportation facilities, as well as for pavement design and rehabilitation, apportionment of pavement damage, and safety-related analysis.

CHAPTER THREE

DESCRIPTION OF THE WIM/AVC STATIONS, SOFTWARE, EQUIPMENT, INSTALLATION, AND CALIBRATION

3.1 Introduction

This chapter describes the WIM/AVC stations and equipment used to gather the data for this research, including installation and calibration.

3.2 WIM/AVC Hardware

The equipment used in this research was installed by Santa Fé Technologies for the Puerto Rico Highway and Transportation Authority. This research uses the data gathered by such equipment. The arrangement used in each lane consists of two Phillips Vibracoax Piezoelectric Sensors and a wired loop detector. The configuration used for the outer lane and the inner lane are different. The outer or driving lane has two class A rigid piezoelectric sensors that weigh and classify vehicles, and a wired loop detector (Figure 3.2.1). The inner or passing lane is composed of a combination of two piezoelectric sensor class B, capable of classifying vehicles, and a wired loop detector (Figure 3.2.2). All lanes are connected to a data collection box with a TEL-2CM, from Mikros System, powered by solar panels (Figure 3.2.3), connected to a battery. Figure 3.2.4, demonstrates the TEL-2CM and Laptop computer used to retrieve site data. In Puerto Rico the data is gathered from the station by a technician, from Santa Fé Technologies, on a weekly basis.

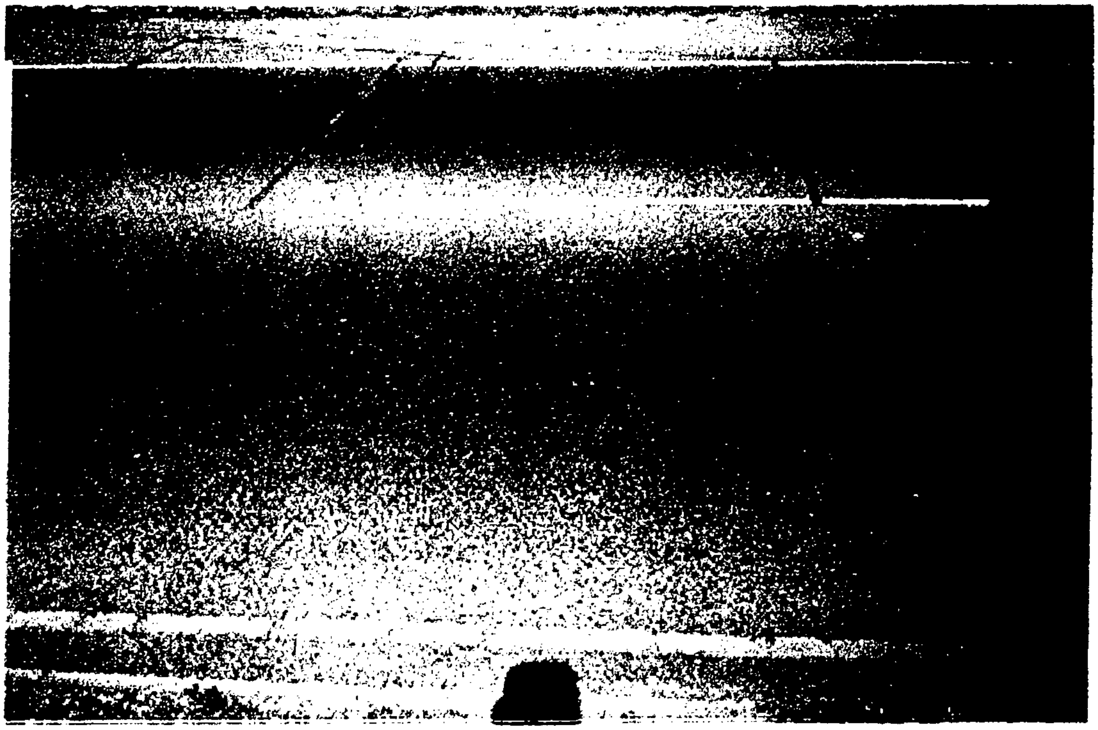


Figure 3.2.1 WIM Configuration in Outer or Driving Lane

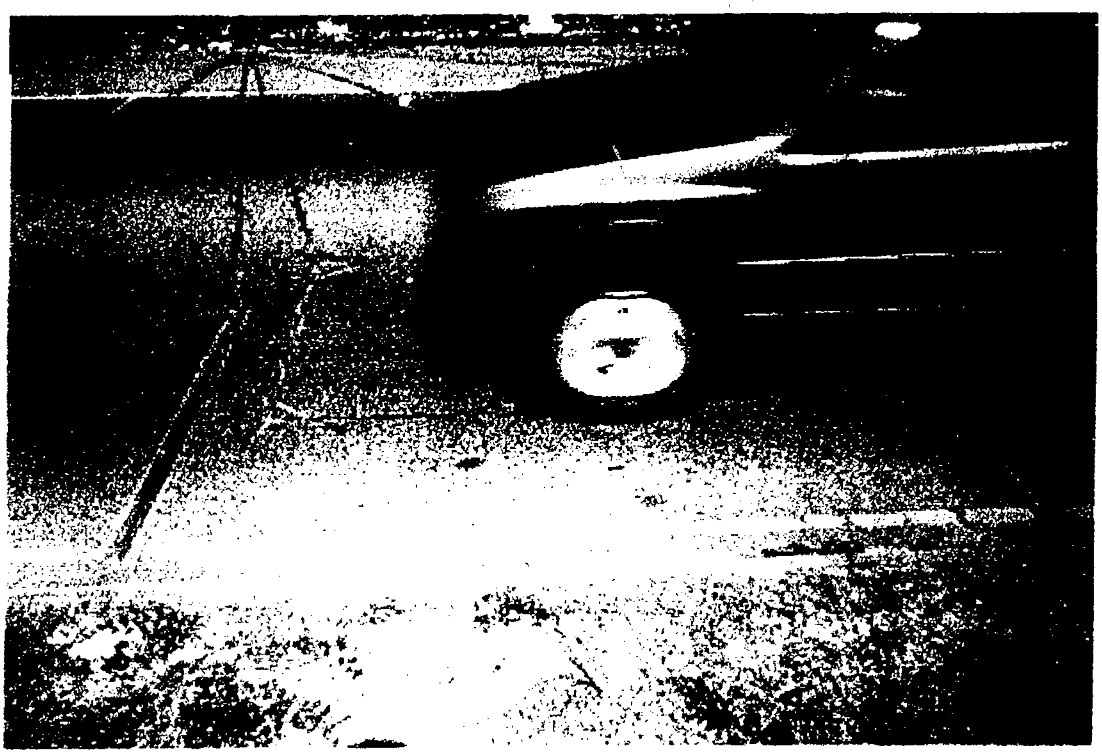


Figure 3.2.2 WIM Configuration on Inner or Passing Lane

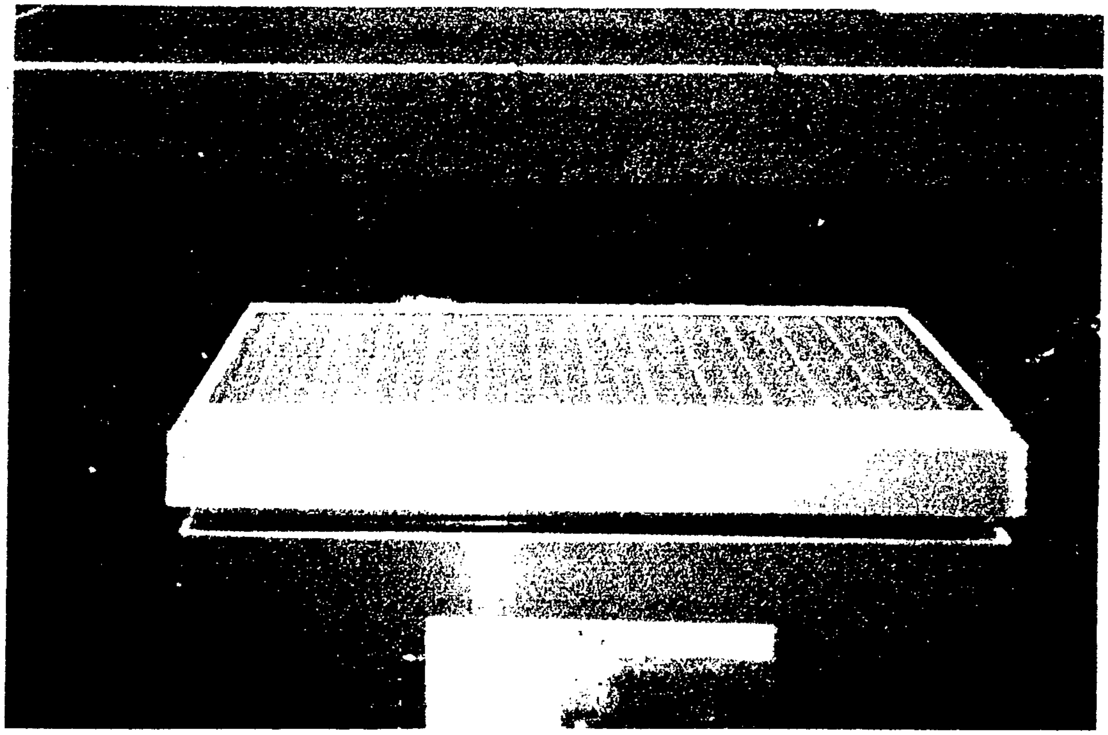


Figure 3.2.3 Solar Panel on Top of Data Collection Box

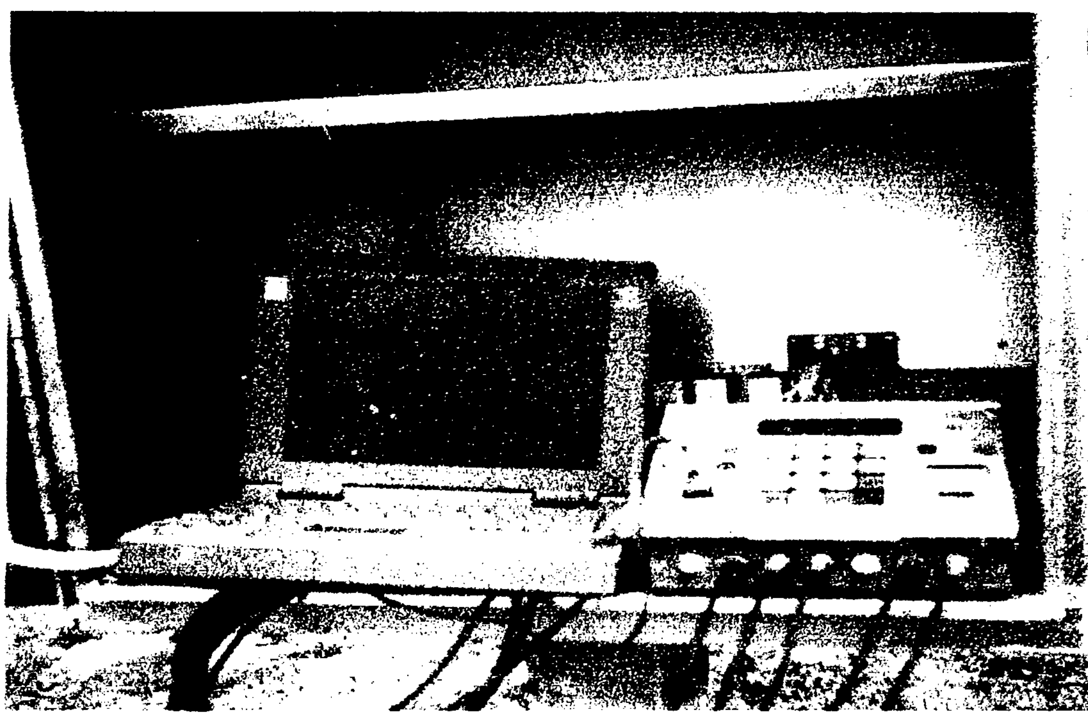


Figure 3.2.4 TEL-CM and Laptop Computer Used to Retrieve Data

3.3 Installation Procedure

The installation of WIM stations is relatively fast, and it can be done one lane at a time in order to minimize traffic disruption. The average price of the HSWIM stations in Puerto Rico was around $37,000 including calibration. A steel saw is used to cut a groove in the pavement surface as seen in Figure 3.3.1. For the piezoelectric sensor the opening in the pavement has to be 1.5 inches (3.81 cm) wide and 1 inch (2.54 cm) deep. The piezoelectric cable installed in the outer lane is 11.5 feet (3.5 m) in length, and the one in the inner lane is 6 feet (1.828 m) long. Sensors are mounted in an aluminum channel by means of encapsulation in a tan sand epoxy or flexan 80 mixture. The spacing between the two piezoelectric sensors used in all the WIM stations is 10 feet (3.048 m), two piezoelectric cables are used to obtain an average of the weigh obtained by each piezoelectric cable. The transmission cable used is a polyethylene jacketed 50-ohm coaxial cable type RG 58 C.U. Figure 3.3.2 shows the installation and the cable used at the WIM station of Mayagüez.

Figure 3.3.1 Saw Used to Cut Pavement to Install WIM Equipment

Figure 3.3.2 Installation of Coaxial Cable at Mayagüez Station

Santa Fé Technologies under the supervision of the PRHTA performed the installation of the WIM stations. The installation dates are presented in Table 3.3.1.

Table 3.3.1 Installation Dates for WIM Stations.

Station #	Town	Road and Km.	Installation Date
1	Arecibo	PR-22 Km. 69.8	January 27th, 1997
2	Arecibo	PR-22 Km. 71.75	November 7th, 1996
3	Caguas	PR-52 Km. 6.7	November 1st, 1996
4	Hatillo	PR-2 Km. 84.6	Pending
5	Gurabo	PR-30 Km. 9.4	August 7th - 11th, 1995 Repaired October 1996
6	Mayaguez	PR-2 Km. 147.8	November 18th - 22nd
7	Rio Grande	PR-3 Km. 26.8	August 1995
8	Peñuelas	PR-2 Km. 213.8	November 15th, 1996
9	Guayama	PR-53 Km. 88.7	September 1995
10	Salinas	PR-52 Km. 70.3	November 1995
11	Ceiba	PR-53 Km. 1.1	September 1995

3.4 Field Calibration Procedure

In order to obtain the best results from the HSWIM system, calibration of the sensors should be performed on site with the sensor installed. In this way, the calibration factor determined was partially compensate for site characteristics that may have an adverse effect on weighing accuracy.

Although individual axle loads can also be used in calibrating the sensor, it is recommended that the Gross Vehicle Mass (GVM) be used for calibrating purposes. This eliminates some of the dynamic variance that must be taken into account. Two types of trucks were used in the field for purpose of calibration, namely a single unit truck class 6 and a tractor semi-trailer truck class 9. A radar gun was used to test vehicle operating speeds. Both trucks were loaded with concrete blocks with at least 5 tons on the rear axle and then weighed at a very precise static scale used for commercial truck weighing. The equipment can be calibrated using the TEL-2cm display or the TELCOM program. The calibration used at WIM stations in Puerto Rico was done using the TELCOM program in a Laptop computer connected to the data port, as shown previously in Figure 3.2.4. The calibration procedure is relatively simple and is described in the following steps:

1. Se tup the TEL-2cm in any individual vehicle weighing program
2. For a new sensor with no calibration history, select the default calibration factor of 4000.
3. Drive the vehicles mentioned above over the WIM and record the GVM for each vehicle.

4. Compare the Static Gross Vehicle Mass of each measured truck with the Dynamic GVM as measured at the HSWIM.

5. Calculate the calibration factor.

6. Enter the new calibration factor and verify.

In Puerto Rico, the calibration was done using a class 6 and a class 9 truck. The calibration dates are presented in Table 3.4.1.

Table 3.4.1 Field Calibration Dates

Station #	Town	Road and Km.	Calibration Date
1	Arecibo	PR-22 Km. 69.8	May 30, 1997
2	Arecibo	PR-22 Km. 71.75	May 16th, 1997
3	Caguas	PR-52 Km. 6.7	Pending
4	Hatillo	PR-2 Km. 84.6	Pending
5	Gurabo	PR-30 Km. 9.4	January 21st 1997
6	Mayagüez	PR-2 Km. 147.8	January 22nd 1997
7	Río Grande	PR-3 Km. 26.8	September 23rd 1996
8	Peñuelas	PR-2 Km. 213.8	May 17th 1997
9	Guayama	PR-53 Km. 88.7	September 24th 1996
10	Salinas	PR-52 Km. 70.3	May 17th 1997
11	Ceiba	PR-53 Km. 1.1	September 23 and 24th 1996

3.5 WIM/AVC Software

Two software programs were used to handle the data for this research: TELCOM and TELDAT, both from Mikros Systems. TELCOM is a program that enables the user to set up, control, monitor, and extract data from the Mikros Systems' Traffic Event Logger (TEL). TELDAT is traffic event logger data-processing software. The software used to read and convert the raw data to spreadsheet format is called WIMAVC, develop by Eng. Israel Pábon under the supervision and guidance of Dr. Benjamin Colucci and Eng. Javier Vega.

The primary functions of TELCOM are:

- set-up and TEL configuration
- system information acquisition
- traffic data extraction
- diagnostics reporter
- calibration
- violation display.

The TELDAT program analyses data collected by the TEL-2cm Traffic Event Loggers. The program primarily analyses data collected by Weigh-in-Motion data captures programs. TELDAT has three primary functions:

- the viewing of logger status and data records as recorded
- the generation of reports from stored data (Section 3.6)
- the conversion of the TEL extracted files to a number of ASCII text format files.

The standard format in which traffic data is stored and extracted from MIKROS Traffic Event Logger is the so-called binary image formats. This not only optimizes data storage, but also stores the maximum amount of information on logger performance. All the reports generated by TELDAT are done from either the IMG (image) format or the XTX (extended text format). The XTX is the MIKROS standard for ASCII text.

For this research the first data analyzed were the reports obtained from the TELDAT program. Such reports are discussed in more detailed in section 3.6 of this work. Later the "raw" data or detailed data by vehicles was obtained and used. The only problem was that the "raw" data was too extensive, and a preprocessor had to be made, called WIM/AVC. Also a spreadsheet such as Excel was used to filter the data and to obtain the errors present in the "raw" data. In Appendix B, an example of the raw data is presented. In Appendix C, the worksheet used to filter and analyze WIM data is presented. In Chapter 4 a more detailed explanation of the "raw" data analysis is presented.

3.6 Description of WIM/AVC Reports

The data gathered from the Weigh-in-Motion and Automatic Vehicle Classification Systems can be obtained in the following standard formats. Each report has different information; a brief description of the type of data in each report is given in Table 3.6.1.

Table 3.6.1 Description of WIM/AVC Reports

Report	Activity
1	Daily Volume Summary
2	Weekly Classification Summary
3	Daily Speed Distribution Summary
4	Daily GVW Versus Class Distribution Summary
5	Daily GVW Distribution Summary
6	Weekly Weigh & Overload Summary
7	Daily ESALs Details / Class
8	Daily EAL Details / Class
9	Daily Binned EAL Details / AxleClass

Each report has information such as type of report, period of data collection, site description, direction (i.e. eastbound), lanes, and report interval (hourly). As an example of the detail included in each report, the Rio Grande station is used. The direction of the lanes for Rio Grande is eastbound and westbound. The WIM/AVC equipment uses the format described in Figure 3.6.1.

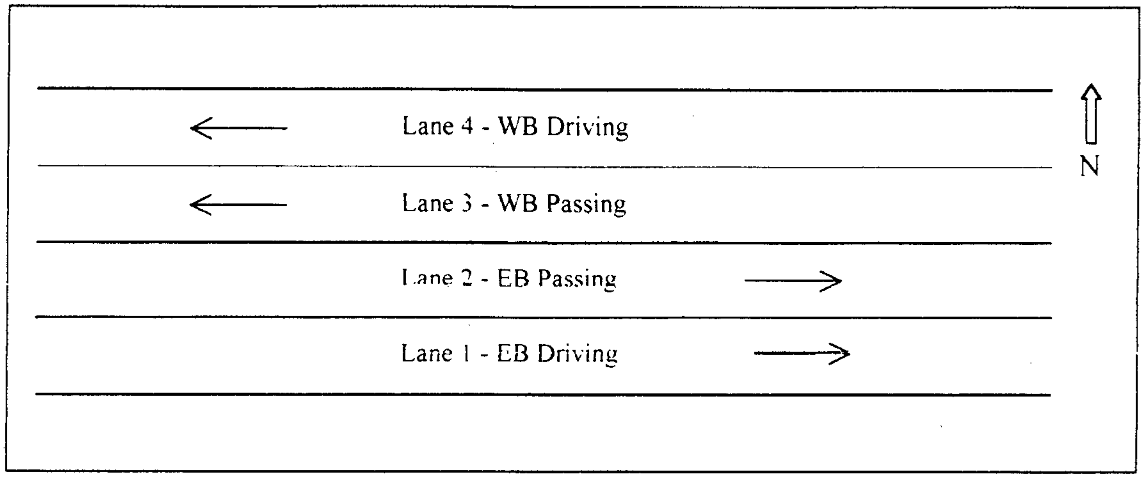


Figure 3.6.1 Schematic of WIM/AVC at Río Grande Station

REPORT 1, Daily Volume Summary

This report is useful to generate traffic versus time graphs. Peak traffic hours can be identified, and they can be compared among lanes, stations and roads. This report can also be used to develop regression equations for predicting traffic.

REPORT 2, Weekly Classification Summary

This report describes the number of vehicles in each class at given time. Using bar charts, the percent of each vehicle can be known. Figure 3.6.2 shows the percent of each vehicle class for the Rio Grande Station. By comparing this type of graph with a visual check in the field, the data can be verified by lanes, direction and road.

Figure 3.6.2 demonstrates that passenger cars are the most used vehicle, as expected. Even though the graph shows the most critical trucks to be class 5 and 8, in reality according to field visits, class 6 and 9 are more common.

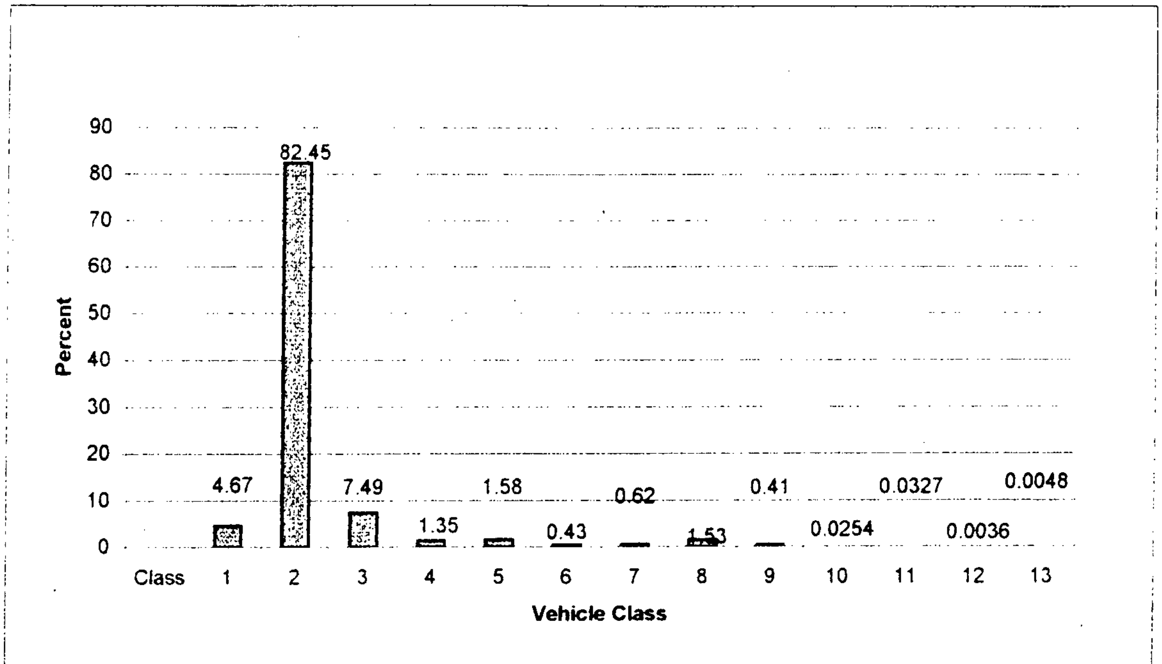


Figure 3.6.2 Percent of Each Class of Vehicles in Río Grande Station

REPORT 3, Daily Speed Distribution Summary

This report gives the distribution of speed by lane and direction, during a 24 hr period. This information can be useful to detect zones with potential for accidents due to vehicles going too fast or too slow. Preventive surveillance by police can be made in sites were velocities are extremely high and can cause a fatal accidents. Figure 3.6.3 shows the distribution of vehicles from 0-40 mph in a week starting from Thursday and ending on a Wednesday. It can be observed that people drive slower on Saturday than on other days. At the other extreme, some drivers exceed 85 mph, especially on Mondays.

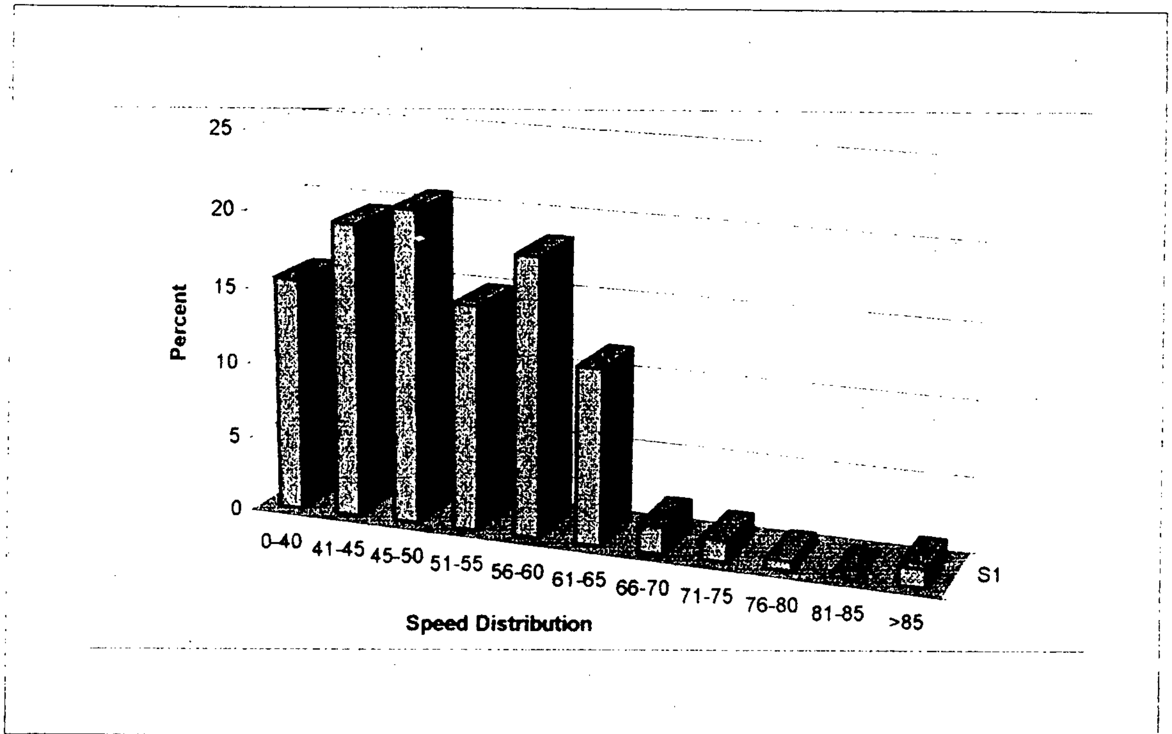


Figure 3.6.3 Speed Distribution Summary - Río Grande Station

REPORT 04, Daily GVM versus Class Distribution Summary

This report reveals the weight distribution by class and thus shows a pattern of vehicle overweight by class. The information is collected 24 hours a day and is presented by lane, direction, or road.

REPORT 05, Daily GVM Distribution Summary

This report presents the weight distribution by the hour of the day. It shows the number of vehicles by weight category (i.e. 25-35 kips). The information is presented by lane, direction and road.

REPORT 06, Weekly Weight and Overload Summary

This report gives a wide range of results in well-organized tables. First, there is a summary of how many light and heavy vehicles the equipment counted. The heavy vehicles in lane 1 and 4 all are weighed and the percent of overload is shown. Figure 3.6.4 shows the type of light and heavy vehicles for the Río Grande station.

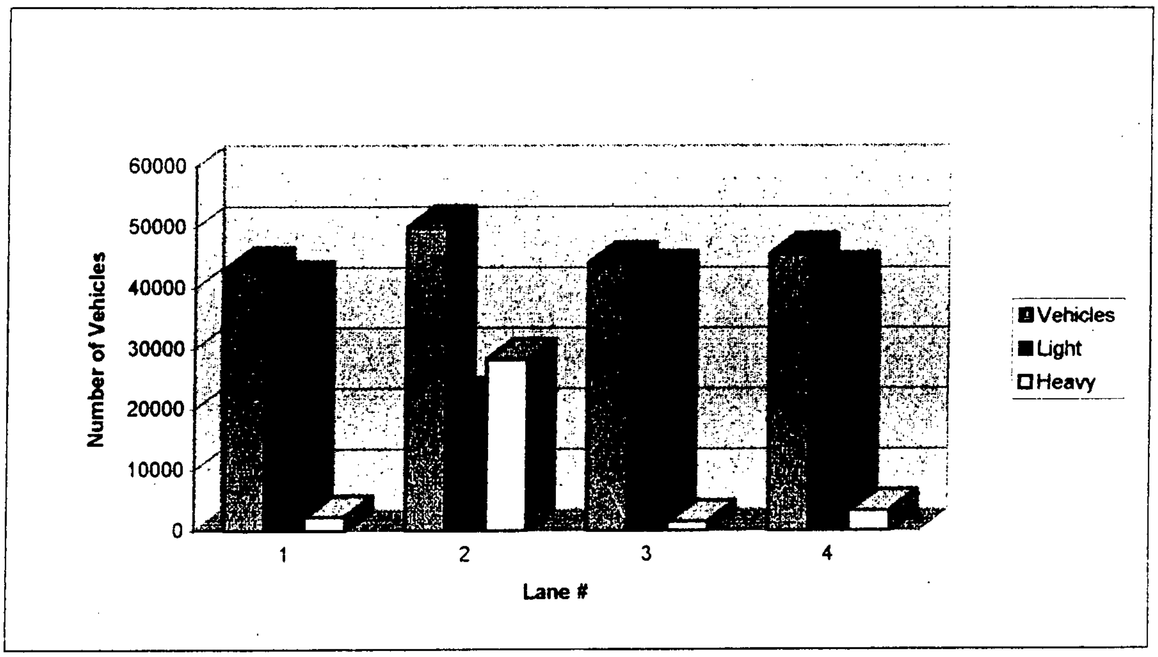


Figure 3.6.4 Distribution of Light and Heavy Vehicles - Río Grande Station

Table 3.6.2 is an example of the type of information found in this particular report, which reveals the overloaded trucks per lane and the number of heavy vehicles not being weighed due to the WIM setup. Also this type of information can serve to verify WIM data with real time data.

Table 3.6.2 Vehicle Summary

Summary	Lane 1	Lane 2	Lane 3	Lane 4	Cway 1	Cway 2	Total
Vehicles	43238	50031	44076	45578	93269	89654	182923
Light	40922	21816	42587	42297	62738	84884	147622
Heavy	2316	28215	1489	3281	30531	4770	35301
Heavy Weighed	2316	0	0	3281	2316	3281	5597
Overloaded	231	0	0	207	231	207	438
% Weighed	100.0%	0.0%	0.0%	100.0%	7.6%	68.8%	15.9%
% Overloaded	10.0%	0.0%	0.0%	6.3%	10.0%	6.3%	7.8%

Table 3.6.2 shows that at Río Grande, lanes 1 and 4 are the only ones with overloaded vehicles. This is because the WIM equipment is located in the outer lanes only, which trucks should use, AVC equipment is on all four lanes. According to Table 3.6.2 more than 10 percent of the vehicles are overloaded in lane 1 and 6.3 percent in lane 4. A total of 7.8% of all trucks traveling on in this road are overloaded.

Another kind of table is the Axle Overload Summary (Table 3.6.3), which gives a range of percent of overload and the trucks overloaded for each direction.

Table 3.6.3 Axle Overload Summary

Overload	Cway 1	Cway 2	Total	%Cway 1	%Cway 2	%Total
0% - 5%	26	50	76	1.10%	1.50%	1.40%
5% - 10%	34	27	61	1.50%	0.80%	1.10%
10% - 15%	24	28	52	1.00%	0.90%	0.90%
15% - 20%	24	18	42	1.00%	0.50%	0.80%
20% - 25%	16	16	32	0.70%	0.50%	0.61%
> 25%	107	68	175	4.60%	2.10%	3.10%

Table 3.6.3 reveals an interesting pattern, the majority of trucks are overloaded by more than 25%, resulting in greater pavement damage. Due to the fact that the

equipment has limited memory capacity, it was set up to record only vehicles in classes 4 through 13. Table 3.6.4 has the details of axle overload for the different vehicles.

Table 3.6.4 Axle Overload Details

Class	Vehicles Weighed	Vehicles Overload	Percent Overload	Percent Axle Overloading					
				0-5	5-10	10-15	15-20	20-25	>25
4	1706	56	3.3	0.6	0.5	0.5	0.5	0.2	1
5	1284	119	9.3	3	1.4	1.3	0.7	0.5	2.3
6	347	106	30.5	2	3.5	2.3	2.6	2.6	17.6
7	28	13	46.4	7.1	3.6	3.6	3.6	10.7	17.9
8	1835	33	1.8	0.3	0.3	0.3	0.2	0	0.8
9	331	93	28.1	2.4	4.2	3	2.7	3	12.7
10	32	7	31.9	3.1	6.3	0	6.3	3.1	3.1
11	19	7	36.8	15.8	0	5.3	0	0	15.8
12	6	3	50	16.7	0	16.7	0	0	16.7
13	9	1	11.1	0	0	0	0	0	11.1

REPORT 07, Daily ESAL Details / Class

This type of report has details of ESAL by vehicle class. It gives the number of axles for each class and the mean and standard deviation. The report also has ESAL factors for rigid and flexible pavements.

REPORT 08, Daily EAL Details / Class

Report 08 is very similar to report 07, the difference being that report 08 is the equivalent axle load and report 07 is equivalent single axle load. Different classes are presented from 4 to 13, as explained above.

REPORT 09, Daily Binned EAL Details / AxleClass

This report gives by class the mean (Ton), Std. Deviation (Ton), and EAL/Axle for each axle by class. The information is given for heavy trucks by lane, direction, and road.

3.7 Description of WIM/AVC Stations

Eleven WIM/AVC stations have been installed in the primary highway network in Puerto Rico. In Appendix D, pictures of all the WIM stations are presented, a description of the structural section for each WIM station is given in Table 3.7.1.

Table 3.7.1 Structural for WIM Stations

#	Town	Road and Km.	Structural Section (meters)
1	Arecibo	PR-22 Km. 69.8	0.20 PCCP; 0.5 B-2; 0.075 B-1; 0.675 Subbase Course Spec. 301
2	Arecibo	PR-22 Km. 71.75	-
3	Caguas	PR-52 Km. 6.7	0.25 PCCP; 0.15 Crushed Stone
4	Hatillo	PR-2 Km. 84.6	0.05 S-1(75); 0.15 B-1(75); 0.15 Agg. Base Course; 1 Subbase Course
5	Gurabo	PR-30 Km. 9.4	"Overlay": 0.05 S-1(75); 0.075-0.1 B-1(75); 0.025 L-2(75)/over existing PCCP(0.20) to be CRR
6	Mayagüez	PR-2 Km. 147.8	0.05 S-1(75); 0.15 B-1(75); 0.15 Agg. Base Course
7	Río Grande	PR-3 Km. 26.8	"Overlay": 0.05 S-1(75); 0.08 B-1(75); 0.025 L-1(75)/over existing PCCP(0.20)
8	Peñuelas	PR-2 Km. 213.8	"Overlay": 0.05 S-1(75); 0.08 B-1(75); 0.025 L-1(75)/over existing PCCP(0.20)
9	Guayama	PR-53 Km. 88.7	0.20 PCCP; 0.05/0.075 B-2 / B-1
10	Salinas	PR-52 Km. 70.3	0.25 PCCP; 0.35 Crushed (Stone or Gravel) class 2
11	Ceiba	PR-53 Km. 1.1	0.20 PCCP; 0.05 B-2; 0.075 B-1; 0.0675 Coarse (Subbase)

3.8 Land Use Patterns

One of the activities done in this research was to identify the land use for the WIM stations in order to have a more comprehensive understanding of the results obtained. For this task, the Planning Board of Puerto Rico was visited to identify the land use patterns around the stations. Only 35% of Puerto Rico is classified in the land use maps. Even though the data was limited, schematics of land use were prepared for this research to show the best representation possible. A brief description of each station is presented below, and their corresponding schematic is shown in Appendix E.

ARECIBO: (001, 002)

Arecibo has two stations located about 2 km apart on PR-22; both are in a 4 lane urban interstate which is part of the SHRP study. PR-22 has a 55-mph posted speed limit, with an Average Annual Daily Traffic (AADT) estimated in 1994 at 31,500 vehicles for station 001 located at km. 69.8, and 44,400 (1995) for station 002 at km. 71.75. Station 001 is in rigid pavement while 002 is in flexible pavement. Their land use varies from R-0 (low density land use where the minimum area is 8,000 mts^2) to R-2 (one or two family houses with area greater than 450 mts^2). Also some commercial and industrial land use is present.

GURABO: (005)

Gurabo station is located on PR-30 at km. 9.4, and is classified as an urban freeway. It is a 4-lane road with a 55 mph posted speed limit. The existing pavement is a flexible pavement overlay over a Portland Cement Concrete Pavement. The ADT is 60,925 (1997-WIM). The volume of traffic on this road is significant due to the fact that it connects the towns of Guarabo, Juncos, Las Piedras, and Humacao with PR-52 going to San Juan or Ponce. The station is surrounded by residential area, but industrial and commercial areas are also present. The annual precipitation is 79.23 inches, and the soil is mainly clayey.

MAYAGUEZ: (006)

Due to the growth of the western part of the island in recent years, Mayagüez is a major trading center for the island. The WIM station is located on PR-2 at km. 147.8, to the north of the downtown area. It is a 4 lane urban interstate with an ADT of 50,143 vehicles (1997-WIM); it's posted speed limit is 55 mph. Its pavement is a three layer flexible pavement. Annual precipitation is 64.92 inches. In interviews with three of the major truck companies in Mayagüez, it was found that trucks traveling to and from San Juan take the route passing over the WIM station 98% of the time. So the location of the WIM station is ideal because the majority of the truck traffic is measured. Some of the industries near the station are Star-Kist/Bumble Bee, K-Mart, Plaza Masso, Holiday Inn, UPS, Glidden, Abonos Super A, ElyLily Pharmaceuticals, the Regional Distribution Center, and the Eugenio Maria de Hostos Airport.

RIO GRANDE: (007)

The Río Grande station is located in the northeast part of the island, on PR-3 at km. 26.8. It is a 4-lane rural interstate and its posted speed limit is 50 mph. Its pavement is an overlay over existing PCCP. AADT in 1991 was 46,800 vehicles. All the commuters traveling to San Juan from the east part of the island use the road. Land use is varied from residential level 2 and 3 (land between 300 m^2 and 450 m^2) to industrial and C-1 (local commercial) and C-2 (local commercial, as bowling alley, barber shop, etc.).

PEÑUELAS: (008)

Peñuela's is located in the south part of the island near Ponce. The WIM station is located at km. 213.8 on PR-2 and is classified as a 4-lane rural interstate with 50 mph as its posted speed limit. The pavement is an overlay of flexible pavement on top of PCCP. This road is the route taken by the majority of the commuters in the west part of Puerto Rico who work in Ponce or pass through Ponce to reach San Juan. Land use to the west part of the WIM station is mainly industrial and to the east is low density residential.

GUAYAMA: (009)

Guayama is located in the southeast part of the island. Its WIM station is on PR-53 that is classified as a rural principal arterial connecting the PR-52 with Guayama, Arroyo, Patillas, etc. It is a 4-lane road with a posted speed limit of 55 mph. The AADT in 1995 was 11,400 vehicles and in 1997, using WIM equipment, the ADT was 15,524. As it can be seen, this road is a medium volume road, low when compared to others like Mayagüez and Gurabo. The surroundings are mainly rural or countryside, but there is a high industrial activity on the southern side of town. Pharmaceutical industries and refineries are present, and they use this road to send and receive products from San Juan and other parts of the island. It has concrete pavement. Annual precipitation is 60.21 inches, and the soil has variations of limestone, silstone, and clay.

SALINAS: (010)

The Salinas station is on the PR-52 at km. 70.3. It is a 4-lane rural interstate with 55 mph as its posted speed limit. Its pavement is composed of 0.25 meters of PCCP over 0.35 meters of crushed stone or gravel. In 1994, the WIM station had an estimated AADT of 27,700 vehicles. The land use surrounding the station is mainly residential of low density according to the zoning maps, but in visits made to the station it was seen that the area is mainly used for agriculture and the population is very low. The traffic passing through the WIM station is mainly due to travelers or commuters travelling between the eastern and western parts of the island. The land use surrounding the station is not an important factor in determining the traffic patterns of trucks.

CEIBA: (011)

The Ceiba station is located on PR-53 at km. 1.1. This road will connect most of the southeast part of Puerto Rico to the metropolitan area. It is located between the municipalities of Fajardo and Ceiba. The station can monitor most of the traffic activity in the southeast part of the island. The AADT measured in 1994 was of 22,700 vehicles.

It has concrete pavement. The land use surrounding the station is mainly agricultural, but it has residential areas.

CHAPTER FOUR

PRELIMINARY ANALYSIS, CHARACTERIZATION OF TRUCK TRAFFIC, AND ANALYSIS OF INDIVIDUAL VEHICLE CLASSES

4.1 Introduction

This chapter describes the work done in the first part of the research, to analyze the data and identify potential sources of error. Later a characterization of truck traffic was done to identify the typical trucks used and the potential damage being done to pavements by the gross vehicle weight. A methodology is developed to eliminate common errors encountered in the data and filter them. Also an analysis of the typical trucks is presented for each station analyzed.

4.2 Preliminary Analysis

In order to get to know the WIM data being gathered by the new equipment installed in some of the station, the data available was analyzed. Graphical representations were done with the data to compare trends among stations. At the beginning of this research the data used for the graphs was preprocessed by the TELCOM software provided to the PRHTA by Santa Fe Technologies. Later on, the data used to make analysis was the "raw data" and a preprocessor called WIMAVC had to be created due to the extensiveness of the data. Tabular form was also used in this preliminary analysis. The most relevant findings are summarized in the following pages along with tables and graphical representations. The findings are divided into different categories.

Overloaded trucks

- Ceiba has the most overloaded trucks with a 18.6%
- Guayama has 14.7% and Rio Grande has 9.05%

Truck Factors (Table 4.2.1 & 4.2.2)

- T_f ranges from 0.245 to 2.66, for a 3A truck
- For a 3-S2, T_f ranges from 1.282 to 3.793
- Guayama has the most critical truck factor, 2.66 on Wednesday for a 3A truck, and 3.793 on Monday for a 3-S2.
- Lowest T_f in a 24 hour day is 0.245 for Guayama (Sunday)
- The most critical day is different for all stations

  Río Grande - Friday

  Guayama - Wednesday

  Ceiba - has no specific critical day, all T_f are similar

Table 4.2.1 Truck Factor for 3A (class 06)

WIM	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Tf (Week)
Rio Grande	*	*	0.742^	1.545	1.643	1.044	*	1.244
Guayama	1.396	2.4	2.66	1.03	0.708	0.626	0.245	1.295
Ceiba	1.714	1.55	1.371	1.524	1.844	1.515	0.973	1.499

*No data available, ^ Data for 12 hours in a day

Table 4.2.2 Truck Factor for 3-S2 (class 09)

WIM	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Tf (Week)
Rio Grande	*	*	1.526^	1.807	2.324	2.175	*	1.958
Guayama	3.793	3.143	3.133	1.498	1.377	1.417	1.347	2.244
Ceiba	1.447	1.528	1.134	1.282	1.535	1.758	1.703	1.484

*No data available, ^ Data for 12 hours in a day

ESAL (Table 4.2.3, 4.2.4 & 4.2.5)

- Rio Grande has the most ESAL/day (207), for a 3A type truck (Thursday)
- For a 3-S2 truck Guayama has 678.9 ESAL/day which is the highest (Monday)

- For the station of Río Grande Fridays is the most critical day of the week, while for Guayama it was Tuesday, and for Ceiba Thursday based on total ESAL (class 04 - 13)
- Guayama has the highest ESAL/day (1074.722), taking into account all types of trucks

Table 4.2.3 ESAL/day for 3A (class 06)

WIM	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Week
Rio Grande	*	*	24.471^	206.99	205.338	57.395	*	494.194
Guayama	51.66	79.191	154.283	46.343	29.013	7.509	0.734	368.733
Ceiba	101.1	106.972	116.534	144.763	82.969	43.974	20.425	616.737

*No data available, ^ Data for 12 hours in a day

Table 4.2.4 ESAL/day for 3-S2 (class 09)

WIM	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Week
Rio Grande	*	*	38.158^	214.978	316.085	110.942	*	680.163
Guayama	678.901	556.328	485.673	266.656	227.212	131.796	39.066	2385.632
Ceiba	96.955	125.262	94.095	67.968	95.189	33.395	5.109	517.973

*No data available, ^ Data for 12 hours in a day

Table 4.2.5 ESAL Total (class 04 - 13)

WIM	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Week
Rio Grande	*	*	728.715	762.971	846.142	358.029	*	2695.857
Guayama	1030.535	1074.722	1000	475.214	452.492	246.833	51.346	4331.142
Ceiba	420.986	452.146	406.574	452.602	425.772	116.79	32.263	2307.133

*No data available, ^ Data for 12 hours in a day

Weekly Frequency (all vehicles taken into account)

- For Rio Grande (Figure 4.2.1), Guayama (Figure 4.2.2), and Ceiba (Figure 4.2.3):
  - ⇒ Frequency has different patterns for weekdays and for weekends
  - ⇒ For weekdays any day could be taken as representative due to the fact that all the daily curves overlap in the mornings, and in the afternoons they stay close together
  - ⇒ Sundays traffic has its highest peak during business hours (11:00 am to 5:00 PM)

Frequency vs. GVM (typical 3-S2)

- Taking into consideration that the 3-S2 truck does the most significant damage to the road as seen in the ESAL/day. Graphical representation is presented to analyze days of the week by the frequency of weight at the three stations.
- Frequency of 3-S2 trucks varies among the days of the week, but at the same time a pattern of loaded and unloaded trucks can be identified.

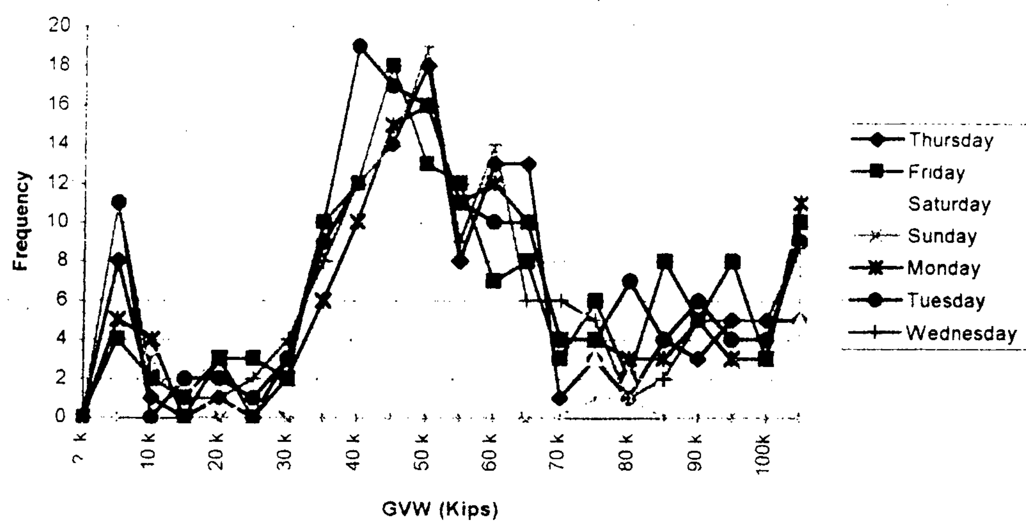


Figure 4.2.1. Frequency vs. GVW for Río Grande Station (Truck 3-S2)

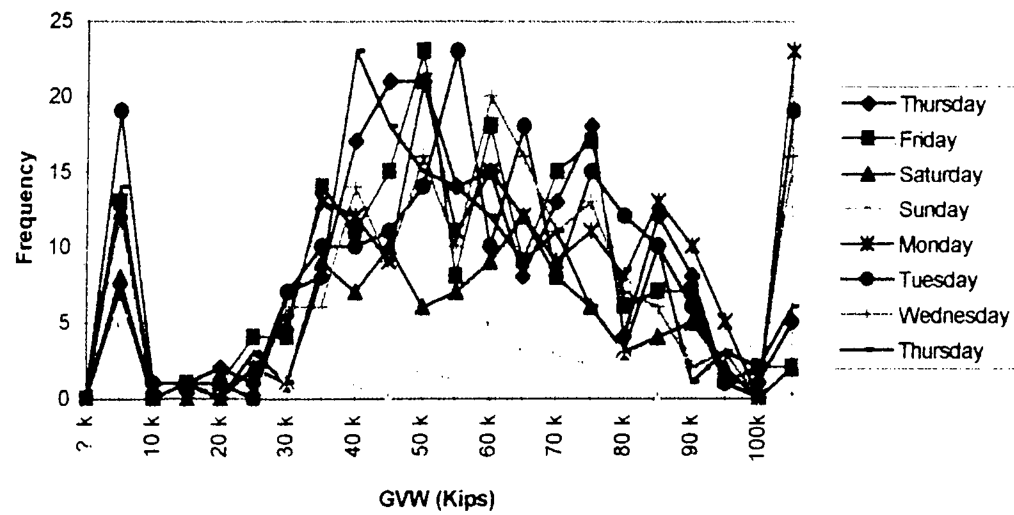


Figure 4.2.2. Frequency vs. GVW for Guayama Station (Truck 3-S2)

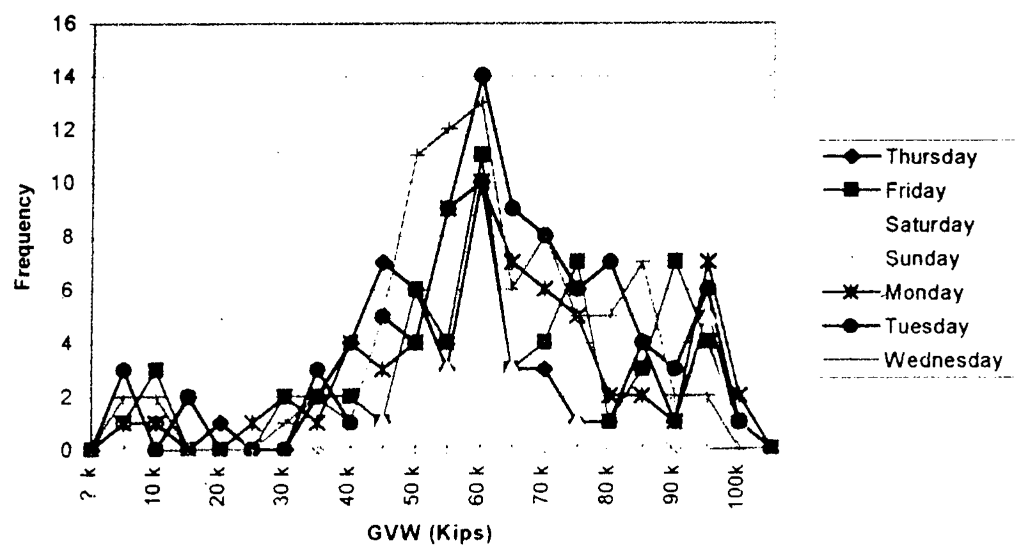


Figure 4.2.3 Frequency vs. GVW for Ceiba Station (Truck 3-S2)

- Figure 4.2.1 for Rio Grande demonstrates that most trucks weigh between 30k and 65k, but there are also many trucks weighing over 95k.

- Figure 4.2.2 demonstrates that the most common weight for the Guayama station is between 30k and 95k; it is interesting to notice that Mondays, Tuesdays and Thursdays are the most critical days with a high frequency of 3-S2 trucks weighing more than 100k. This fact is in accordance with the high truck factors and ESAL/day, mentioned before.
- Figure 4.2.3 demonstrates that the 3-S2 trucks passing through the Ceiba station vary in weight between 40k and 100k.
- The data from the Ceiba station don't show a 3-S2 over 100k, and the frequencies in general are not as high as for the other two stations.

General Conclusion:

- Ceiba is the most overloaded station with 18.6% according to the data given by the reports of TELCOM, while at the same time Ceiba's trucks are lower than Guayama. This indicates that there may be some kind of error in the analysis.
- Highest truck factor = 3.793 for 3-S2, and 2.66 for 3A (Guayama).
- Guayama has the highest ESAL/day for 3-S2 truck = 679 ESAL/day.
- Guayama has the highest ESAL/day for the total of all the classes = 1074.
- Therefore Guayama is the most critical station.
- There are different critical days of the week for each station.

Based on the preliminary analysis and some irregularities in the results of the preprocessed data, we proceeded to analyze the raw data to locate and magnitude of errors produced by the equipment.

4.3 WIM/AVC Preprocessor

In order to process the raw data, a preprocessor program called WIMAVC was prepared by Eng. Israel Pabón, with specifications given to him by Dr. B. Colucci, and Eng. Javier Vega. A quick reference guide to the program is given in Appendix F.

One of the tasks performed by the program is to read the data from files *.trf and convert them to files that could be read by a spreadsheet program. Microsoft Excel is used to analyze and filter. Due to the extensive amount of data, computer files for each day of the week are processed, and then the preprocessor WIMAVC created one file for each classification of truck, class 1 through 13, for each day of the week. Since the WIM equipment stores only classifications 4 to 13, only the files generated for classes 4 to 13 are important. Therefore, 10 files for each day of the week for each station are created and analyzed.

Different algorithms were used in Excel to make the process as automatic as possible. There are four different sheets in the worksheet used for each classification. An explanation is given below which is useful for explaining what each sheet would do, also in Appendix C a set of sheets is given as an example of the process;

1. **Sheet 1, Class #**

The first step was to filter the data for common errors. An IF-THEN statement was created in Excel to read each vehicle file and determine if it had errors. Some common errors encountered and filtered from the data were; Speed = 255 mph, spacing between axles of more than 45 feet or less that 3 feet in tandem axles, or more than 8 feet in tandem axles. Other errors encountered were excessive axle weight, for example 5,000 kips on one axle. Also the length of the trucks was checked due to some excessive values encountered, for example a 500-foot long truck or trucks 10 feet long. If the truck data had no error the Excel formula wrote OK, if it had errors it wrote ERROR.

2. **Sheets 2 & 3, Lane 1 & Lane 4**

For each truck, the program reports information on one of two sheets, depending on what lane the truck was using. If the program identifies an error for a specific truck, that truck's information is not reported, so the daily results obtained are as errorless as possible. Also this is where the trucks overweighed according to "Reglamento de Pesos y Medidas" of 1994, and the class they belong to, be identified.

3. **Sheet 3, General Information**

This last spreadsheet displays basic statistics: Gross Vehicle Mass (GVM), the minimum, maximum, and average count of trucks, and the standard deviation for each lane and variable such as speed, axle mass, axle spacing, and length.

Also the vehicle within limits, overweighed and percent overweighed for each direction is calculated. The errors for each station are then calculated and display.

4.4 Vehicle Classes Analyzed

Although the existing FHWA classification of vehicles has 10 different trucks, it was found from preliminary analysis that vehicle classes 5, 6, and 9 are the most used in Puerto Rico, see Figure 4.4.1. The most common truck is class 5, a two-axle, six-tire single unit vehicle, used by UPS, for delivery of general cargo, etc. This type of truck has a legal load of 36,000 pounds. Another typical truck encountered is the class 6, which is a three-axle single unit truck, mainly used for cargo of aggregates and general goods. This type of truck is legal load is 54,000 pounds. The third typical truck encountered was the class 9 or 3-S2, five-axle single trailer truck. This type of truck is very common since it is used to carry most loads from the docks in San Juan to the different towns. Although the legal load limit is set at 96,000 pounds, trucks traveling at night have been recorded weighing as much as 145k.

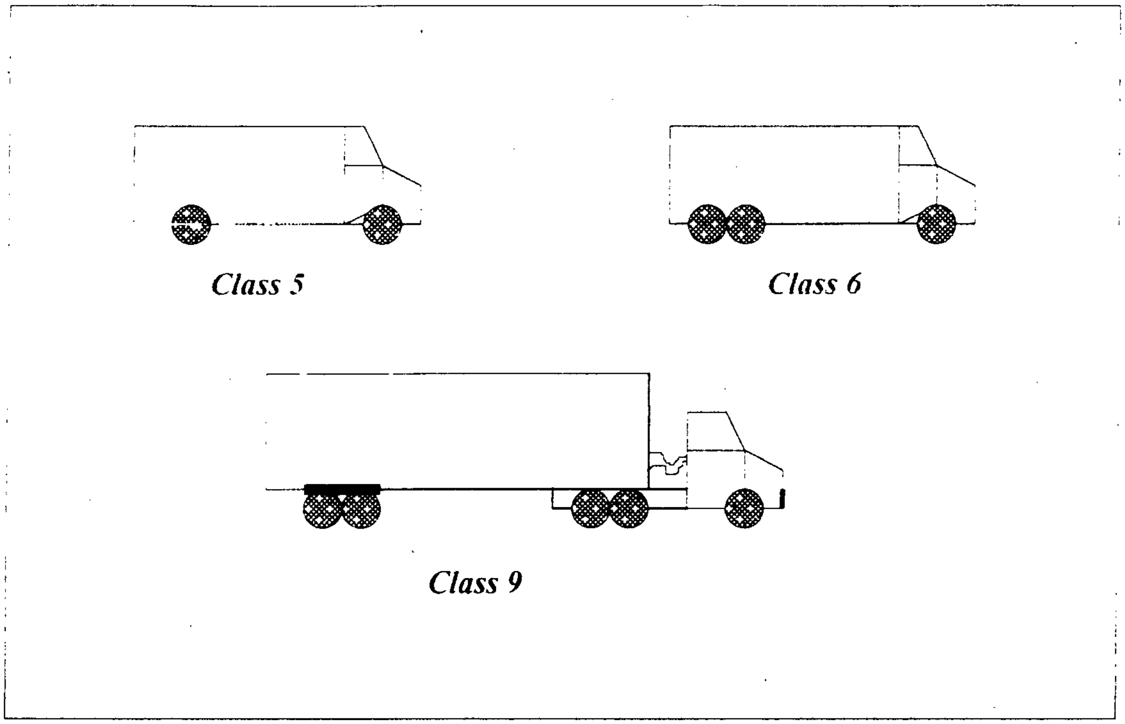


Figure 4.4.1 Typical Trucks Encountered at the WIM Stations

4.5 File Coding

Files *.trf were coded for station and date. The source of the data can be easily identified. Table 4.5.1 shows the abbreviation used for each station.

Table 4.5.1 Station Abbreviation Used

Arecibo Flexible - Af	Gurabo - Gb	Guayama - Gm	Caguas - Cg
Arecibo Rigid - Ar	Mayagüez - Mg	Salinas - Sn	Hatillo - Ht
Rio Grande - Rg	Peñuelas - Pn	Ceiba - Cb	

For example, a file named Af970714, means Arecibo flexible 1997, July 14.

4.6 Analysis of Typical Vehicles

This section presents the analysis of the data and the errors encountered in it. Appendix G shows the weekly results of the analysis for each class presented in this section along with the maximum, minimum, and average gross vehicle load and the number of overloaded and underloaded trucks.

Class 5

As seen in Table 2.8.1 the legal load limit for a steering axle is 12,000 pounds and for a single axle is 22,000 pounds, therefore the maximum allowable gross vehicle weight for a class five truck is 34,000 pounds.

In Figure 4.6.1 it can be seen that the station with the greatest percentage of overweight class 5 trucks is Mayagüez with almost 47% in Lane 1. Lane 1 in Mayagüez is the northbound driving lane. This pattern is expected due to the fact that Mayagüez is the commercial center of the Northwest part of the island. Peñuelas station follows a similar pattern with 23% of overweighed trucks in lane 1. Lane 1 is the southbound driving lane. This pattern is expected in Peñuelas due to the fact that Ponce is the second largest city of the island and a commercial trade center.

Although 34k pounds is the limit for a class 5 truck, we can see in Figure 4.6.2 that Mayagüez reports vehicles weighing almost 80k, twice the limit. In Arecibo flexible, Peñuelas, and Ceiba the maximum Gross Vehicle Mass (GVM) almost reached 70k. In fact, all the stations report trucks surpassing the legal limit. If we analyze both Figures 4.6.1 and 4.6.2 we can see that Mayagüez has the highest percent of overweight trucks and Salinas the lowest. The maximum GVM is almost 70,000 pounds. In order to have a clear viewpoint of the different stations both graphs have to be viewed together.

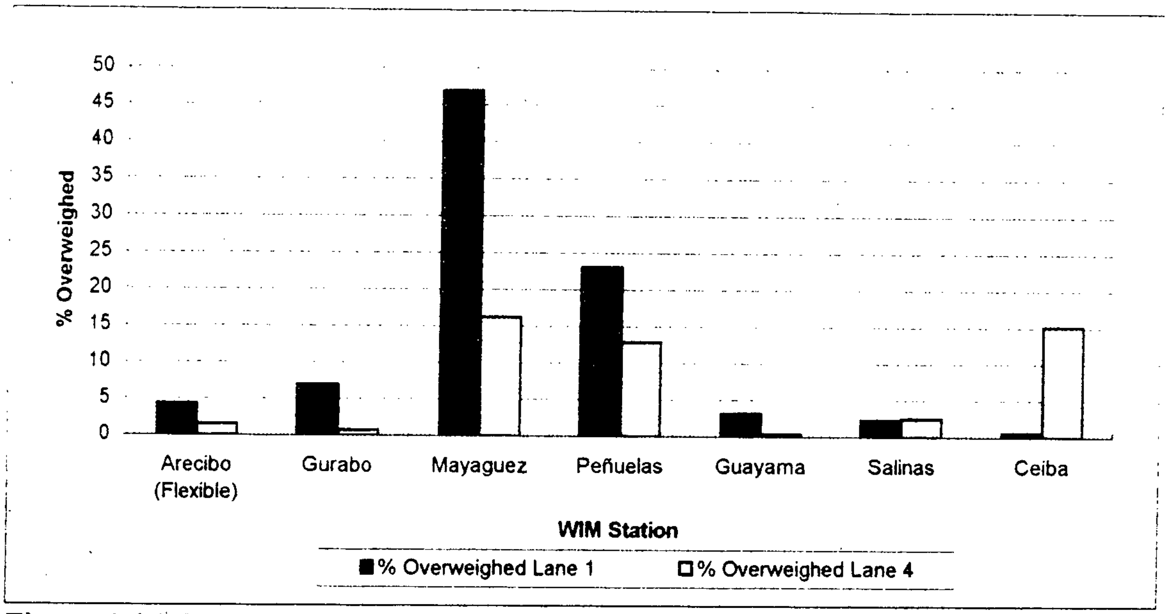


Figure 4.6.1 Percent Overweighed in Class 5 (2A) Truck

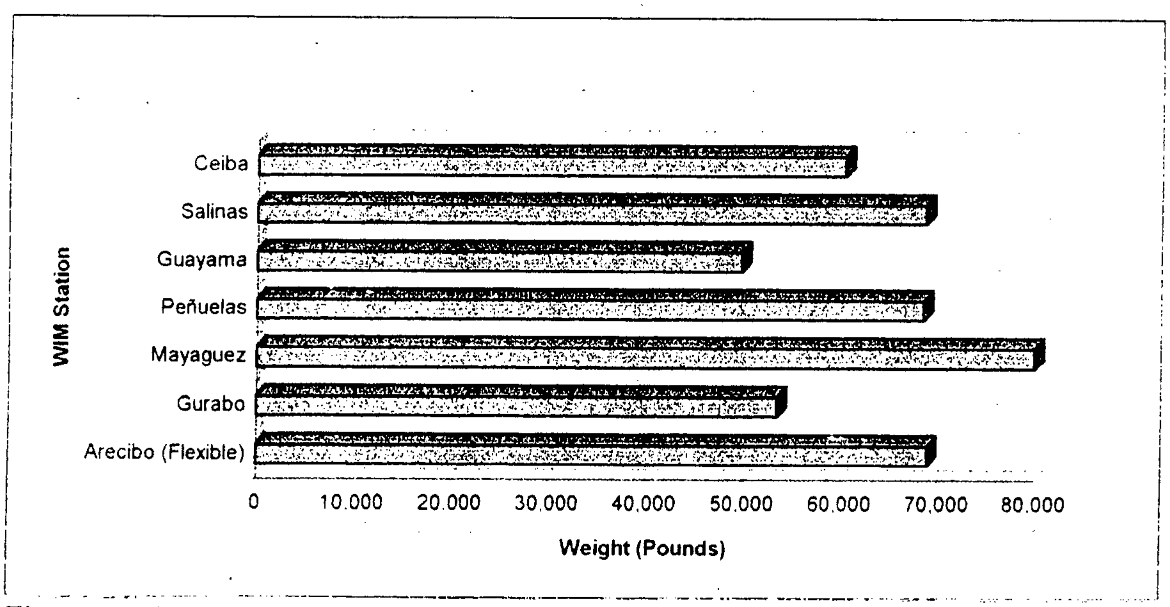


Figure 4.6.2 Maximum GVM Registered in Class 5 (2A) Truck

Figure 4.6.3 shows the percent of error for all WIM stations for a class 5 truck for a representative week. The error presented is the total of all individual errors, including speed, length, axle spacing, etc.

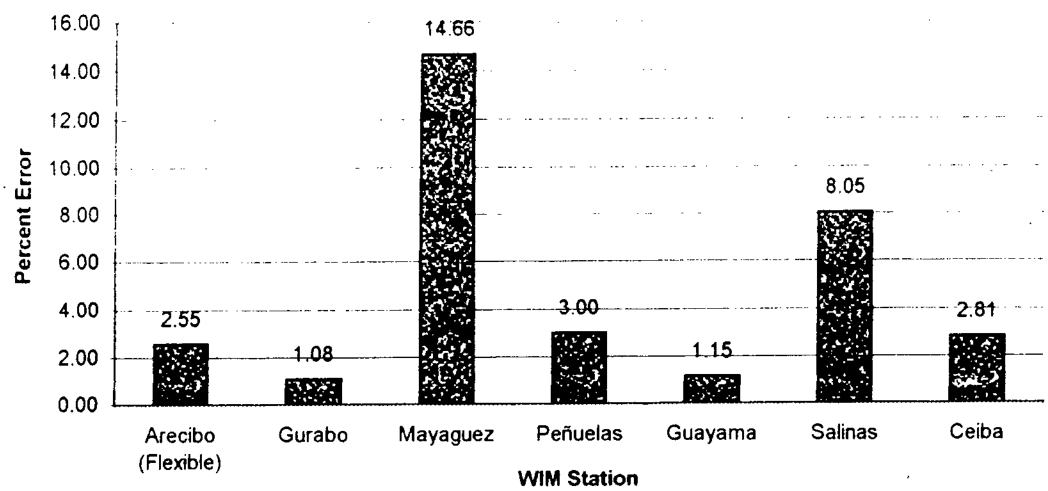


Figure 4.6.3 Percent Error for Class 5 (2A) Truck

One theory regarding the size of the error is that it increases with volume, due to closeness of vehicles. The data in Figure 4.6.4 do not support this theory. Even though the Arecibo WIM station has the most vehicles in class 5 on a weekday, the error in this station is less than a 2%. Gurabo has the second highest number of errors, but that error is lower than all the other stations analyzed in this class range. Mayagüez has the greatest percent of error, but the number of vehicles is less than Arecibo and Gurabo. So it can be concluded that the number of vehicles passing a given station has no influence on the error.

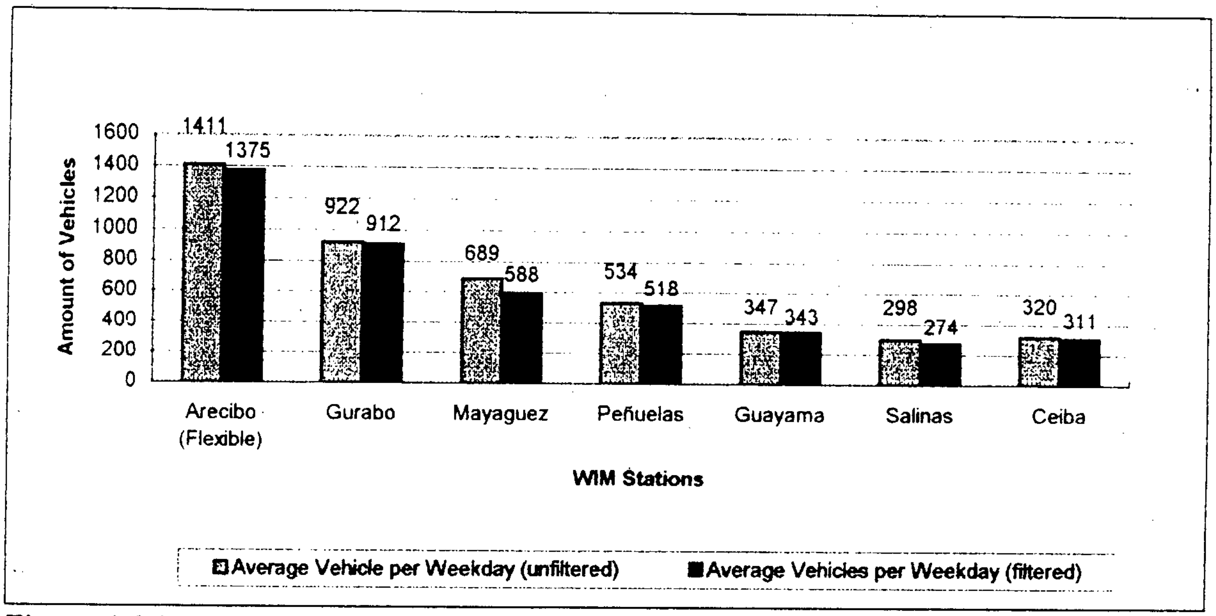


Figure 4.6.4 Average Number of Vehicles for Class 5 for a Weekday

Class 6

A class 6 truck has a maximum weight of 12k for the steering axle and 42k for the tandem axle. So the maximum allowable weight is 54,000 pounds. This type of truck is used mainly in the aggregate business. Truckers usually overload this type of truck to get more money from each trip made. Figure 4.6.5 takes into account the weight limit for Puerto Rico and reports only the vehicles that had no errors.

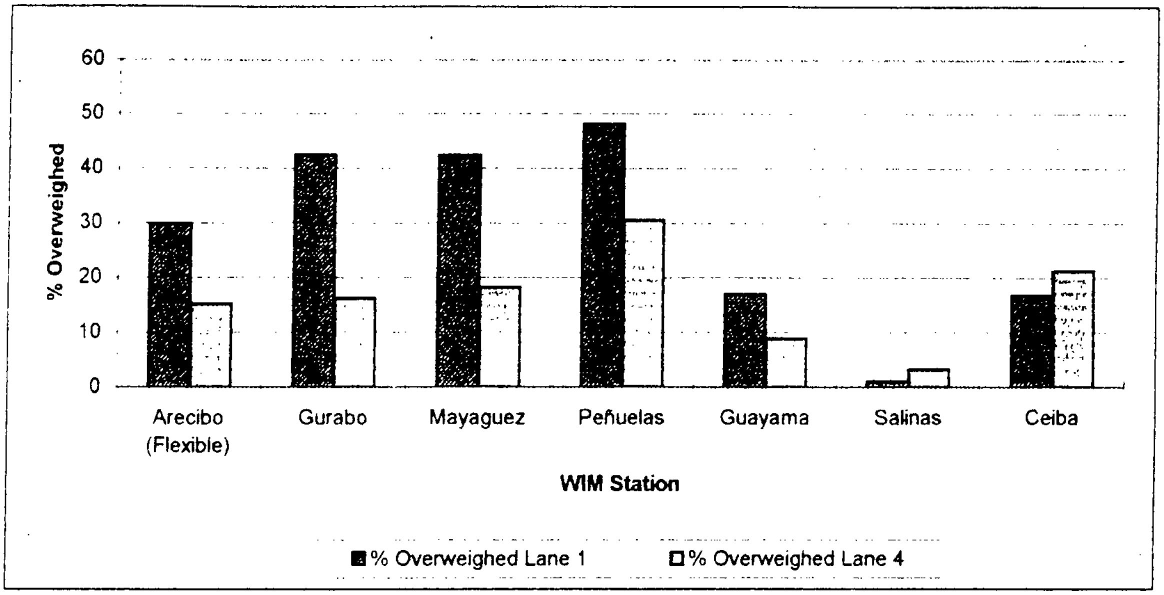


Figure 4.6.5 Percent of Overweighed Class 6 (3A) Truck

Figure 4.6.5 presents the percent of overweight trucks for each station in lanes 1 and 4. Peñuelas has the highest percent of overweight class 6 trucks in both lanes, Mayagüez and Gurabo also show a high percent of overweight trucks with more than 40%. Salinas has the lowest percent of overweight trucks. These statistics may suggest that this kind of truck is overloaded most often on short trips. The stations of Mayagüez, Gurabo, Peñuelas, and Arecibo are located at points where trucks with aggregates are traveling to construction projects.

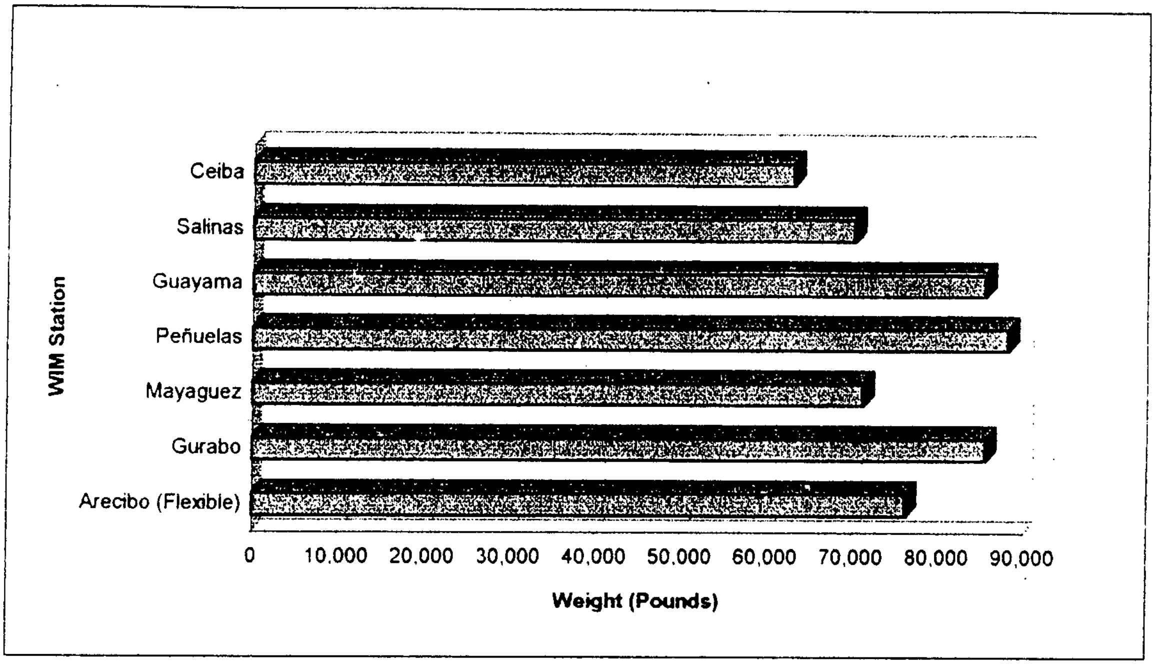


Figure 4.6.6 Maximum GVM Registered in WIM Station for a Class 6 Vehicle

Figure 4.6.6 shows the maximum GVM registered for each station. Trucks passing all stations surpass the 54k limit, often reaching 90k. The stations with the greatest weight are Peñuelas, Gurabo, and Guayama. Peñuelas is also the station with the most overweight vehicles in this class. This result does not mean that the stations with a high percent of overweight trucks are going to have the greatest GVM, but it indicates that there is a greater possibility that this will happen.

Figure 4.6.7 shows that the error for all the stations analyzed is less than 7%, indicating that this type of vehicle is well captured and analyzed by the WIM equipment being used in Puerto Rico. Mayagüez has the highest percent of error, as it had for the class 5 vehicles, even though the class 6 error is much lower than the class 5 error.

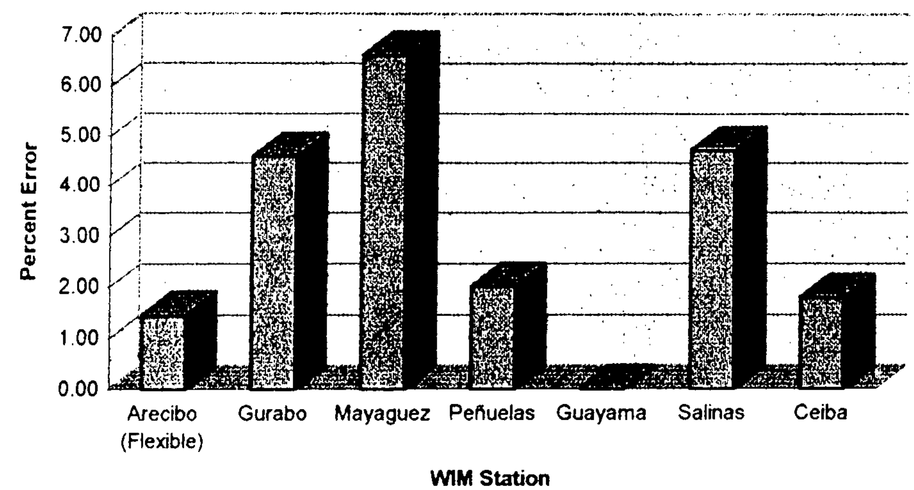


Figure 4.6.7 Percent Error for all WIM Stations in a Class 6 Vehicle

Also, an increase in the class 6 error over the class 5 error at Gurabo, from one to almost five percent error, was observed. All the other stations kept the low error that they had in class 5, except Guayama that reported zero percent error for class 6 vehicles. Arecibo has its usual low error (1%) even though it can be seen in Figure 4.6.8 that more number of vehicles pass through this station. Gurabo is in second place followed by Mayagüez, Peñuelas, Salinas, Ceiba, and then Guayama. Even though one may hypothesize that Guayama has a lower error because fewer vehicles pass this station, the data from Arecibo show a very low error, about the same as Guayama, with the highest number of vehicles of all stations.

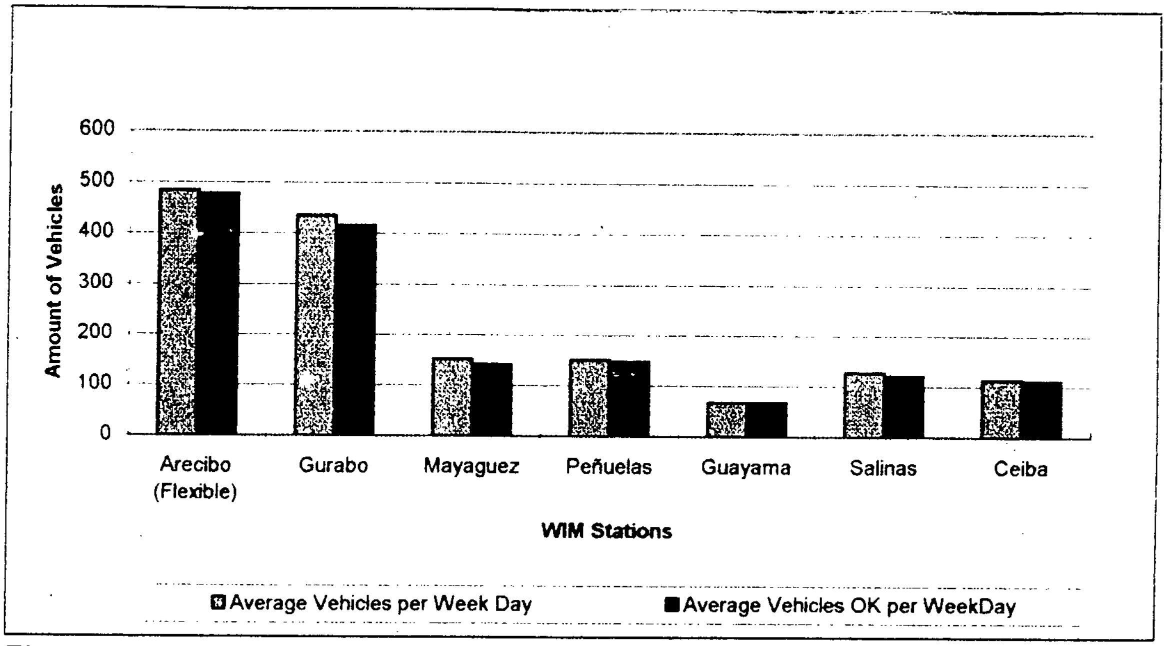


Figure 4.6.8 Average Vehicle Class 6 per Weekday

Class 9

The class 9 truck is widely used in Puerto Rico to transport cargo across the island. Due to the fact that there are no railroads companies in operation on the island, all goods and commodities have to be transported by truck. The maximum allowable load for this type of truck is 12,000 lbs. for the steering axle and 42,000 lbs. for each of the two tandem axles. for a total load of 96.000 lbs. Figure 4.6.9 shows the percent of class 9 trucks measured overweight. As in class 5, Mayagüez shows the greatest percent of overweight trucks, followed by Peñuelas and Guayama. The Guayama station records 11% of trucks overweight in lane 1, primarily the tank trucks carrying gasoline and diesel fuel processed at the refineries located in this area.

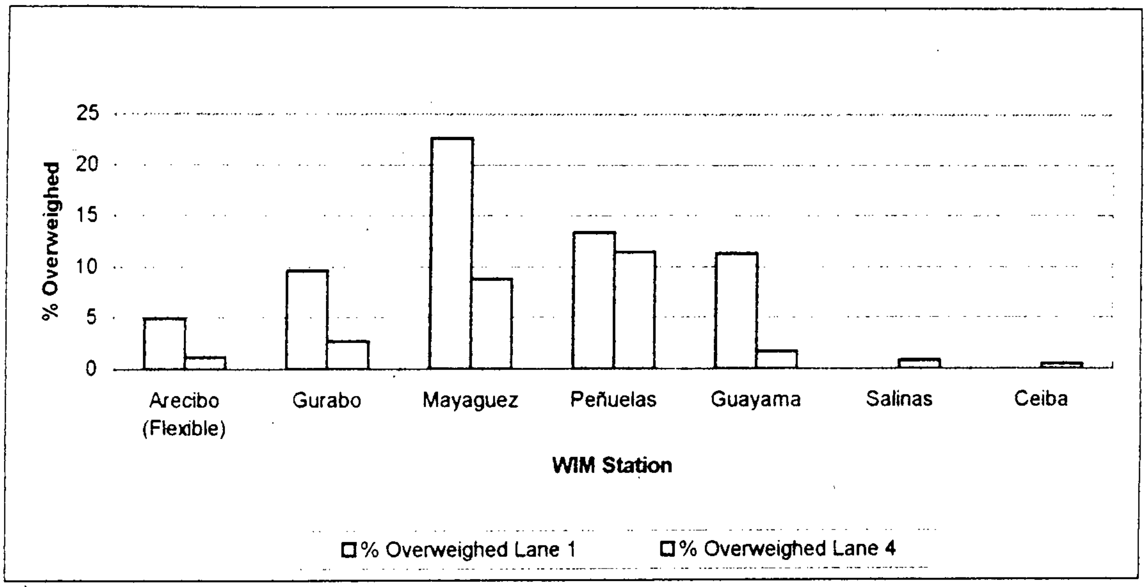


Figure 4.6.9 Percent of Overweighed Vehicle Class 9

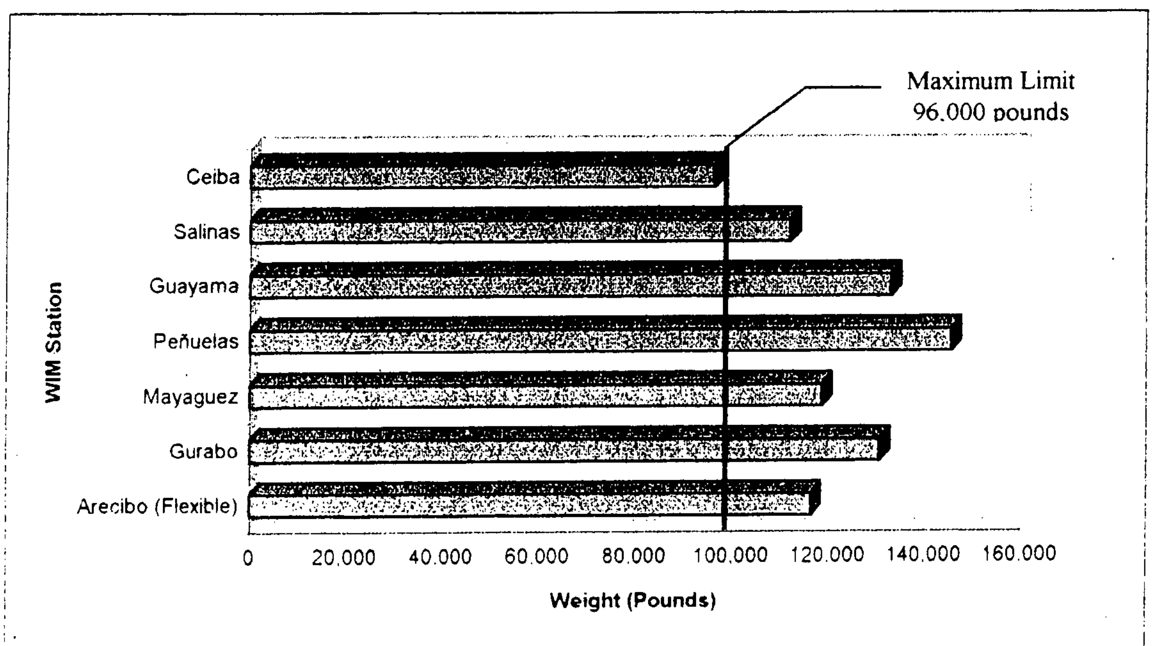


Figure 4.6.10 Maximum GVM Registered for a Class 9 Vehicle

The Maximum GVM registered for the stations analyzed are presented in Figure 4.6.10. All the stations except Ceiba are much higher than the specified limit. The GVM limit for all trucks is 110,000 pounds and stations such as Peñuelas reached as high as 145,510 pounds. This exaggerated overload was not taken into consideration in the present design of roads. Damage caused by overweight vehicles is expected to reduce the life of the pavement by more than half.

Figure 4.6.11 shows that Salinas has more than 40% of error producing a situation of more damage unknown that is of great importance due to the highly loaded truck of this type. Peñuelas and Ceiba are between 10-15% and the rest are below 10% error. The magnitude of the error at these stations is not as bad as it seems when Figure 4.6.12 is analyzed. The stations with low error are the ones having a greater number of vehicles. On the other hand, Peñuelas and Ceiba have low volumes of this kind of truck. So the theory of the error increasing with vehicle volume is not certain. In Arecibo, the volume is the highest while the error is the lowest.

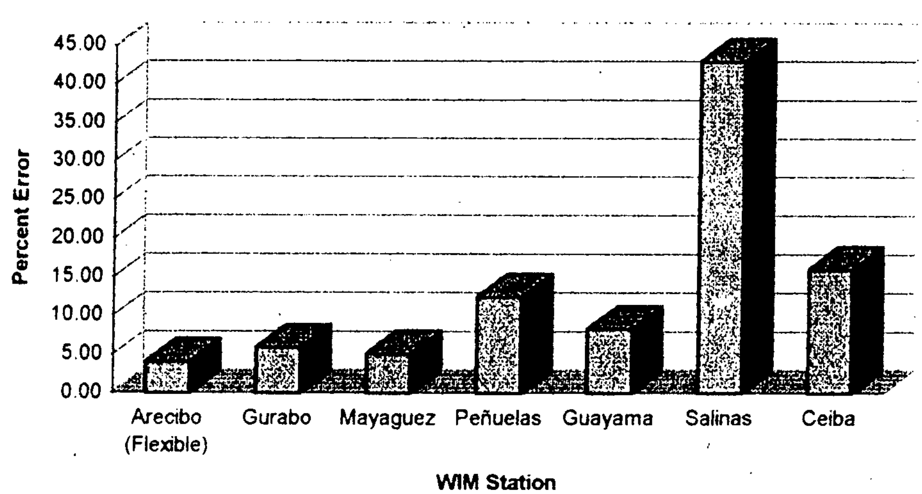


Figure 4.6.11 Percent Error for Class 9 Vehicle

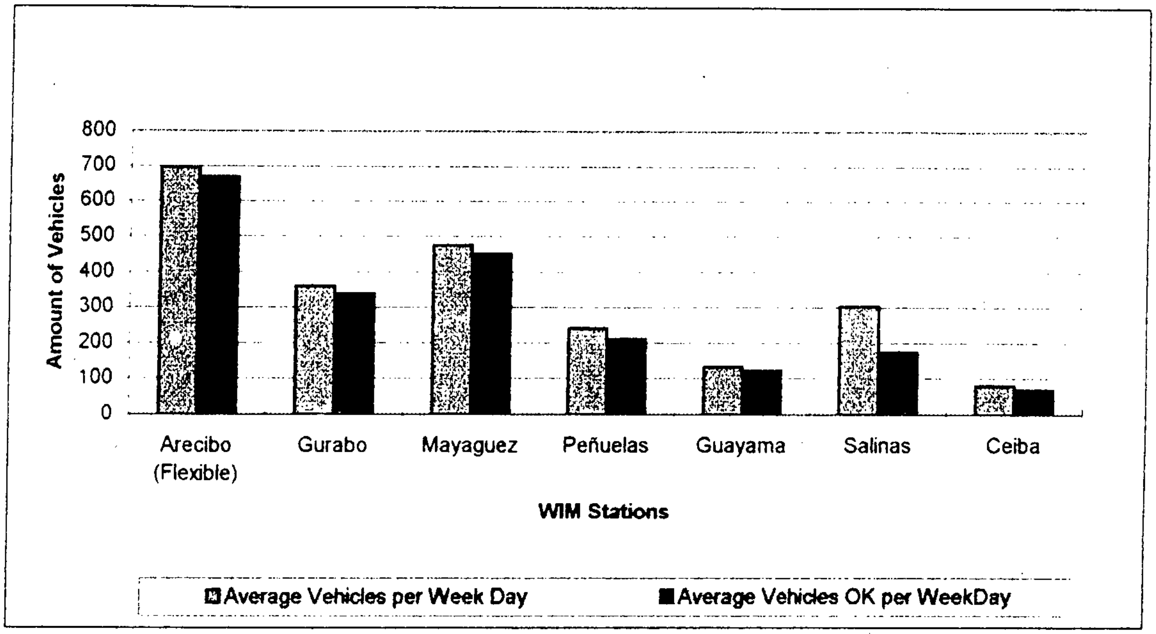


Figure 4.6.12 Average Class 9 Truck for a Weekday

Class 8

A common error encountered at all stations was found for class 8 truck. This type of truck is not common in Puerto Rico, but for some reason the WIM equipment or program classifies vehicles in this class. The percent of error among trucks in this class is very high, between 70 and 95 percent as seen in Figure 4.6.13. The error is highest at Salinas, 95.7 percent of error, and lowest at Arecibo, 71.4 percent.

Figure 4.6.14 shows that the number of trucks for each station is more than typical trucks. In interviews done to trucking companies in Mayagüez, it was found that this kind of truck is hardly used, so it must be concluded that WIM data for this kind of truck is very unreliable and only a small percent would be useful. Also the percent of trucks in every station is affected because the quantity of erroneous class 8 trucks is very high.

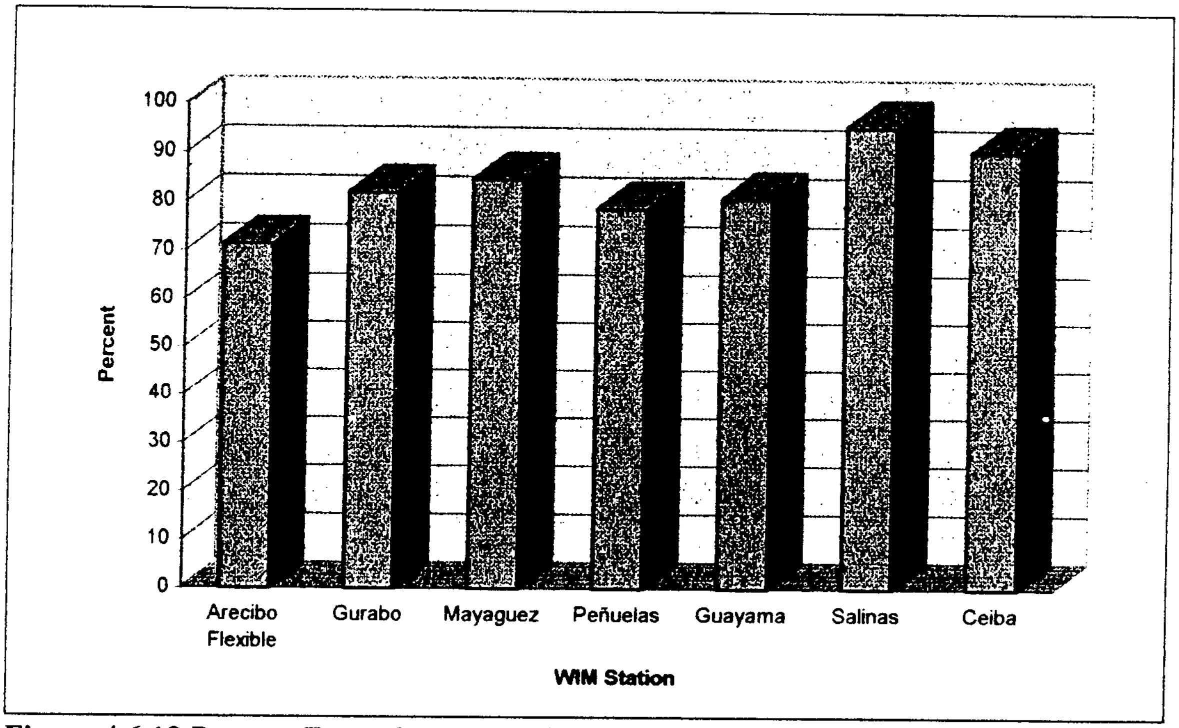


Figure 4.6.13 Percent Error for a Class 8 Vehicle

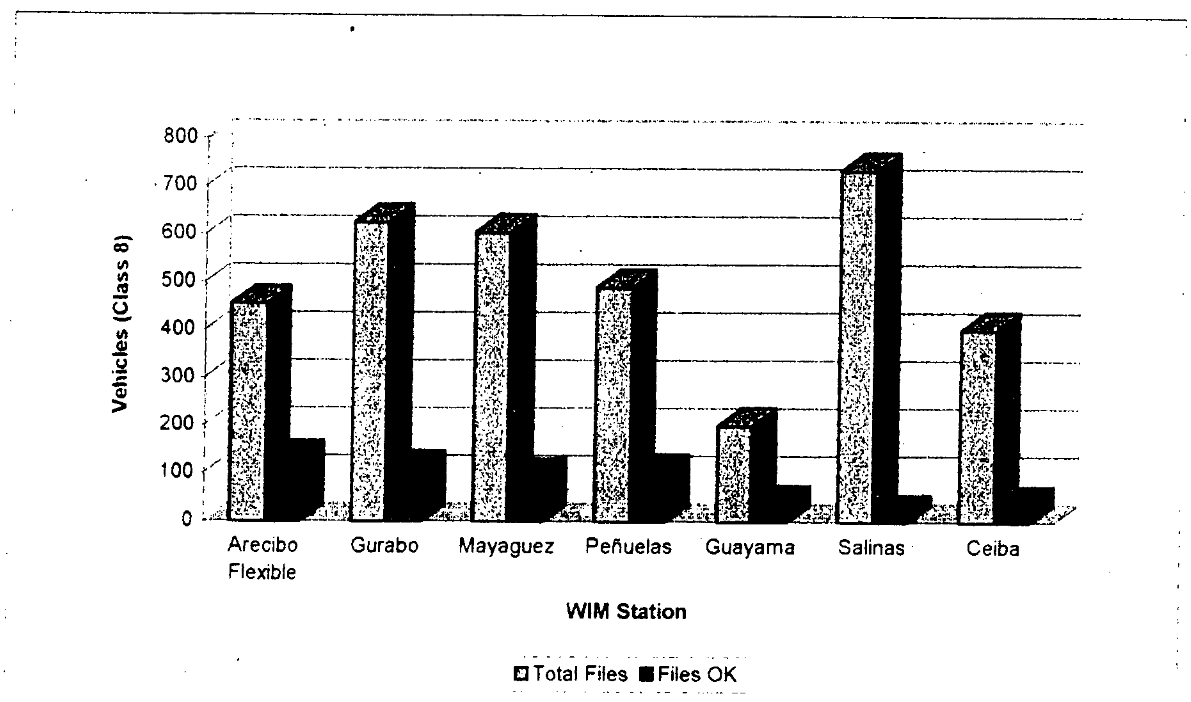


Figure 4.6.14 Total Class 8 Vehicles vs. Vehicles OK

4.7 Typical Errors for All the WIM Stations Analyzed

By analyzing the raw data and comparing real values for important parameters, the errors in the data were filtered to keep those parameters errorless as possible. The variables analyzed and compared with real variables were based on the classification of the particular vehicle under analysis. This procedure had to be done by vehicle class since the threshold values for each vehicle are different. For example, the length for a class 4 vehicle is not the same as for a class 9 vehicle. Nevertheless, some variables are the same regardless of the vehicle classification, for example speed, and maximum gross vehicle mass. The variables analyzed for contradictions to real expected variables were the following: vehicle length, gross vehicle mass, spacing between axles, individual axle weight, and speed.

The specific common errors that were identified in the data verification process and their respective threshold values are:

- ✓ speed >150 mph
- ✓ minimal vehicle length of trucks less than 15 feet
- ✓ excessive vehicle length greater than 100 feet
- ✓ axle spacing more than 45 feet (could vary depending on the type of vehicle)
- ✓ spacing between steering axle and next axle more than 15 feet
- ✓ tandem axles with spacing less than 3.0 feet
- ✓ axle mass greater than 50 kips
- ✓ gross vehicle weight greater than 150 kips.

Usually the errors filtered out were excessive amounts that were easily filtered. Avoiding these types of error is necessary to provide reliable data for analysis. It should be noted that TELCOM's role in filtering data before providing the reports mentioned in section 3.6 of this document is unknown; therefore the data was analyzed in its raw state. Figure 4.7.1 shows an example of the raw data for a vehicle.

```
-----------------------------------------------------------------------------------
Date : 06/01/1997  Time   : 10:14:29     Lane   :  1           Ref No. : 13127
Class: F08           Length: 13.3 ft     Speed :  52 mph      Headway :        sec
Axle Mass    1)  [illegible]KIP   2)  [illegible]KIP   3)  3.01KIP
Axle Space   1,  349.5ft     2,   11.2ft
Axle Group   1)   1.26KPS    2)   6.88KPS
Gross Vehicle Mass :   8.14klb          SF :  1  8600 105.0
Violations : None.
-----------------------------------------------------------------------------------
```

Figure 4.7.1 Example of WIM Raw Data

The errors present in this data are the following: length less than fifteen feet even when a class 8 truck is a trailer truck with four or fewer axles, and the spacing between axles is 349.5 feet, which is excessive. In Appendix B, an example of some of the raw data analyzed for the Mayagüez WIM station is presented.

Figure 4.7.2 was constructed to compare the general error with the installation date and determine if the installation date influenced the error encountered. It should be noted that the error presented is taking all vehicles into account from classes 4-13. In Appendix H, worksheets are presented with the vehicles determined to be correct and the number of errors for all the stations analyzed. The error was computed comparing the vehicles reported for a specific classification and the vehicles in such classification passing the filter.

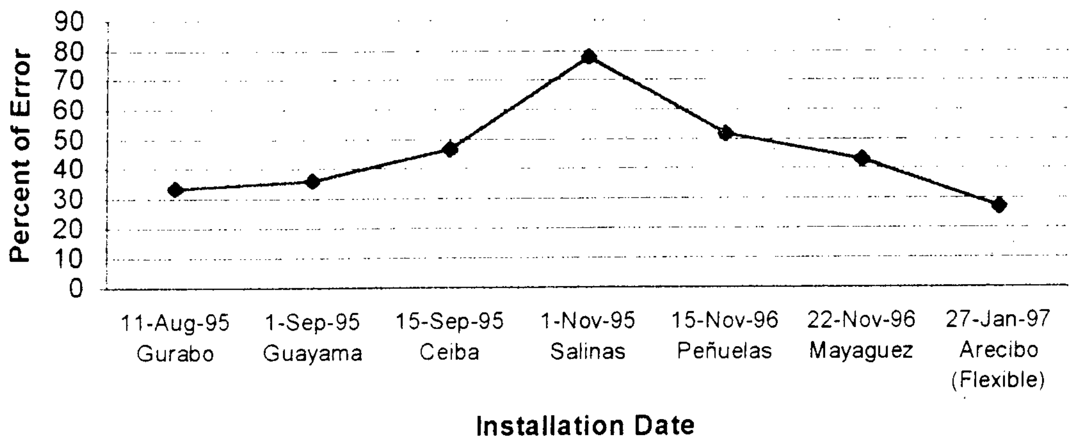


Figure 4.7.2 Installation Date vs. Error

CHAPTER FIVE

STATISTICAL ANALYSIS AND MODELS DEVELOPMENT

5.1 Introduction

This chapter describes the methodology used for data verification that took place in the Mayagüez WIM station. In addition the development of land use models is explained and the models presented. Furthermore a methodology for the development of weight probability distribution is presented, and models to derive the ESAL and Truck Factors are developed.

5.2 Data Verification

Due to the errors encountered in the data, a field verification of classification was set up. This type of verification was done using real time data from the WIM computer at the Mayagüez station with the assistance of Santa Fé Technology personnel and the Pavement Management Office of the PRTHA, directed by Eng. Wilfredo Castro Hernández. For this task a video camera was set up to record the vehicles passing over the WIM station. Manual notes were also made and real time classification was compared to actual vehicle classification. This type of verification only detects errors in vehicle classification. Later a comparison of the data recorded by the WIM equipment and the data recorded by the video camera was made.

To establish the number of trucks required for this study, the military sampling technique was used. The purpose of this technique is to minimize sampling errors, type 1 and 2; α and β are the probability that type 1 and 2 errors occur, respectively.

The hypothesis established is that the equipment is calibrated. Desired values for α and β are selected, $\alpha = 5\%$, and $\beta = 10\%$. Then an inspection level is chosen. There are three general inspection levels, and three special inspection levels. For this study, the general inspection level II was used, as it is the ordinary level. Level III is used when human life is at risk, and Level I is when human life is not at risk. Figure 5.2.1 shows the operation characteristics (α, β) curve for the three inspection levels. The (α, β) curve exhibits that level III is much more strict than level II or I.

The number of trucks for the Mayagüez station for a selected day, Thursday, was 2,347. The verification was done in October 9, 1997, a Thursday. Taking the number of trucks per day (lot size) in Table 5.2.1 with a General Inspection Level of II, the code letter would be K. Then if we go to Table 5.2.2 we find that the sample size is 125 trucks. Therefore the sample size used for the verification was 125 trucks.

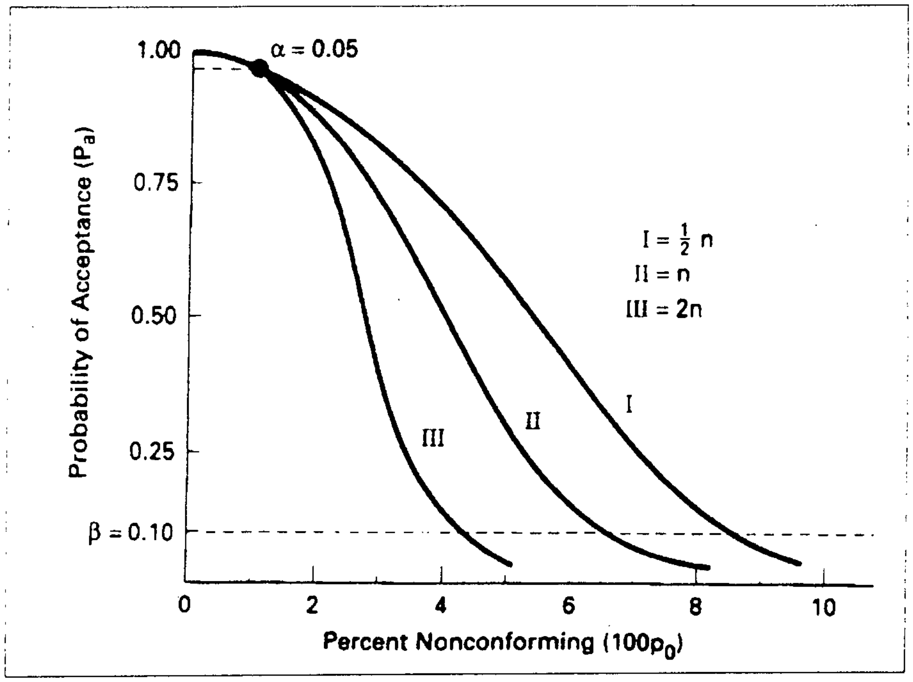


Figure 5.2.1 Comparison of Inspection Levels I, II, and III

Table 5.2.1 Sample-Size Code Letter

LOT OR BATCH SIZE	SPECIAL INSPECTION LEVELS				GENERAL INSPECTION LEVELS		
	S-1	*S-2*	*S-3*	*S-4*	*I*	*II*	*III*
2–8	A	A	A	A	A	A	B
9–15	A	A	A	A	A	B	C
16–25	A	A	B	B	B	C	D
26–50	A	B	B	C	C	D	E
51–90	B	B	C	C	C	E	F
91–150	B	B	C	D	D	F	G
151–280	B	C	D	E	E	G	H
281–500	B	C	D	E	F	H	J
501–1200	C	C	E	F	G	J	K
1201–3200	C	D	E	G	H	K	L
3201–10,000	C	D	F	G	J	L	M
10,001–35,000	C	D	F	H	K	M	N
35,001–150,000	D	E	G	J	L	N	P
150,001–500,000	D	E	G	J	M	P	Q
500,001 and over	D	E	H	K	N	Q	R

Table 5.2.2 Single Sampling Plans for Normal Inspection

Sample size code letter	Sample size	0.010 Ac Re	0.015 Ac Re	0.025 Ac Re	0.040 Ac Re	0.065 Ac Re	0.10 Ac Re	0.15 Ac Re	0.25 Ac Re	0.40 Ac Re	0.65 Ac Re	1.0 Ac Re	1.5 Ac Re	2.5 Ac Re	4.0 Ac Re	6.5 Ac Re	10 Ac Re	15 Ac Re	25 Ac Re	40 Ac Re	65 Ac Re	100 Ac Re	150 Ac Re	250 Ac Re	400 Ac Re	650 Ac Re	1000 Ac Re
		Acceptable Quality Levels (normal inspection)																									
A	2	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31
B	3	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45
C	5	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	↑
D	8	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	↑	↑
E	13	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	↑	↑	↑
F	20	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	↑	↑	↑	↑
G	32	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑
H	50	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑
J	80	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑
K	125	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
L	200	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
M	315	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
N	500	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
P	800	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Q	1250	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
R	2000	↑	↑	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑

↓ = Use first sampling plan below arrow. If sample size equals, or exceeds, lot or batch size, do 100 percent inspection.
↑ = Use first sampling plan above arrow.

Ac = Acceptance number.
Re = Rejection number.

One of the findings of this visual verification of classification was that class 5, 6, and 9 are the typical trucks used in Puerto Rico. In the sample analyzed, no trucks class 11, 12, or 13, nor class 7 or 8 were encountered. Truck class 10 was seen only once.

Analyzing the data, it was detected that 45 percent of class 5 trucks in lane 1 were not classified as 5. In lane 4, the error was 53 percent. Many of the class 5 trucks were classified as class 3 (pickup). A possible explanation for the error is that when class 5 trucks have a short length, the program classifies them as class 3. Another possibility is that the equipment is not identifying that the axle has four tires (class 5) and it processes the data as trucks having only two tires (pickup, class 3). The first explanation can be tested by during a short class 5 truck and a normal or long class 5 truck, past a WIM station and viewing the real time mode. The problem that arises is that about 50 percent of the data from class 5 are lost due to the fact that class 3 is not a truck and the percent of trucks is lower than measured by the equipment. On the other hand, class 8 trucks are abundant in the data even when this type of truck is used less than 10 percent of what the equipment is registering. So some of the class 5 trucks could be incorrectly classified in the class 8 category.

Another truck that had a high percent of error was class 6 with 56 percent. This type of truck is mainly used to transport aggregates to construction sites. They are frequently overloaded, which means that a large number of the loads are not recorded or incorrectly classified so the load use for design would be below the real load.

Class 9 trucks are the most accurately classified by the equipment, with a 37% error, which is low, compared to the other classes. That means that out of ten class 9 trucks, only three would be lost.

A common error encountered results when trucks shift lanes on top of the WIM sensors; in these circumstances a class 9 truck can be classified as a class 13. Another common error results from tow trucks carrying a car; this arrangement may be classified as class 11 or 12. A simple way to identify common errors is to view the truck weight distribution. Remember that typical trucks encountered in Puerto Rico are classes 5, 6, and 9. Class 8 trucks are also encountered but their percentage is very low, as in the case of truck class with classes 7, 11, 12, and 13. Class 10 trucks are being used more today for tankers but their percentage is not as high as class 5, 6, and 9 truck.

5.3 Land Use Model

A Land Use model was developed with the intention of predicting the error that would be encountered in the WIM data. Due to the different sources of error for any WIM station, the model made may not represent the real scenario. The model is intended to be used for predicting the expected error in future WIM locations established in the future. This equation could be used as part of the analysis performed to choose a road to install permanent WIM/AVC stations. This model is presented to show a possible methodology for developing future models using some or all the parameters used in this model. Before developing a new model, different sources of error should be verified such as errors in hardware and software. Also calibrating should be verified by another method.

The statistical model developed was the result of fitting a multiple regression model to describe the relationship between the error and 9 independent variables. The model incorporates land use and type of road, as a indicator variables. Equation 5.1 shows the basic multiple regression model used.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 \ldots (5.1)$$

Where: Y = Total percent of error generated by all the vehicles in the WIM/AVC station

β_i = Regression Constants, i = 0, 1, 2, ..., 9

X_1 = Land Use Indicator Variable (Industrial, Commercial, Residential, etc.)

X_2 = Type of Road Indicator Variable (Full or Partial Access Controlled)

X_3 = Percent of Class 4 Vehicle

X_4 = Percent of Class 5 Vehicle

X_5 = Percent of Class 6 Vehicle

X_6 = Percent of Class 8 Vehicle

X_7 = Percent of Class 9 Vehicle

X_8 = Percent of Class 11 Vehicle

X_9 = Daily Truck Traffic

It should be noted that the percent of class 7, 12, and 13 vehicles was incorporated in the original model, but these variables were removed because the P-value was greater than 0.10, meaning that the term is not statistically significant at the 90% or higher confidence level. The resulting final model is shown below:

Error = 429.302 - 3.53369*LandUse - 7.43365*Typeofroad - 3.68305Class4 - 3.96373*Class5 - 3.7963*Class6 - 2.27882*Class8 - 3.41791*Class9 - 27.7024*Class11 - 0.00530052*DTT ....(5.2)

Where:

- Error = Total error in the data for class 4-13, in the particular location where the WIM AVC station is projected to be installed.
- LandUse = Predominant land use in the area. Use 1-5
  1 Mainly Industrial
  2 Mainly Commercial
  3 Mainly Residential
  4 Equal Combination of Industrial, Commercial, and Residential
  5 Rural
- Typeofroad = If the access is fully controlled use 1, if not use 2

- Class4…11 = Percent of trucks for the particular class, taken from at least 2 hour sampling.
- DTT = Daily Truck Traffic, number of vehicles class 4 through 13 that used the road in a 24 hour period. These can be projected from sampling during peak hours and off peak hours.

The R^2 of the model is 96.788%, which indicates that the model as fitted explains 96.78% of the variability in the Error. The adjusted R^2 statistic, which is more suitable for comparing models with different numbers of independent variables, is 95.6317%. The standard error of the estimate shows the standard deviation of the residuals to be 3.32884. Parameter estimation for the model shown above is exhibited in Table 5.3.1.

Table 5.3.1 Multiple Regression Analysis

Parameter	Estimate	T Statistic	p-value
CONSTANT	429.302	9.58978	0.0000
LandUse	-3.53369	-4.91319	0.0000
Typeofroad	-7.43365	-4.17246	0.0003
Class4	-3.68305	-5.13456	0.0000
Class5	-3.96373	-10.2806	0.0000
Class6	-3.7963	-6.15226	0.0000
Class8	-2.27882	-3.60249	0.0014
Class9	-3.41791	-6.56639	0.0000
Class11	-27.7024	-3.10089	0.0047
DTT	-0.00530052	-4.05763	0.0004

This model can be used to estimate the error that would be present at a WIM/AVC station. The model provides the PRHTA with another tool to select new sites for the installation of new WIM/AVC stations.

5.4 Development of Weight Probability Distribution

A new method is proposed to derive probability density functions based on observed data and on the principles of a cumulative probability density function. The proposed approach is general and a simple application is presented within the framework of weigh-in-motion data collected in the highway system of Puerto Rico. The average daily traffic, the distribution of trucks, and the distribution of individual truck weights are used to estimate the traffic load for an in-service pavement. Regression approach is used to derive the weight probability density function for a specific truck type, and regression analysis is also been used to identify models to predict the traffic load at a specific pavement segment at a given point in time.

The proposed methodology is an especially useful tool for those pavement segments in which the weigh-in-motion equipment is not installed. The suggested methodology has been implemented at a single weighing station and a numerical example is used to predict the truck damages.

It is expected that the suggested methodology will assist design engineers and support technical personnel in estimating the cumulative traffic load required, and in studying the in-service pavement performance. This methodology will also be useful in the process of evaluation and management of pavement conducted by the Puerto Rico Highway and Transportation Authority, Strategic Highway Research Program, and the Long-Term Pavement Performance Program.

The conventional approach to developing the probability density function for a given random variable consists of collecting data and performing a hypothesis test to determine whether or not the underlying variable behaves according to known theoretical model (i.e., normal, poisson or gamma distribution). When the collected data are different from the known probabilistic models, it is desirable to derive a mathematical model to properly represent the associated random variable instead of forcing the data to follow a known model.

A new method is proposed to derive the weight probability distribution associated with the truck weight random variable. The suggested methodology consists of four major steps:

1. **Cumulative Distribution.** The empirical distribution is computed based on historical WIM data for a specific truck.
2. **Fitting Cumulative Distribution.** A nonlinear function is fitted to the cumulative frequency to derive a mathematical model that represents the cumulative probability density function.
3. **Probability Density Function.** The probability density function (pdf) for the underlying data is obtained after computing the first derivative of the cumulative probability density function.
4. **Density Function Testing**. Analytical or numerical integration is performed to make sure that the identified model corresponds to the pdf of the random variable.

Function evaluation is conducted in the whole range of the random variable to test whether or not the function is positive in any part of the range.

It should be noted that the proposed methodology is valid only for a continuous random variable. If the considered random variable is discrete, then the empirical probability density function can be used to estimate the population density function. In Figure 5.4.1 a description of the methodology is presented.

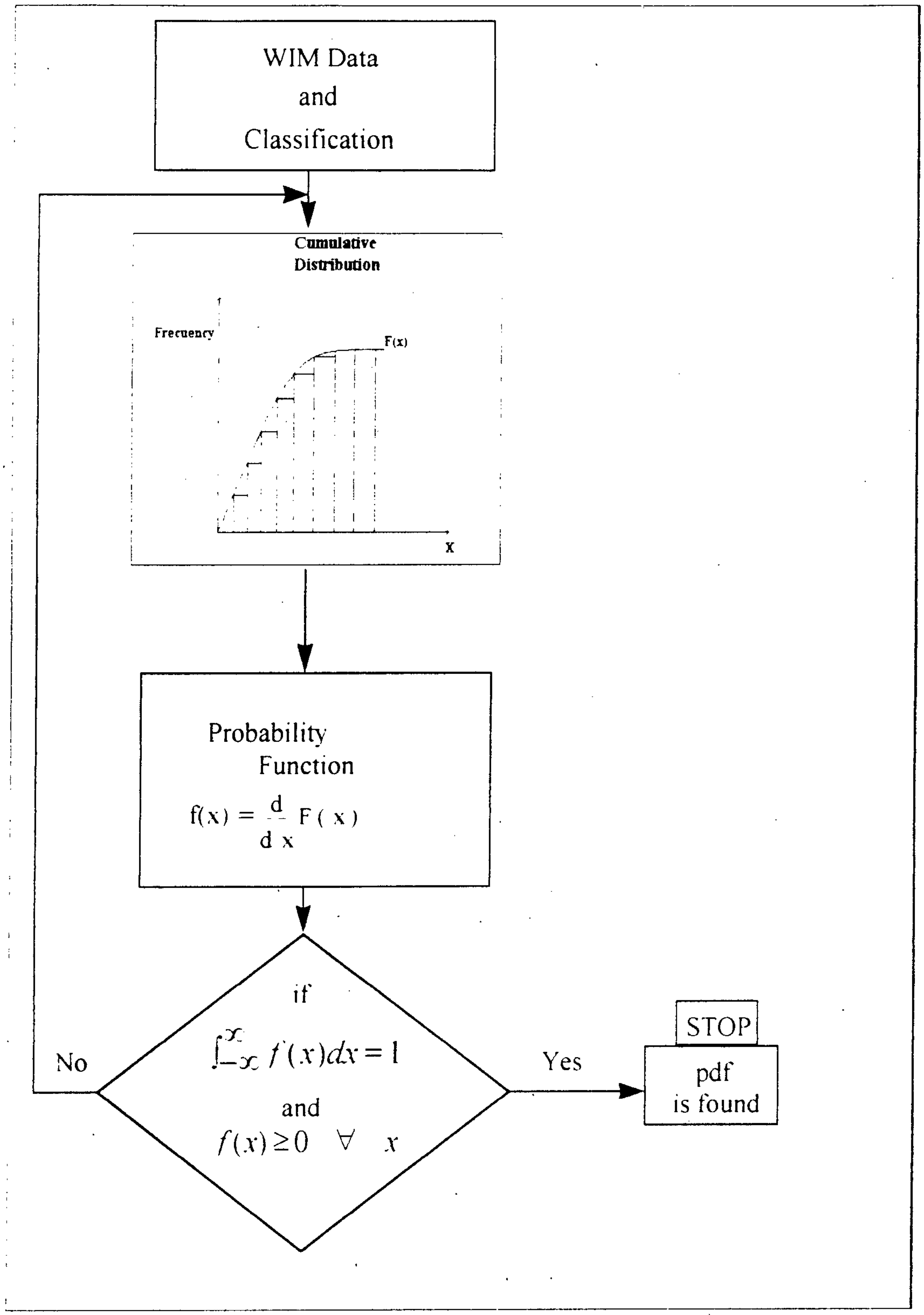


Figure 5.4.1 Description of Methodology

5.5 Case Study Application

I. Development of Probabilistic Models

Weight probability distributions were developed for Guayama, Mayagüez, and Gurabo stations. The procedure described herein is general, and was used only at these specific stations due to time constraints. A case study for Guayama WIM/AVC station is presented below. In Appendix I, the models developed for the WIM/AVC stations at Mayagüez and Gurabo are presented.

Step 1. Cumulative Distribution. Historical WIM data from the Guayama weighing station was used for the case study. The available data for this station includes the following periods October 2-10, 1996 and April 4-7, 1997 (see Table 5.5.1). Truck type 9 (3-S2) was selected to illustrate the analytical procedure. Any truck within this classification which has a gross vehicle weight (GVW) in excess of 96,000 lbs. according to the truck load limits in Puerto Rico, is considered an overloaded truck. On the other hand, a truck within this classification that is below the load limits is considered an underloaded truck. Figure 5.5.1 and 5.5.2 show the empirical cumulative distribution for over and underloaded trucks, respectively.

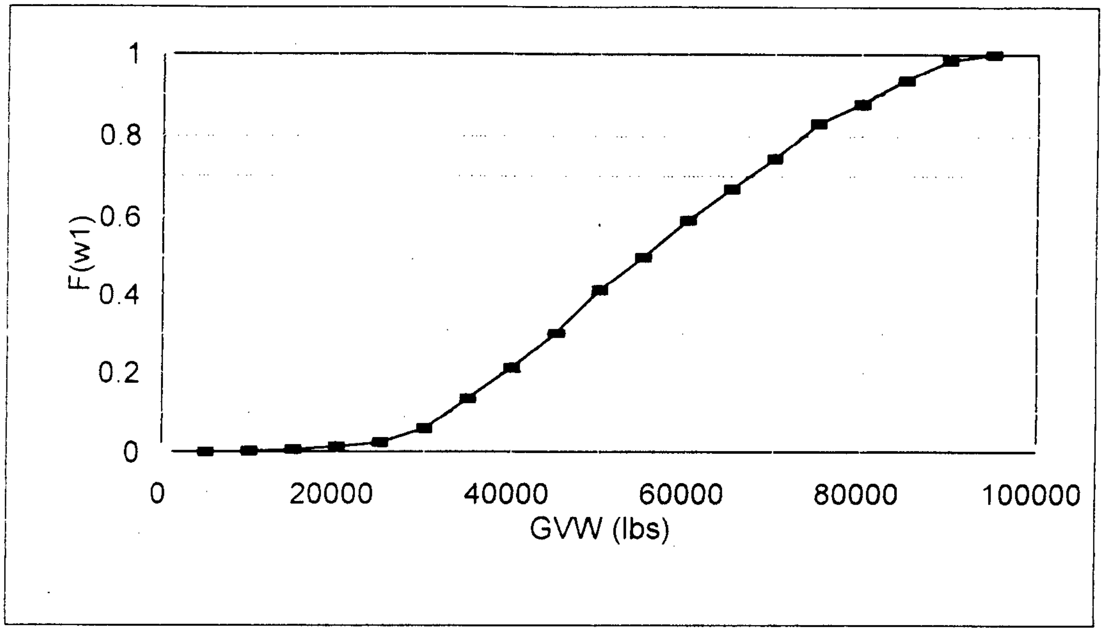


Figure 5.5.1 Cumulative Distribution for Underloaded Truck Class 9 (3-S2) for Guayama WIM Station

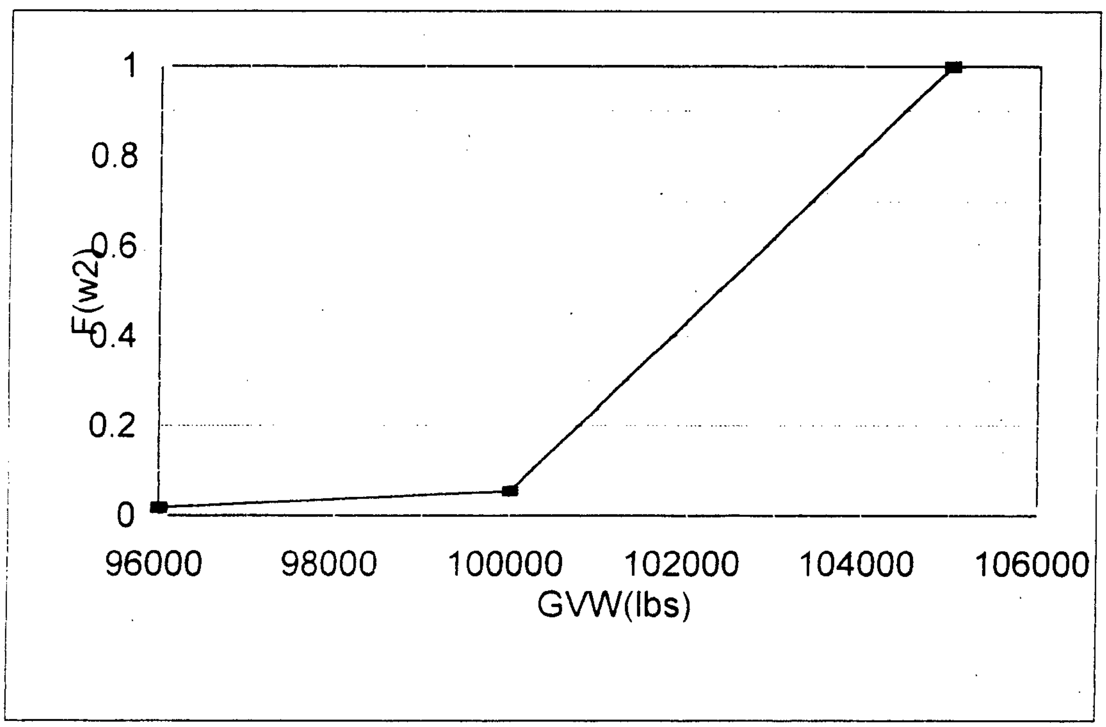


Figure 5.5.2 Cumulative Distribution for Overloaded Truck Class 9 (3-S2) for the Guayama WIM Station

Step 2. Fitting Cumulative Distribution. The cumulative distribution for underloaded trucks is used to derive the weight probability density function (pdf). A regression model was identified for the cumulative distribution and the fitted mathematical model can be expressed as:

$$F(w_1) = \exp\left\{a - b\frac{In(w_1)}{w_1^2}\right\}, \quad 2 \le w_1 \le 96{,}000 \quad lbs \qquad \textbf{(1)}$$

where w_1 is the GVW for an underloaded truck type 9; a and b are parameters estimated from data. The resulting coefficients obtained from the Guayama weighing station and for the analyzed period are presented below:

a = 0.3597 and b = $2.89\text{x}10^8$

Step 3. Probability Density Function (pdf). The first derivative of the cumulative probability density function was computed to obtain the pdf for the weight distribution for this truck type.

$$f(w_1) = \frac{b(2In(w_1) - 1)}{w_1^3}\exp\left\{a - b\frac{In(w_1)}{w_1^2}\right\} \quad 2 \le w_1 \le 96{,}000 \quad lbs \qquad \textbf{(2)}$$

where w_1, a, and b were defined in equation (1). The behavior of the pdf for the weight of truck type 9 for the underloaded conditions is exhibited in Figure 5.5.3.

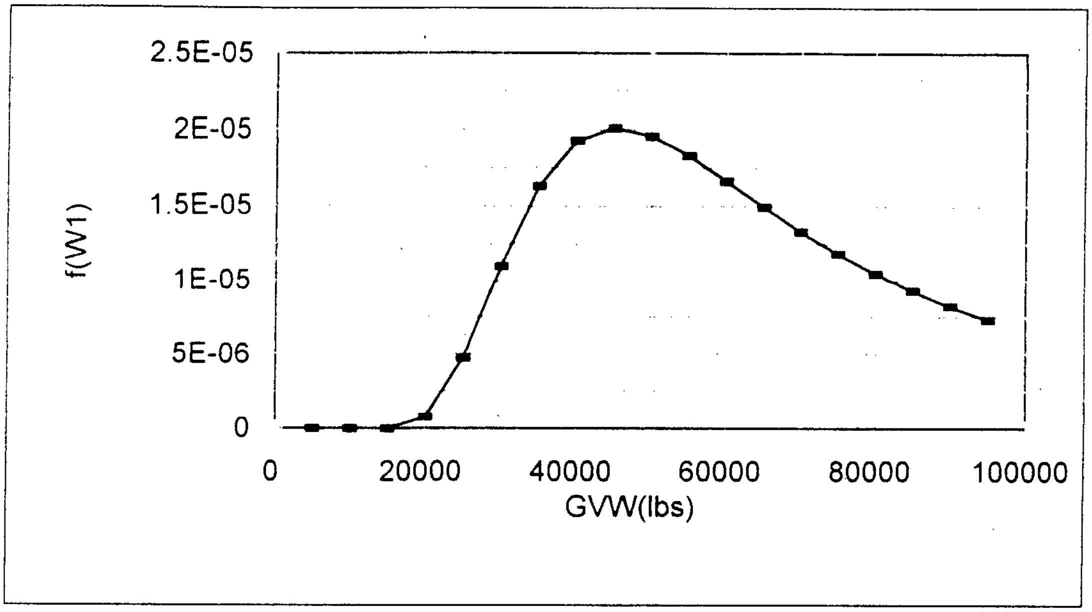


Figure 5.5.3 Weight Probability Density Distribution for Underloaded Truck Class 9 (3-S2) for the Guayama WIM Station

Step 4. Density function testing. It should be noted that $f(w_1)$ is the pdf for w_1 since this function is positive for the whole range of w_1 and also because the integral from 2 to infinity is equal to one. One of the applications of this distribution is to compute the expected value for the GVW of a type 9 truck. The expected GVW for an underloaded type 9 truck is computed by solving the following integral:

$$\int_{2}^{96000} f(w_1)w_1dw_1 \quad = 56{,}730 \text{ lbs} \tag{3}$$

Following a similar procedure, the cumulative and probability distribution for an overloaded type 9 truck, are equations 4 and 5, respectively.

$$F(w_2) = \left(c - \frac{d}{w_2}\right)^2 \qquad 96{,}000 \le w_2 \le 150{,}000 \qquad \textbf{(4)}$$

$$f(w_2) = 2d\left(\frac{cw_2 - d}{w_2^3}\right) \qquad 96{,}000 \le w_2 \le 150{,}000 \qquad \textbf{(5)}$$

where c, d, and e are model coefficients, and w_2 is the GVW for an overloaded type 9 truck.

The estimated coefficients for an overloaded type 9 truck are:

$$c=25.9, \text{ and } \quad d=\left(\frac{8}{3}\right)10^5$$

Again, the expected value for an overloaded truck was computed by solving the following integral (see Figure 5.5.4):

$$\int_{96000}^{150000} w_2 f(w_2) d(w_2) \quad = 127{,}800 \text{ lbs} \qquad \textbf{(6)}$$

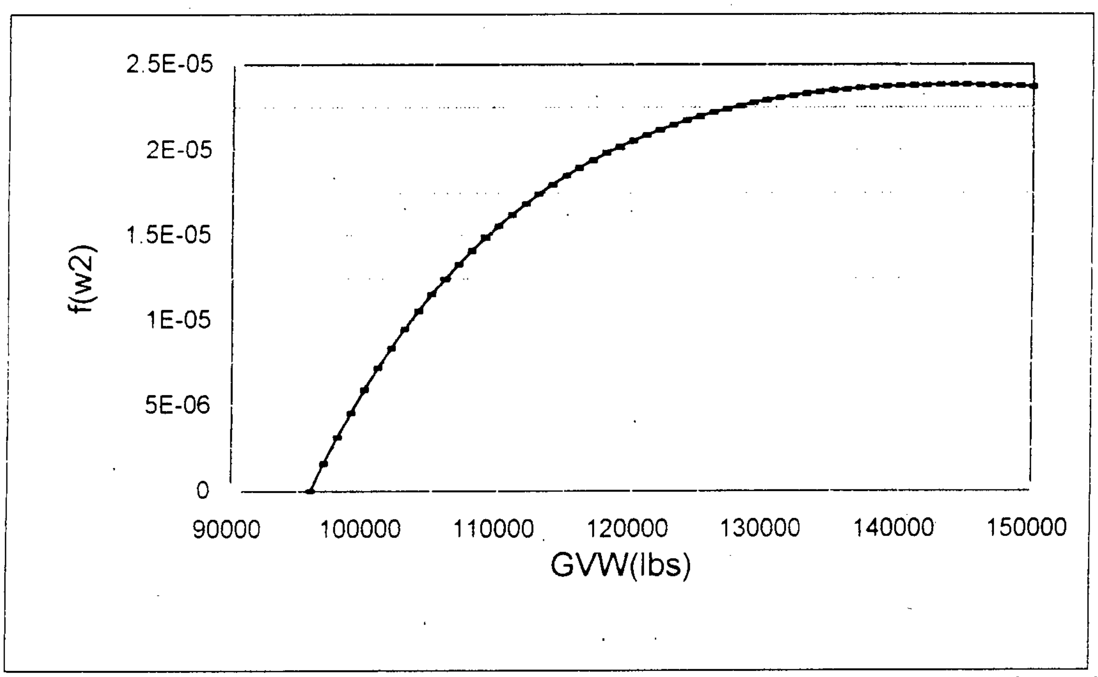


Figure 5.5.4 Weight Probability Distribution for Overloaded Truck Class 9 (3-S2) for the Guayama WIM Station

II. Regression Models To Predict ESAL AND T_f.

Regression analysis was used to determine mathematical models to predict the traffic load for each truck classification. A regression model is expected to derive for each truck classification and for each homogeneous climatic region. Colucci, Ramirez, and Rodriguez (1997) applied clustering techniques to divide Puerto Rico into four homogeneous climatic regions. With the available WIM data, a preliminary model was developed for type 9 trucks. The identified model is adequate for the climatic region where the Guayama station is located. The derived model is exponential due to the fact that load can never have a negative value:

$$y_9 = \exp\left(\beta_1 x_1^{0.7} + \beta_2 x_2^{0.7} + \beta_3 x_1 x_2^{1.5} + \varepsilon\right) \quad \textbf{(7)}$$

where x_1 and x_2 are the expected cumulative traffic load of the j^{th} (j=4,5,...,13) truck classification under and above the traffic load limits, respectively. The values of x's correspond to the GVW and are given in pounds scaled to 10^{-6} to obtain appropriate coefficient estimates. The dependent variable, y_j, is the pavement damage expressed in terms of equivalent single axle load ($ESAL_{18}$) by day in the j^{th} truck classification; β's are parameters to be estimated from data, and, ε is a random error.

Table 5.5.1 shows the data that were used to develop a regression model. A stepwise procedure was used to identify and estimate the model's parameters. After several trials, it was found that the algorithm obtains a satisfactory regression model with coefficient of multiple determination, $R^2 = 0.98$. Table 5.5.2 shows the summary of the parameter estimation.

Table 5.5.1 Data Used to Develop Non Linear Regression Model

Date	TT/ Lane	Pr{Type Truck} P_i	S_j	E_j	N_j	K_{1j}	K_{2j}	W_{1j}	W_{2j}	X_1	X_2	Observed ESAL	Estimated ESAL	Estimated T_f
2-Oct	135	0.2258	30	0.0667	0.9333	28	2	56730	127800	1.5884	0.2556	17.125	17.164	0.5632
3-Oct	761	0.2258	172	0.0640	0.9360	161	11	56730	127800	9.1335	1.4058	435.850	621.586	3.6180
4-Oct	784	0.2258	177	0.0621	0.9379	166	11	56730	127800	9.4172	1.4058	372.802	605.094	3.4186
5-Oct	393	0.2258	89	0.0674	0.9326	83	6	56730	127800	4.7086	0.7668	218.15	256.480	2.8907
6-Oct	195	0.2258	44	0.0682	0.9318	41	3	56730	127800	2.3259	0.3834	68.155	40.269	0.9147
7-Oct	726	0.2258	164	0.0610	0.9390	154	10	56730	127800	8.7364	1.2780	989.899	644.893	3.9346
8-Oct	740	0.2258	167	0.0641	0.9359	156	11	56730	127800	8.8499	1.4058	823.198	638.098	3.8195
9-Oct	752	0.2398	180	0.0778	0.9222	166	14	56730	127800	9.4172	1.7892	708.612	459.210	2.5461
10-Oct	503	0.2398	121	0.0826	0.9174	111	10	56730	127800	6.2970	1.2780	381.302	696.076	5.7699
1-Apr	749	0.1356	102	0.0392	0.9608	98	4	56730	127800	5.5595	0.5112	159.7	152.231	1.4985
2-Apr	779	0.1356	106	0.0377	0.9623	102	4	56730	127800	5.7865	0.5112	182.013	159.952	1.5139
3-Apr	512	0.1356	69	0.0435	0.9565	66	3	56730	127800	3.7442	0.3834	280.107	62.232	0.8961
4-Apr	844	0.1356	114	0.0439	0.9561	109	5	56730	127800	6.1836	0.6390	146.848	243.501	2.1271
5-Apr	393	0.1356	53	0.0377	0.9623	51	2	56730	127800	2.8932	0.2556	27.253	27.612	0.5180
6-Apr	230	0.1356	31	0.0323	0.9677	30	1	56730	127800	1.7019	0.1278	2.873	8.891	0.2850
7-Apr	791	0.1356	107	0.0374	0.9626	103	4	56730	127800	5.8432	0.5112	143.602	161.923	1.5093

Table 5.5.2. Parameter Estimation

Parameter	Estimate	t-value (approx.)	p-value
β_1	0.708262	2.2197	0.0448
β_2	4.954124	3.1222	0.0081
β_3	-0.209359	-4.0373	0.0014

The procedure to estimate the x's is shown below:

1. $X_{ij} = k_{ij} w_{ij},\ i = 1,2 \quad j = 4, 5, \ldots, 13$ **(8)**
   - W_{ij} = weight probability distribution
   - i = 1(underloaded), 2(overloaded)
   - j = class 4, class 5, ..., class 13
2. For underloaded class 9 trucks use the following model to compute $k_{1,9}$:
   - $k_{1,9} = \alpha_0 + \alpha_1 TT + \alpha_2 (P_9)^{1.6}$ **(9)**
   - TT = Truck Traffic for the road, P_9 = Percent of class 9 vehicle
   - the multiple regression analysis of equation 9 is presented in Table 5.5.3, the R^2

for the equation is 96.14, which indicates that the model explains 96.14% of the variability in $k_{1,9}$

Table 5.5.3 Multiple Regression Analysis for $k_{1,9}$

Parameter	Estimate	Standard Error	T Statistic	p-value
α_0	-68.5136	10.2793	-6.6652	0.0000
α_1	0.180353	0.0110789	16.2789	0.0000
α_3	920.159	97.1878	9.46784	0.0000

Model parameters given by Statgraphics computer program

3. For overloaded class 9 trucks use the following model to compute $k_{2,9}$:

- $K_{2,9} = \phi_0 - \phi_1 TT - \phi_2 P_j - \phi_3 (P_j)^{0.1}$ **(10)**
- TT = Truck Traffic for the road, P_9 = Percent of class 9 vehicle
- the multiple regression analysis of equation 10 is presented in Table 5.5.4; the R^2 for the equation is 94.07, which indicates that the model explains 94.07% of the variability in $k_{2,9}$

Table 5.5.4 Multiple Regression Analysis for $k_{2,9}$

Parameter	Estimate	Standard Error	T Statistic	p-value
ϕ_0	1262.34	493.87	2.55602	0.0252
ϕ_1	0.0107953	0.00121938	8.85308	0.0000
ϕ_2	860.524	307.694	2.79668	0.0161
ϕ_3	-1688.1	653.873	-2.58169	0.0240

Model parameters given by Statgraphics computer program

The expected truck weight in the j[th] classification is computed from the generic probability distributions as shown below:

$$\overline{w_{1j}} = \int_{0}^{L_j} f(w_{1j})\, w_{1j}\, d_{1j} \quad and \quad \overline{w_{2j}} = \int_{L}^{\infty} f(w_{2j})\, w_{2j}\, dw_{2j} \qquad \textbf{(11)}$$

where w_{1j}, and w_{2j} are the gross vehicle weight for each truck in the j[th] truck classification under and above the traffic load limits, respectively. $f(w_{1j})$ and $f(w_{2j})$ are the generic probability density functions for w_{1j}, and w_{2j} random variables, respectively. L_j is the traffic load limits for the j[th] truck classification.

The daily truck factor for each type of truck can be estimated by using the following expression:

$$T_f(j) = y_j \quad S_j, \quad j = 4,5,....,13 \qquad \textbf{(10)}$$

where $T_f(j)$ is the daily truck factor for the truck type j, y_j is the ESAL calculated, and S_j is the percentage of trucks j times the total number of trucks.

Example:

For purposes of illustration, a numerical example for predicting the daily $ESAL_{18}$ and $T_f(j)$ for the 9[th] classification is provided. Suppose that the following information is known:

1.The average number of trucks for the highway is 761

3.The percentage of trucks for the 9[th] classification is 22.58, (p=0.2258)

The values of $k_{1,9}$ and $k_{2,9}$ are computed as follows:

$k_{1,9} = -68.5136 + 0.180353(761) + 920.159(.2258)^{1.6} = 154$

$k_{2,9} = 1262.34 + 0.0107953(761) + 860.524(.2258) - 1688.1(.2258)^{0.1} = 10$

The $x_{i,9}$ values are:

$x_{1,9} = k_{1,9}\,(w_{1,9}) = 154(56,730) = 8,736,420$ - use 8.736

$x_{2,9} = k_{2,9}\,(w_{2,9}) = 10(127,800) = 1,278,000$ - use 1.278

Then the ESAL is calculated:

$$y_9 = \exp\left(\beta_1 x_1^{0.7} + \beta_2 x_2^{0.7} + \beta_3 x_1 x_2^{1.5} + \varepsilon\right)$$

$y_9 = exp(0.708562(8.736)^{0.7} + 4.954124(1.278)^{0.7} - 0.209359(8.736)(1.278)^{1.5})$

$y_9 = 645.787\ ESAL_{18}$

Truck Factor is then:

$T_f = 645.7587 / (761*0.2258) = 3.758$

Conclusion:

A general method for deriving probability density functions for a continuous random variable is proposed. Application of this methodology has been illustrated using WIM data from the Guayama weighing station. A regression model has been derived to predict the traffic damages for in-service pavement in terms of equivalent single axle load ($ESAL_{18}$) and truck factor, T_f.

This methodology is especially useful for predicting the traffic load for in-service pavement in which WIM equipment has not been installed. The derived regression equation requires the use of generic probability density functions, truck traffic, and percent of trucks to obtain traffic load predictions. Prediction accuracy of the derived regression models can be improved by updating the WIM data and increasing the sample size.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

Weigh-in-Motion technology is being used all over the world to gather data for planning, enforcement, and for determining the traffic parameters required for the design of new and rehabilitated pavements structures. In Puerto Rico, WIM/AVC equipment is being installed to gather data primarily for planning purposes.

This investigation provided the opportunity to evaluate the installation, calibration, and operation procedures of Weight-in-Motion equipment located along the primary highway network in Puerto Rico and analyze representative data sets of seven out of eleven WIM stations. The analysis provided the basis for short and long term improvements in the process of data acquisition, validation and in the identification of future sites to adequately represent the truck traffic distribution in the island pavement network.

6.2 Conclusions

Based on the site visits conducted at the eleven WIM stations, analysis performed with the representative data sets of seven WIM stations, and inspection performed during a typical installation and calibration of a WIM station, the following conclusions are made:

- Currently in Puerto Rico eight out of the eleven stations are working properly. Caguas and Hatillo WIM stations are waiting for calibration.

- **WIM/AVC Equipment**

  The accuracy and reliability of WIM stations was measured based on the common errors encountered in the data. All stations had some sort of error, which is to be expected due to the different truck configurations and lane switching among other factors. Even if a technician is gathering the data, in-situ error would be present and probably it would be greater. The equipment can gather reliable and accurate data, but site selection and calibration is important.

- **Typical Trucks.**

  The two-axle six-tire single unit truck (class 5), the three-axle single unit truck (class 6) commonly used to carry aggregates, and the five axle semi-trailer truck (class 9) are the most typical trucks encountered in the primary highway network and represent approximately an 85% of the entire truck stream.

- **WIM Stations & Vehicle Groups Errors**

  - From the stations and trucks analyzed, it was found that there is an excessive number of overloaded class 5 trucks in Mayagüez. Some are overweight by up to 45%. It was seen than even though the load limit is 34,000 pounds, the maximum weight encountered in the stations was double or more of the limit. The error presented is high in the Mayagüez WIM station (14%), for class 5 trucks, but is low at all the other stations with less than 10%. Errors may be caused by overweight registered at the Mayagüez WIM station. The number of vehicles using the road, since Arecibo (Flexible) WIM station registered 54% more trucks than Mayagüez WIM station, does not produce the error.

- In class 6, almost all the stations analyzed have a high percent of overweight trucks, exceeding 10% overweight and reaching as high as almost 50%. The gross vehicle weight encountered sometimes reaches 90,000 pounds and the limit is 54,000 pounds. Error in this class is low, with less than seven percent for all the stations. The Mayagüez WIM station has the highest percent of error of all the stations.
- Class 9 trucks also have a significant number of overweight vehicles, at the Mayagüez WIM station almost reaching the 25% threshold. Even though the number of overweight vehicles is less than for class 6, the magnitude of the load is higher, as high as 145,000 pounds. Obviously the passage of a truck with this magnitude of load will decrease the longevity of the pavement. The error encountered for this type of truck is low for all the stations except for Salinas WIM station.
- A common error encountered at all the WIM stations was for class 8 trucks. The equipment seems to throw all the bad data into this category because the error found was between 80% and 95%. This type of vehicle is not used a lot in Puerto Rico, and the numbers for each station surpass the number of the trucks typically used on the Island. The Arecibo WIM station shows the lowest percent of error, with a 70%, which is high, but lower than all the other stations.

- Overall the error encountered demonstrated that Class 8 data is erroneous and could give false results if used. Another finding is that the Arecibo (flexible) WIM station in this analysis is the best station, producing the lowest percentage of errors as shown previously. One observation is that the error has nothing to do with vehicular volume but with the density of vehicular flow. This explanation was supported at the Mayagüez station where the error was high possibly due to a signalized intersection located just prior to the WIM station.

- **Calibration**

  By analyzing the different errors encountered and the field verification done in Mayagüez, it was found that the calibration procedure currently used might need to be modified. Trucks being used in the calibration are the typical truck class 6 and 9, which does not present too much error. A new calibration process should include more types of vehicles in order to verify that they match the FHWA classification scheme. Also overweight trucks should be used to calibrate the WIM stations.

- **Land Use**

  Land use analysis could be initially used to establish traffic patterns when the station is located on a road that originates in a particular town or communities with no access control. For stations on highways with full access control, as in the case of the Salinas WIM station, the land use would hardly be associated with the traffic patterns that uses this facility, because the traffic passes by and the land use does not contribute creating the traffic pattern.

- **Weight Probability Distribution, ESAL, and Truck Factors**

  A general method for deriving probability density functions for continuous variables is proposed. Application of this methodology was illustrated using WIM data for Guayama. A regression model was derived to predict the traffic damage for in-service pavement in terms of equivalent single axle load ($ESAL_{18}$) and truck factor (T_F). This methodology is especially useful for predicting the traffic load for in-service pavement in which WIM equipment has not been installed. The derived regression equation requires the use of a generic probability density function, and traffic data to obtain traffic load predictions. Prediction accuracy of the derived models can be improved by updating the WIM data and increasing the sample size. A generic probability density function can be used to obtain reliable estimates of truck factor and cumulative ESAL. It is also expected that, generic probability density function may also be useful in estimating remaining pavement life and the design of required pavement overlays.

- **Law Enforcement and Weight Regulations**

  Due to the magnitude of loads being transported in Puerto Rico. it is important that strict enforcement of legal load limits be strictly enforced, especially along the principal road network, if not pavement deterioration will continue. Weight regulations should be posted on highways and other major streets so drivers are aware of them.

6.3 Recommendations

The following recommendations result from this research:

- To get more reliable WIM data and to minimize the number of errors encountered in the data, a more efficient calibration method should be enforced. A better calibration is needed for evaluating the performance capabilities of a new WIM system under excellent conditions and under representative traffic loading. The WIM system being evaluated in the new calibration should be subjected to the following:
  - A loading test unit consisting of three test vehicles, namely class 5, class 6 and class 9 loaded with a non-shifting load
  - 51 additional vehicles selected from the traffic stream at the WIM station. The number of vehicles in each Vehicle Class shall be selected in random order from the traffic stream following Table 6.3.1

Table 6.3.1 Suggested Vehicles for Calibration

Vehicle Class	Number of Selected Vehicles
4	3
5	20
6	8
7	3
8	4
9	10
10	3
Total	51

- All vehicles comprising the loading test unit shall de weighed statically on certified weighing devices at a suitable site within reasonable proximity to the acceptance-test site
- All vehicles comprising the loading test shall pass the WIM station at least five times
- The velocity for the passages of the test vehicles shall be the following; 25, 45, 55 (twice), and 70 mph.

- WIM equipment should be installed on a level surface, away from a signalized intersection in order that the platoon of vehicles departing the intersection have sufficient distance to maintain a gap under open road conditions.
- An education program is needed to warn the truckers of the damage being done to the pavement by excessive loads. Literature could be sent to trucking companies and different companies that own and operate trucks. TV commercials could also be used to educate people who operate trucks.
- An enforcement program should be implemented to reduce the numbers of overloaded trucks on the roads. It should be designed to minimize the hassle to other drivers and legally loaded trucks. This could be done by using existing WIM technology in conjunction with video imaging to pre-select trucks that may be overloaded and later weigh them using static scales at a weighing station nearby. Also low speed WIM equipment could be used at toll booths, creating a specially designed lane only for trucks where the weight is recorded as the toll is paid and a specially trained operator

decides if the truck can or not use the road. Such a program will reduce premature damage to toll roads.

- A review of the penalties for the overweight vehicles should be made, so the fines given to overloaded trucks are appropriate for the damage being done by the truck.
- Although a computer program was developed during this investigation, a more complex program should be developed to organize and analyze information by station, month, week, and day. The program should be capable of managing large quantities of data and filter the based on parameters established in this investigation. Another task is to merge data files for several months and years, for each WIM station.
- In the future, WIM equipment should be installed in strategic locations to capture the heavy truck traffic entering and departing from major cities, ports, and other places generating traffic; for example in Mayagüez, Ponce, San Juan, and Caguas. Although this is has already partially been done, the effort must continue to sample as much vehicular volume as possible for both planning and enforcement.

6.4 Future Research

Future research could include the following:

- Develop the weight probability distribution for the whole range of weights instead of dividing them into two parts, as it was done during this research. Also the weight probability distribution could be developed for single and tandem axles, as well as for gross vehicle weight.

- Study the effect of the type of pavement installed on. For example at the Arecibo WIM station (PR-22, Km. 69.8) located on the rigid pavement versus the one located in the flexible pavement (PR-22, Km. 71.75).
- Analyze the economic effect of overloaded trucks, using the magnitude recorded by WIM equipment, associated to rehabilitation of pavements.

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APPENDIX A

ASTM Designation E 1318-94

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Standard Specification for Highway Weigh-in-Motion (WIM) Systems with User Requirements and Test Method[1]

This standard is issued under the fixed designation E 1318; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification describes Weigh-in-Motion (WIM), the process of measuring the dynamic tire forces of a moving vehicle and estimating the corresponding tire loads of the static vehicle. Gross-vehicle weight (mass) of a highway vehicle is made up of the mass of several contiguous vehicle components, and is distributed among the tires of the vehicle through connectors such as springs, motion dampers, and hinges. Highway WIM systems are capable of estimating the gross weight of a vehicle as well as the portion of this weight that is carried by each wheel assembly (half-axle with one or more tires), axle (with two or more wheel assemblies lying approximately on a common axis oriented transversely to the nominal direction of motion of the vehicle), and axle group on the vehicle.

1.2 Ancillary information concerning the speed, lane of operation, date and time of passage, number and spacing of axles, and classification (according to axle arrangement) of each vehicle that is weighed in motion is desired for certain purposes. It is feasible for a WIM system to measure or calculate these traffic parameters and to process, summarize, store, display, record, hard-copy, and transmit the resulting data. Furthermore, differences in measured or calculated parameters as compared with selected control criteria can be detected and indicated. In addition to tire-load information, a WIM system is capable of producing all, or specified portions of, this information.

1.3 Highway WIM systems generally have three applications: (1) collecting statistical traffic data, (2) aiding enforcement, and (3) enforcement. This specification classifies WIM systems according to their application and gives the related performance requirements and user requirements for each type of system.

1.4 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are for informational purposes only. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other.

1.5 The following safety hazards caveat applies only to the test method portion, Section 7, of this specification. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Document

2.1 *ASTM Standard:*

E 1155 Test Method for Determining Floor Flatness and Levelness Using the F-Number System (Inch-Pound Units)[2]

3. Terminology

3.1 *Descriptions of Terms Specific to this Standard:*

3.1.1 *accuracy*—the closeness or degree of agreement (within a stated tolerance and probability of conformity) between a quantity measured or estimated by a WIM system and an accepted reference value. Precision and bias of the test method used to determine WIM-system accuracy are discussed in Section 7.

3.1.2 *axle-group load*—the sum of all tire loads on a group of adjacent axles.

3.1.3 *axle load*—the sum of all tire loads on an axle. An axle is comprised of two or more wheel assemblies lying approximately on a common axis oriented transversely to the nominal direction of motion of the vehicle.

3.1.4 *gross-vehicle weight*—the total mass of the vehicle or the vehicle combination including all connected components.

3.1.5 *tire load*—the portion of the gross-vehicle weight imposed upon the static tire at the time of weighing, expressed in units of mass, pounds (kilograms), due only to the vertically-downward force of gravity acting on the mass of the static vehicle.

3.1.6 *tolerance*—the defined limit of allowable departure from the true value of a quantity measured or estimated by a WIM system.

3.1.7 *weigh*—to measure the tire load on one or more tires by using a vehicle scale, an axle-load scale, a portable axle-load weigher, or a wheel-load weigher (see Sec. 2.20, of the National Institute of Standards and Technology Handbook 44).[3] These devices are usually subjected to field standard test weights at each locality of use and are adjusted to indicate units of mass (see 3.2, Appendix B, NIST Handbook 44).

3.1.8 *Weigh-in-Motion* (WIM), *n*—the process of estimating a moving vehicle's gross weight and the portion of

[1] This specification is under the jurisdiction of ASTM Committee E-17 on Vehicle Pavement Systems and is the direct responsibility of Subcommittee E17.42 on Traffic Characteristics.

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[2] *Annual Book of ASTM Standards*, Vol 04.07.

[3] "Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices," *National Institute of Standards and Technology Handbook 44*, U.S. Department of Commerce, Washington, DC 20234.

that weight that is carried by each wheel, axle, or axle group, or combination thereof, by measurement and analysis of dynamic vehicle tire forces.

3.1.9 *weight*—synonymous with mass. The mass of a body is a measure of its inertia, or resistance to change in motion.

3.1.10 *wheel load*—the sum of the tire loads on all tires included in the wheel assembly which comprises a half-axle.

3.1.11 *WIM System*—a set of sensors and supporting instruments which measures the presence of a moving vehicle and the related dynamic tire forces at specified locations with respect to time; estimates tire loads, speed, axle spacing, vehicle class according to axle arrangement, and other parameters concerning the vehicle; and processes, displays, and stores this information. This specification applies only to highway vehicles.

4. Classification

4.1 WIM systems shall be specified to meet the needs of the user for intended applications in accordance with the following types. Exceptions and options may be specified. All systems shall be designed to operate on 110V, a-c, 60-Hz power, and lightening protection for affected system components shall be provided by the vendor. The user may specify as options a completely battery-powered system or battery-backup power in case of failure of normal power.

4.1.1 *Type I:* This type of WIM system shall be designed for installation in up to four lanes at a traffic data-collection site and shall be capable of accommodating highway vehicles moving at speeds from 10 to 70 mph (16 to 113 km/h), inclusive. For each vehicle processed, the system shall produce all data items shown in Table 1. A user-controlled feature of the system shall allow tire-force information from the wheel(s) on only one half of an axle to be used to estimate axle load. Provisions shall be made for entering selected limits for wheel, axle, axle-group (including bridge-formula grouping[4]) loads, and gross-vehicle weights as well as speed and for detecting and indicating suspected violation of any of these limits by a particular vehicle. A feature shall be provided so that the user can determine whether or not the WIM system will prepare selected data items for display and recording. Use of this feature shall not inhibit the system from receiving and processing data. Data shall be processed on-site in such a way that all data items shown in Table 1 can be displayed in alphanumeric form for immediate review. Means for recording data items 1, 5, 6, 7, 8, 9, 10, and 11 for permanent record shall be provided. On-site presentation of a hard-copy of all data items produced by the system shall be an optional feature (Option 1) of the system. Option 2 for this type of WIM system shall additionally provide means for counting and for recording hourly the lanewise count of all vehicles traveling in all lanes, up to a maximum of ten lanes, at a data-collection site, including lanes without WIM sensors. Option 3 shall provide for counting, classifying (via axle arrangement), measuring the speed of, and recording the hourly totals concerning all such vehicles by class and by lane of travel.

[4] *Traffic Monitoring Guide, June 1985*, U.S. Department of Transportation, Federal Highway Administration, Office of Highway Planning, Washington, DC 20590.

TABLE 1 Data Items Produced by WIM System

1.	Wheel Load
2.	Axle Load
3.	Axle-Group Load
4.	Gross-Vehicle Weight
5.	Speed
6.	Center-to-Center Spacing Between Axles
7.	Vehicle Class (via axle arrangement)
8.	Site Identification Code
9.	Lane and Direction of Travel
10.	Date and Time of Passage
11.	Sequential Vehicle Record Number
12.	Wheelbase (frontmost to rearmost axle)
13.	Equivalent Single-Axle Load (ESAL)
14.	Violation Code

4.1.2 *Type II:* This type of WIM system shall be designed for installation at traffic data-collection sites and should be capable of accommodating highway vehicles moving at speeds from 10 to 70 mph (16 to 113 km/h), inclusive. For each vehicle processed, all data items shown in Table 1 except Item 1 shall be produced by the system. All other features and options of the Type II WIM system shall be identical to those described in 4.1.1 for the Type I WIM system.

4.1.3 *Type III:* This type of WIM system shall be designed for installation in one or two lanes at weight-enforcement stations to identify vehicles operating at speeds from 15 to 50 mph (24 to 80 km/h), inclusive, that are suspected of weight-limit or load-limit violation. For each vehicle processed, the system shall produce all data items shown in Table 1 except 7, 12, and 13 and shall also estimate acceleration (while the vehicle is over the WIM-system sensors). Provisions shall be made for entering selected limits for wheel, axle, axle-group (including bridge-formula grouping[4]) loads, and gross-vehicle weight as well as speed and acceleration and for detecting and indicating suspected violation of any of these limits by a particular vehicle. Means shall be provided for automatically controlling official traffic-control devices which will direct each suspect vehicle to a scale for confirmation weighing and guide all non-suspect vehicles past the scale without stopping. Manual operation of these official traffic-control devices shall be provided as an optional feature (Option 1) of the Type III WIM system. Information used in determining a suspected violation shall be displayed in alphanumeric form for immediate review and recorded permanently. Option 2 shall provide means for presenting this information in hard-copy form if requested by the system operator. Option 3 may be specified to exempt the Type III WIM system from producing wheel-load information (Item 1 in Table 1) if this data item is not of interest for enforcement. Option 4 for this type of WIM system shall provide for recording the following data items shown in Table 1 for every vehicle processed by the system: 1 (2 in lieu of 1 when Option 3 is specified), 5, 6, 8, 9, 10, and 11. These items allow subsequent computation of statistical traffic data.

4.1.4 *Type IV:* This type of WIM system shall be designed for use at weight-enforcement stations to detect weight-limit or load-limit violations. Speeds from 0 to 10 mph (0 to 16 km/h), inclusive, shall be accommodated. For each vehicle

TABLE 2 Functional Performance Requirements for WIM Systems

Function	Tolerance for 95 % Probability of Conformity				
	Type I	Type II	Type III	Type IV	
				Value ≥ lb (kg)[A]	±lb (kg)
Wheel Load	±25 %		±20 %	5 000 (2 300)	250 (100)
Axle Load	±20 %	±30 %	±15 %	12 000 (5 400)	500 (200)
Axle-Group Load	±15 %	±20 %	±10 %	25 000 (11 300)	1 200 (500)
Gross-Vehicle Weight	±10 %	±15 %	±6 %	60 000 (27 200)	2 500 (1 100)
Speed			±1 mph (2 km/h)		
Axle-Spacing			±0.5 ft (150 mm)		

[A] Lower values are not usually a concern in enforcement.

that is processed, the system shall produce all data items shown in Table 1 except 7, 9, 12, and 13 and shall also estimate acceleration (while the vehicle is over the WIM-system sensors). Provisions shall be made for entering and displaying selected limits for wheel, axle, axle-group (including bridge-formula grouping,[4]) loads, and gross-vehicle weights as well as speed and acceleration and for detecting and indicating violation of any of these limits by a particular vehicle. Information used in determining a violation shall be displayed in alphanumeric form for immediate review and recorded permanently. Option 1 shall provide means for presenting this information in hard-copy form if requested by the system operator. Option 2 may be specified to exempt the Type IV WIM system from producing wheel-load information (Item 1 in Table 1) if this data item is not of interest for enforcement.

5. Performance Requirements

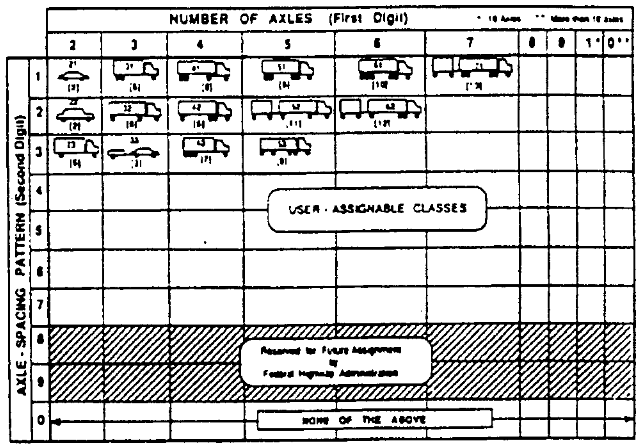
5.1 Each type of WIM system shall be capable of performing the indicated functions within the accuracy shown in Table 2. A test method for determining compliance with these requirements is given in Section 7. After computation of the data items shown in Table 2, no digit which indicates less than 10 lb (5 kg) (load or weight), 1 mph (2 km/h) (speed), or 0.1 ft (30 mm) (axle spacing) shall be retained.

5.2 Vehicle classification according to axle arrangement shall be accomplished by Type I and Type II WIM systems. The vendor shall incorporate software within each Type I and Type II WIM system for using the available WIM-system axle-count and axle-spacing information for estimating the Federal Highway Administration (FHWA) Vehicle Types described briefly in Table 3. See U.S. Department of Transportation Traffic Monitoring Guide[4] for the complete description of FHWA Vehicle Types. The FHWA Vehicle Type shall be indicated by the 2-Digit Code shown in Table 3. A vehicle type code 00 shall be applied to any vehicle which the software fails to assign to one of the types shown.

5.2.1 As an option to the FHWA vehicle classes indicated by the 2-digit code, the user may specify the 3-Digit Vehicle

TABLE 3 FHWA Vehicle Types

2-Digit Code	Brief Description
01	Motorcycles
02	Passenger Cars
03	Other Two-Axle, Four-Tire Single-Unit Vehicles
04	Buses
05	Two-Axle, Six-Tire, Single-Unit Trucks
06	Three-Axle, Single-Unit Trucks
07	Four-or-More Axle Single-Unit Trucks
08	Four-or-Less Axle Single-Trailer Trucks
09	Five-Axle Single-Trailer Trucks
10	Six-or-More Axle Single-Trailer Trucks
11	Five-or-Less Axle Multi-Trailer Trucks
12	Six-Axle Multi-Trailer Trucks
13	Seven-or-More Axle Multi-Trailer Trucks

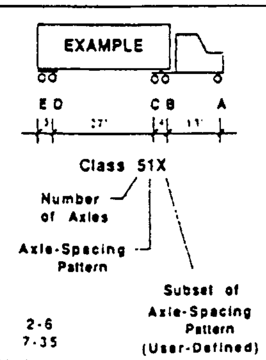


NOTE—Corresponding Federal Highway Administration (FHWA) Vehicle Types are shown as [ ]. e.g., Class 51 shown above is FHWA [9].
Third Digit allows the user to describe a subset(s) of the axle-spacing pattern defined by the second digit.

FIG. 1 Graphical Representation of 3-Digit Vehicle Classes

TABLE 4 Axle-Spacing Patterns for 3-Digit Vehicle Classes

CLASS	RANGE OF SPACING BETWEEN PAIRS OF AXLES (FT)					
	A,B	B,C	C,D	D,E	E,F	etc.
21	6-9					
22	9-11					
23	11-25					
20	"OTHER"					
31	8-26	2-6				
32	8-20	11-45				
33	6-10	6-22				
30	" OTHER 3-AXLE "					
41	8-20	11-45	2-6			
42	8-20	2-6	11-45			
43	8-25	2-6	2-6			
40	...... OTHER 4-AXLE					
51	8-25	2-6	11-55	2-6		
52	8-22	11-36	6-20	7-35		
50	.... OTHER 5-AXLE					
61	8-20	2-6	11-42	2-6	2-6	
62	8-20	2-6	11-30	7-15	11-25	
60	.... OTHER 6-AXLE					



Classes shown graphically in Fig. 1 and numerically in Table 4. In the 3-digit code, the first digit indicates the total number of axles on the vehicle or the combination, the second digit indicates the axle-spacing pattern, and the third digit indicates a user-assigned subset of the axle-spacing pattern. Provisions shall be made for the user to enter additional axle-spacing criteria for the user-assignable classes shown in Fig. 1 as well as for the user-assignable subsets of the axle-spacing patterns which are to be designated by a selected third digit.

5.3 Provisions shall be made in Type I, Type II, Type III, and Type IV WIM systems for entering, displaying, and recording a 10-character alphanumeric Site Identification Code for each data-taking session. This code can be used to incorporate information required for FHWA Truck Weight Data Collection.[4]

5.4 A lane and direction-of-travel code for each vehicle processed by Type I, Type II, and Type III WIM systems shall consist of a number beginning with 1 for the right-hand northbound or eastbound traffic lane and continuing until all the lanes in that direction of travel have been numbered; the next sequential number shall be assigned to the lanes in the opposite direction of travel beginning with the left-hand lane and continuing until all lanes have been numbered. Provision shall be made for 12 numbers in the code. This code may be used to incorporate information required for FHWA Truck Weight Data Collection.[4]

5.5 Date of passage shall be indicated numerically for each vehicle processed by Type I, Type II, Type III, and Type IV WIM systems in the following format: MM/DD/YY, where M is the month, D is the day, and Y is the year.

5.6 Time of passage shall be indicated numerically for each vehicle processed by Type I, Type II, Type III, and Type IV WIM systems in the following format: hhmm:ss, where h is the hour beginning with 00 at midnight and continuing through 23, m is the minute, and s is the second.

5.7 Type I, Type II, Type III, and Type IV WIM systems shall provide sequential-numbering (user-resettable) for each recorded vehicular data set.

5.8 Type I and Type II WIM systems shall compute wheelbase as the sum of all axle spacings between the front most and the rearmost axles on the vehicle or combination that have tires in contact with the road surface at the time of weighing. This value shall be rounded to an integer value (in ft) (or to the nearest 0.1 m) before display or recording.

5.9 Type I and Type II WIM systems shall compute Equivalent Single-Axle Load (ESAL) as described in the Annex to this standard. The WIM system shall be capable of computing ESALs for single and tandem axles for both flexible and rigid pavements, and provision shall be made for the user to select one of these pavement types for application during any given data-collection session. The system shall compute the total ESALs for each vehicle or vehicle combination and prepare these data for display as part of each vehicle record. When displayed, this value shall be truncated to 2 digits following the decimal and presented in the following format: FESAL = for flexible pavements, and RESAL = for rigid pavements. The parameter for serviceability at the end of time t, P_t, shall be adjustable by the user, but 2.5 shall be programmed as a default value. Similarly, the value for structural number, $\overline{SN}$, used for computing flexible pavement equivalency factors shall be user adjustable, but shall be defaulted to 3.0. The value for thickness of rigid pavement slab, D, used in computing rigid pavement equivalency factors shall be user adjustable, and shall be defaulted to 8.0 in. (203 mm) in the WIM-system program. Provision shall be made in the program to list on demand all parameters actually utilized in the ESAL computation during any given data-collection session.

5.10 Violations of all user-set parameters shall be determined by Type I, Type II, Type III, and Type IV WIM systems. A 2-character violation code, such as shown in Table 5, shall be used for each detected violation and shall be included in the displayed data. Provision shall be made for the user to define up to 15 violation codes. An additional optional feature that calls attention to any data items which are in violation of user-set limits may be specified by the user, for example, flashing, underlining, bold-facing, or audio tones.

5.11 Type III and Type IV WIM systems shall measure vehicle acceleration, which is a change in velocity. Negative acceleration is also called deceleration. The forces acting on a vehicle to produce acceleration can effect significant change in the distribution of the gross-vehicle weight among the axles and wheels of the vehicle as compared to the distribution when the vehicle is static. Therefore, any severe acceleration while the vehicle is passing over the WIM-system sensors can invalidate wheel and axle loads estimated by the system. Average acceleration of 2 ft/s^2 (0.6 m/s^2) or greater during the time that the wheelbase (see 5.8) of the vehicle is passing over the tire-force sensors should be considered as a violation. This value shall be user-adjustable, but the vendor shall program 2 ft/s^2 (0.6 m/s^2) as the default value in these WIM systems.

5.12 For Type I, Type II, Type III, and Type IV WIM systems, provision shall be made to allow manual entry of a user-assignable 3-digit code into any vehicular data set prior to recording.

6. User Requirements

6.1 In order for any WIM system to perform properly, the user must provide and maintain an adequate operating environment. Construction or selection of each WIM site as well as continuing maintenance of the site and the sensors are extremely important considerations. The following site conditions, or better, shall be provided by the user.

6.1.1 The horizontal curvature of the roadway lane for 150 ft (45 m) in advance of and beyond the WIM-system sensors shall have a radius not less than 5700 ft (1.7 km) measured along the centerline of the lane for all types of WIM systems.

TABLE 5 Violation Code

Violation	Code
Wheel Load	WL
Axle Load	AL
Axle—Group Load	AG
Gross-Vehicle Weight	GV
Bridge—Formula Load	BF
Over Speed	OS
Under Speed	US
Acceleration	AC
Deceleration	DE

6.1.2 The longitudinal gradient of the road surface for 150 ft (45 m) in advance of and beyond the WIM system sensors shall not exceed 2 % for Type I, Type II, and Type III WIM-system installations, and shall not exceed 1 % for Type IV installations.

6.1.3 The cross-slope (lateral slope) of the road surface for 150 ft (45 m) in advance of and beyond the WIM-system sensors shall not exceed 2 % for Type I, Type II, and Type III WIM system installations, and shall not exceed 1 % for Type IV installations.

6.1.4 The width of the paved roadway lane for 150 ft (45 m) in advance of and beyond the WIM-system sensors shall be between 10 and 12 ft (3.0 and 3.7 m), inclusive. For Type III and Type IV WIM systems, the edges of the lane throughout this distance shall be marked with solid white longitudinal pavement marking lines 4 to 6 in. (100 to 150 mm) wide, and at least 3 ft (1 m) of additional clear space for wide loads shall be provided on each side of the WIM-system lane.

6.1.5 The surface of the paved roadway 150 ft (45 m) in advance of and beyond the WIM-system sensors shall be maintained in a condition such that a 6-in. (150-mm) diameter circular plate 0.125-in. (3 mm) thick cannot be passed beneath a 20-ft (6-m) long straightedge when the straightedge is positioned and maneuvered in the following manner:

6.1.5.1 Beginning at the longitudinal center of the WIM-system sensors, place the straightedge along each respective lane edge with the outer end at the distances from the longitudinal center of the sensors as indicated below, pivot the straightedge about this end, and sweep the inner end between the lane edges while checking clearance beneath the straightedge with the circular plate. Equivalent flatness may be determined by an alternative means such as is described in Test Method E 1155.

Lane Edge	Longitudinal distance from Center of Sensors, ft (m)
Right	20, 30, 44, 60, 76, 92, 108, 124, 140, and 156 (6, 9, 13, 18, 23, 28, 33, 38, 43, and 48)
Left	20, 36, 52, 68, 84, 100, 116, 132, 148, and 164 (6, 11, 16, 21, 26, 30, 35, 40, 45, and 50)

6.1.6 The user shall provide and maintain a foundation to accommodate the WIM-system sensors and shall install and maintain the sensors in accordance with the recommendations of the system vendor.

6.1.7 The user shall provide and maintain a climatic environment for the WIM-system instruments in accordance with those specified by the user and agreed upon by the system vendor.

6.1.8 The user shall provide an adequate 110V, ac, 60-Hz electrical power supply at each WIM site and/or specify an optional battery-powered system as suggested in 4.1.

6.2 Any desired optional features described in Section 4 and Section 5, any exceptions, and any additional features of the WIM system shall be specified by the user. The user shall also specify the data items to be included in the display, the number of vehicle records to be displayed simultaneously, and whether the ability to hold a selected record(s) on display without interference with continuous data taking by the system is required. The user should note that the number of data items selected will affect the number of vehicle records that can be displayed simultaneously.

6.3 The user shall recalibrate every WIM system following any maintenance or relocation, and at a minimum annually. Recalibration of system Types I, II, and III shall be performed in accordance with the method presented in 7.5, and system Type IV shall be recalibrated in accordance with the method presented in 7.4.5.

7. Test Method for WIM System Performance

7.1 A test method for evaluating the performance of each type of WIM system is presented in this section. Procedures are given for (1) acceptance testing of any new type WIM system, and (2) on-site calibration (to remove as much bias as practicable from the weight estimates) at the time of system installation or when site conditions have changed.

7.1.1 *Apparatus for Weighing Static Vehicles*—When wheel-load data are required from the WIM system, the corresponding reference tire-load values for Type I, Type III, and Type IV WIM systems shall be determined with wheel-load weighers which meet the respective tolerance specification of the current edition of NIST Handbook 44.[3] The minimum number of wheel-load weighers required is 2 and the preferred number is 6. When wheel-load data are not required, axle-load scales, multi-platform vehicle scales, portable axle-load weighers, or a pair of wheel-load weighers which meet the respective tolerance specification of the current edition of NIST Handbook 44, shall be used for obtaining reference tire-load values for Type II and Type III WIM systems. Either an axle-load scale or a multi-platform vehicle scale, along with wheel-load weighers if required, shall be used for measuring reference tire-load values for Type III and Type IV WIM systems.

7.1.2 *Use of Apparatus for Weighing Static Vehicles*—The tire-pavement contact surfaces of all tires on the vehicle being weighed shall be within 0.25 in. (6 mm) of a plane passing through the load-receiving surface(s) of the multi-platform vehicle scale, wheel-load weighers, portable axle-load weighers, or axle-load scales whenever any tire-load measurement is made. The maximum slope of this plane from horizontal shall be 2 %. Suitable blocking or mats may be utilized, or the weighing device(s) may be recessed into the pavement surface to provide the required vertical orientation of the tire-pavement contact surfaces. When wheel-load information is required, wheel and axle load shall be measured simultaneously using a pair of wheel-load weighers. When wheel-load information is not required, axle-load shall be determined by positioning each axle to be weighed either simultaneously or successively on an axle-load scale(s), a multi-platform vehicle scale, a portable axle-load weigher(s), or a pair(s) of wheel-load weighers. Axle-group load shall be determined either by positioning all axles in the group simultaneously on the required number of weighing devices (preferred) or by successively positioning each axle in the group on a pair of wheel-load weighers or on an axle-load weighing device. The number of movements of the vehicle to accomplish the successive tire-load measurements shall be minimized. A tire-load measurement shall be made only when the brakes of the vehicle being weighed are fully released and all tires are properly positioned on the load-receiving surface(s) of the weighing device(s). Suitable means (for example, chocks) shall be used to keep the tires properly positioned while the brakes are released. Gross-vehicle weight shall be the sum of all wheel loads or axle loads for the vehicle. No tire-load measurement shall be taken until inertially-induced oscillations (for example, via a load of liquid) of the vehicle have subsided to a point that indicated tire load is changing less than three scale divisions in 3s.

7.2 *Acceptance Test for Type I and Type II WIM Systems:*

7.2.1 *Scope*—An acceptance test is described for evaluating the performance capabilities of a new WIM system under excellent conditions and under traffic loading that is representative of that which will be of interest where Type I and Type II WIM systems will be applied. Performance requirements for each type of WIM system are given in Section 5 of this standard, and associated user requirements are given in Section 6. The WIM system being evaluated in the acceptance test shall be subjected to a loading test unit consisting of (a) two test vehicles loaded with a non-shifting load, plus (b) 51 additional vehicles selected from the traffic stream at the acceptance-test site. Other types of vehicles may be added to the loading test unit at sites where large numbers of vehicles of classes not already included are operating. The two test vehicles, which will make multiple passes over the WIM-system sensors at the minimum and at the maximum speed specified by the user between 10 and 70 mph (16 to 113 km/h) and at an intermediate speed, serve two functions. First, they provide a basis for evaluating the performance of the WIM system over the full, specified range of speeds, and second, they provide a means (via repeated measurements on the same static vehicle) for ensuring that reference-value tire-load measurement procedures yield reproducible values. The additional vehicles included in the loading test unit serve the function of subjecting the WIM system to loading by a representative variety of vehicle classes. All vehicles comprising the loading test unit shall be weighed statically on certified weighing devices as described in 7.1.1 and 7.1.2 at a suitable site within reasonable proximity to the acceptance-test site.

7.2.2 *Significance and Use*—Interpretation of the results from the acceptance test will allow the user to determine whether the tested Type I or Type II WIM system is capable of meeting or exceeding the performance requirements stated in Section 5. This can also indicate the potential upper limit of performance which can be achieved by the particular type of system as the road surface conditions, which potentially affect the location and magnitude of dynamic tire forces significantly, shall be the best available for conducting the acceptance test and shall, as a minimum, satisfy the user requirements shown in Section 6. Once a specimen WIM system has passed this rigorous acceptance test, it should not be necessary for each subsequent user to repeat the test for every system of the same type from the same vendor.

7.2.3 *Site for Acceptance Test*—Both the user (or a recognized representative of user's interests) and the vendor shall approve the acceptance test site as well as the WIM-system installation prior to conducting the acceptance test. The actual road-surface and WIM-system sensor conditions which prevail during acceptance testing shall be documented in terms of surface conditions measured in a way that verifies compliance with the user requirements given in Section 6. This documentation, along with all acceptance test results, shall be reported to ASTM Committee E-17 on Pavement Management Technologies so that statements about bias and precision of the test can be formulated as experience is accumulated.

TABLE 6 Composition of Test Unit for Acceptance-Test Loading of WIM Systems

Vehicle Class	Number of Selected Vehicles
23	5
31	5
32	4
41	4
42	4
51	20
52	3
62	3
71	3

7.2.4 *Test Unit for Acceptance Test Loading*—The test unit for loading the WIM system being evaluated in the acceptance test shall be comprised of two loaded test vehicles which will make multiple runs over the WIM-system sensors at prescribed speeds along with other vehicles selected from the traffic stream at the acceptance test site. One of the loaded test vehicles shall be Class 23 and the other Class 51 (see Fig. 1 and Table 4). These test vehicles shall be loaded to within 90 to 110 % of their respective registered gross-vehicle weight with a non-shifting load and shall be in excellent mechanical condition. Special care shall be exercised to ensure that the tires on the test vehicles are in excellent condition (preferably dynamically balanced) and inflated to recommended pressures. The number of vehicles in each Vehicle Class (see 5.2) to be selected in random order from the traffic stream for inclusion in the test unit is shown in Table 6 (see Fig. 1 and Table 4). If a significant number of vehicles of another class(s) is operating at the site, define the class(s), and add three selected vehicles of each such class to the test unit.

7.2.5 *Calibration and Certification*—Within 48 h prior to beginning the acceptance test, the WIM system shall be calibrated in accordance with the method presented in 7.5. The radar speed meter shall be calibrated by the method recommended by its vendor within 30 days prior to the acceptance test. All weighing apparatus used in the acceptance test shall be certified as meeting the applicable maintenance tolerance specified in National Institute of Standards and Technology Handbook 44 within 30 days prior to beginning the acceptance test.

7.2.6 *Procedure*—The following steps shall be performed in conducting the acceptance test.

7.2.6.1 As a joint effort between the user (or a recognized representative of user's interests) and the vendor, select the best available WIM-system site which, as a minimum, meets the applicable requirements stated in Section 6.

7.2.6.2 Ensure that a suitable site for weighing vehicles statically is available within a reasonable distance of the WIM site, that traffic can be controlled safely at this location, and that test vehicles can turn around safely and conveniently for multiple passes. Obtain approval from the public authority having jurisdiction over the site for the traffic control procedures that will be used during testing.

7.2.6.3 Install the WIM system in accordance with the vendor's recommendations and calibrate as required in 7.2.5.

7.2.6.4 Measure and record surface conditions as described in 7.2.3.

7.2.6.5 Using traffic control procedures approved by the appropriate public authority and other reasonable safety precautions, have each loaded test vehicle (see 7.2.4) make a series of three runs over the WIM-system sensors at the minimum and at the maximum speed specified by the user between 10 and 70 mph (16 and 113 km/h), record all data, and note the vehicle record number for each run of each test vehicle.

7.2.6.6 For reference values, measure the speed of the test vehicle each time it passes over the WIM-system sensors with a calibrated radar speed meter or by some other means (such as wheelbase/time) acceptable to both the user (or a recognized representative of user's interests) and the vendor, and record the observed speed.

7.2.6.7 At the site where the vehicle is weighed statically, measure the center-to-center spacing between axles on each test vehicle and record these data to the nearest 0.1 ft (30 mm) as reference values.

7.2.6.8 Weigh the test vehicle statically as described in 7.1.1 and 7.1.2 for every run to determine reference-value tire loads. Sum the applicable tire loads to determine reference-value wheel, axle, and axle-group loads as well as gross-vehicle weight.

7.2.6.9 Confirm that the procedure used for determining reference-value tire loads yields acceptable results by making the calculations shown in 7.2.7.1 before continuing the test.

7.2.6.10 If all the measured or calculated loads and weights of the two static test vehicles fall within the specified ranges, run each test vehicle over the WIM-system sensors three more times at a speed which is representative of truck traffic speed at the site, make reference-value determinations of load, weight, speed, and axle spacing for each of these runs, record all data, and proceed to 7.2.6.14.

7.2.6.11 If any of the measured or calculated load or weight values exceeds the specified range, correct deficiencies in the reference-value weighing process and weigh each test vehicle three more times.

7.2.6.12 Repeat 7.2.6.11 until the weighing process yields reference-value loads and weights which are within the specified range.

7.2.6.13 After the observed values for load and weight of the two static test vehicles have been found to be within the specified ranges, run each of the loaded test vehicles over the WIM-system sensors three more times at each of the following attempted speeds: the minimum and the maximum specified by the user between 10 and 70 mph (16 and 113 km/h) and at a speed which is representative of truck-traffic speed at the site. Make reference-value determinations of load and weight (verify that all these values satisfy the ranges specified in 7.2.7.1), speed, and axle spacing for every run of the test vehicles, and record all data.

7.2.6.14 Make the calculations shown in 7.2.7.2 for 18 runs (three runs at three speeds by two vehicles) of the loaded test vehicles and compare the performance of the WIM system with all specification requirements stated in Section 5.

7.2.6.15 If any WIM-system data item resulting from the test-vehicle runs fails to satisfy the standard, have the user (or a recognized representative of user's interests) decide whether to continue the test or declare that the system has failed to meet specification requirements.

7.2.6.16 If continuation is approved, select vehicles from the traffic stream to complete the makeup of the test unit for acceptance-test loading as specified in 7.2.4.

7.2.6.17 Allow each of the selected vehicles to pass over the WIM-system sensors at normal speed and require each vehicle to stop for weighing and for measurement of axle spacing.

7.2.6.18 Make the calculations shown in 7.2.7.2 and compare the performance of the WIM system with the specification requirements stated in Section 5 for the remainder of the vehicles in the test unit.

7.2.6.19 Interpret and report the results as described in 7.2.8.

7.2.7 *Calculation*—Calculation is needed for evaluating (a) variability in the reference-value loads and weights of the static test vehicles, and (b) conformity of data items produced by the WIM-system to specification requirements.

7.2.7.1 *Procedure for Calculating Reference-Value Loads and Weights*—Only certified weighing devices shall be utilized for determining reference-value tire loads. Reference-value loads and weights are calculated by summing tire loads. For WIM systems which produce estimates of wheel loads, calculate reference-value axle load by summing two wheel loads, axle-group load by summing four wheel loads for the wheels in each tandem-axle group, and gross-vehicle weight by summing all wheel loads separately for each of the two loaded test vehicles specified in 7.2.4. For WIM systems which do not produce estimates of wheel loads, sum the appropriate axle loads to calculate axle-group loads and gross-vehicle weight, if wheel-load weighers are not used. If wheel-load weighers are used, use the procedure stated above for summing tire loads. Calculate the arithmetic mean for each set of values for wheel load, axle load, axle-group load, and gross-vehicle weight; also calculate the difference, in percent, from this mean of each individual value used in calculating the respective mean. Compare these differences to the following specified range for each applicable load or weight: Gross-Vehicle Weight = ±2 %, Axle-Group Load = ±3 %, Axle Load = ±4 %, and Wheel Load = ±5 %. These limits define a practicable range into which an individual observation must fall in order to demonstrate that the static weighing process is producing acceptable results. When multiple weighings are made, always use the mean as the reference-value for load or weight.

7.2.7.2 *Procedure for Calculating Percent of Non-Conforming Data Items*—For each data item that is produced by the WIM system and shown in Table 2, calculate the difference in the value and the corresponding reference value by the following relationship:

$$d = 100[(C - R)/R]$$

where:

d = difference in the value of the data item produced by the WIM system and the corresponding reference value expressed as a percent of the reference value, %,

C = value of the data item produced by the WIM system, and

R = corresponding reference value for the data item.

Determine the number of calculated differences that exceeded the tolerance shown in Table 2 for each data item and express this number as a percent of the total number of observed values of this item by the following relationship:

$$P_{de} = 100[n/N]$$

where:

P_{de} = percent of calculated differences that exceeded the specified tolerance value,

n = number of calculated differences that exceeded the specified tolerance value, and

N = total number of observed values of the data item.

7.2.8 *Interpretation of Test Results and Report*—If more than 5 % of the calculated differences for any applicable data item (specified in Section 4) resulting from all passes of the two loaded test vehicles (each vehicle made three passes at three difference speeds) and from the single pass of each selected vehicle over the sensors at normal speed exceed the specified tolerance (specified in Section 5) for that item, declare the WIM system inaccurate and report that it failed the acceptance test. Regardless of whether the system fails or passes the acceptance test, tabulate all data used in making the determination, including the surface conditions, and send the results to ASTM Committee E-17 on Pavement Management Technologies within 90 days after completion of on-site data collection so that statements about bias and precision of the test can be formulated as experience is accumulated.

7.2.9 *Precision and Bias*—A statement about precision and bias of a test method should allow potential users of the test to assess in general terms its usefulness for a particular purpose. It is intended to provide guidance as to the amount of variation that can be expected in test results when the test is conducted in one or more comparable laboratories or situations. This is a new test method which produces pass-or-fail results. The precision and bias of the procedure and calculations in this acceptance test for Type I and Type II WIM systems are being determined.

7.3 *Acceptance Test for Type III WIM Systems:*

7.3.1 *Scope*—A procedure is given for conducting an acceptance test of a Type III WIM system. This type of system is designed for installation at weight-enforcement stations to identify vehicles operating within a user-specified range of speeds between 15 and 50 mph (24 and 80 km/h), inclusive, that are suspected of weight-limit or load-limit violation. The system must also control official traffic-control devices which direct suspect vehicles to a scale for confirmation weighing and measurement and direct non-suspect vehicles past the scales without stopping. The acceptance test shall be conducted under excellent site conditions and under traffic that includes vehicles which are representative of the vehicle classes of interest where Type III WIM systems will be installed. Performance requirements for this type system are presented in Section 5, and user requirements are given in Section 6. Tolerances for Type III WIM systems are somewhat smaller than for Types I and II because speeds are lower and, with the required reference-value weighing devices continually available, on-site calibration is practicable at any chosen time. Test loading for the acceptance test is designed to allow evaluation of the variability in measured or calculated loads and weights of static vehicles as well as the accuracy of WIM-system estimates of the various data items produced by the system. Capability of the system to detect excessive acceleration of a vehicle while it is over the WIM-system sensors is also evaluated. All vehicles used for test loading the Type III WIM system shall be weighed statically as described in 7.1.1 and 7.1.2 using the certified scales installed at the weight-enforcement site where the acceptance test is conducted.

7.3.2 *Significance and Use*—Interpretation of the results from the acceptance test will allow the user to determine whether the test Type III WIM system is capable of meeting or exceeding the performance requirements stated in Section 5. This can also indicate the potential upper limit of performance that can be achieved by the particular type of system as the road surface conditions, which potentially affect the location and magnitude of dynamic tire forces significantly, shall be the best available for conducting the acceptance test and shall, as a minimum, satisfy the user requirements shown in Section 6. Once a specimen WIM system has passed this rigorous acceptance test, it should not be necessary for each subsequent user to repeat the test for every system of the same type from the same vendor.

7.3.3 *Site for Acceptance Test*—See 7.2.3.

7.3.4 *Test Unit for Acceptance Test Loading*—The test unit for loading the WIM system being evaluated in the acceptance test shall be the same as specified in 7.2.4, except that each vehicle selected from the traffic stream for inclusion in the loading test unit shall have one or more of the following loads or weights that is 80 % or more of the applicable legal limit: gross-vehicle weight, axle-group load, axle load, or wheel load.

7.3.5 *Calibration and Certification*—See 7.2.5.

7.3.6 *Procedure*—The procedure for conducting the acceptance test for Type III WIM systems shall be the same as described in 7.2.6 with the following exceptions:

7.3.6.1 In 7.2.6.5 and 7.2.6.13, the speeds of the loaded test vehicles shall be at the minimum and at the maximum speed specified by the user between 15 and 50 mph (24 and 80 km/h), and

7.3.6.2 After 7.2.6.15, if continuation is approved, verify the ability of the WIM system to detect excessive acceleration by having the driver of each loaded test vehicle approach the WIM-system sensors at a speed between 30 and 40 mph (50 and 60 km/h) and apply heavy braking for approximately one second while the vehicle is passing over the sensor array. Excessive negative acceleration (deceleration) should be indicated by the Violation Code DE (see Table 5). Compare the WIM-system estimates of weights for these runs with those for steady-speed runs and include these comparisons in the data reported to ASTM Committee E-17 on Pavement Management Technologies. Proceed with 7.2.6.16.

7.3.7 *Calculation*—See 7.2.7.

7.3.8 *Interpretation of Test Results and Report*—See 7.2.8.

7.3.9 *Precision and Bias*—The precision and bias of the procedure and calculations in this acceptance test for the Type III WIM system are being determined.

7.4 *Acceptance Test for Type IV WIM Systems:*

7.4.1 *Scope*—The Type IV WIM system is designed to detect weight-limit or load-limit violations by highway vehicles for enforcement purposes. A procedure for acceptance testing of this type system to determine conformity with the performance requirements specified in Section 5 is presented. The procedure includes data collection needed for evaluating the variability in reference-value tire loads measured by certified wheel-load weighers, axle-load scales, a multi-platform vehicle scale, or a combination thereof, as well as the performance of the WIM-system in either measuring the tire loads of a vehicle stopped on the WIM-system sensors or estimating the tire loads and dimensions of a static vehicle from measurements made with the vehicle moving at a steady speed of 10 mph (16 km/h) or less. Reference-value tire loads shall be measured by a multi-platform vehicle scale or an axle-load scale (see 7.1.1) when Option 2 (see 4.1.4) has been specified for the Type IV WIM system under test. When this option has not been specified, reference-value tire loads shall be measured by placing wheel-load weighers directly on the load-receiving surface of the multi-platform vehicle scale or the axle-load scale and raising all tire-pavement contact surfaces approximately into the same plane as described in 7.1.2. The sum of the tire-load values from the wheel-load weighers should compare, within applicable tolerances, with the corresponding value from the scale upon which they are placed; then, the wheel-load-weigher indications should be used only to apportion the axle load(s) indicated by the scale between/among the wheels on the axle(s).

7.4.2 *Significance and Use*—Interpretation of the results from the acceptance test will allow the user to determine whether the tested Type IV WIM system is capable of meeting or exceeding the performance requirements stated in Section 5. This can also indicate the potential upper limit of performance which can be achieved by the particular type of system as the test conditions at the weight-enforcement site shall be the best available for conducting the acceptance test and shall, as a minimum, satisfy the user requirements shown in Section 6. Once a specimen WIM system has passed this rigorous acceptance test, it should not be necessary for each subsequent user to repeat the test for every system of the same type from the same vendor.

7.4.3 *Site for Acceptance Test*—Either an axle-load scale or a multi-platform vehicle scale is required at the site. Other site requirements are the same as 7.2.3.

7.4.4 *Test Unit for Acceptance-Test Loading*—See 7.3.4.

7.4.5 *Calibration and Certification*—Within seven days prior to beginning the acceptance-test, the Type IV WIM system shall, when subjected to field standard test weights, be adjusted to meet the acceptance tolerance for wheel-load weighers or for portable axle-load weighers as stated in NIST Handbook 44, depending upon whether wheel-load data or only axle-load data (4.1.4, Option 2) are of interest. All weighing apparatus used in the acceptance test for determining reference-value tire loads shall be certified as meeting the applicable maintenance tolerance specified in NIST Handbook 44 within 30 days prior to beginning the acceptance test.

7.4.6 *Procedure*—The procedure for conducting the acceptance test for Type IV WIM systems shall be the same as described in 7.2.6 with the following exceptions:

7.4.6.1 In 7.2.6.2, also ensure that an axle-load scale or a multi-platform vehicle scale is available at or near the site.

7.4.6.2 In 7.2.6.5 and 7.2.6.13, the speeds of the loaded test vehicles shall be 0 and 10 mph (0 and 15 km/h).

7.4.6.3 In 7.2.6.9, calculate the difference in each load or weight from the arithmetic mean, in pounds (kilograms), and compare the difference to one-half the applicable tolerance for a Type IV WIM system shown in Table 2. Also, verify that the sum of the tire loads from the wheel-load weighers agrees with the corresponding value from the scale upon which they are placed within applicable tolerances if wheel-load weighers are used. Then, use the wheel-load-weigher indications only to apportion the axle load(s) indicated by the scale between/among the wheels on the axle(s).

7.4.6.4 After 7.2.6.15, if continuation is approved, verify the ability of the WIM system to detect excessive acceleration by having the driver of each loaded test vehicle approach the WIM-system sensors at a speed between 8 and 10 mph (12 and 16 km/h) and apply heavy braking for approximately 1 s while the vehicle is passing over the sensor array. Excessive negative acceleration (deceleration) should be indicated by the Violation Code DE (see Table 5). Compare the WIM-system estimates of loads and weights for these runs with those for steady-speed runs and include these comparisons in the data reported to ASTM Committee E-17 on Pavement Management Technologies. Proceed with 7.2.6.16.

7.4.6.5 In 7.2.6.18, calculate differences in weight and express the differences in pounds (kilograms).

7.4.7 *Calculation*—See 7.2.7 except as described in 7.4.6.

7.4.8 *Interpretation of Test Results and Report*—See 7.2.8.

7.4.9 *Precision and Bias*—The precision and bias of the procedure and calculations in this acceptance test for the Type IV WIM system are being determined.

7.5 *On-Site Calibration Procedure for Type I, Type II, and Type III WIM Systems:*

7.5.1 *Scope*—A procedure is given for on-site calibration of Type I, Type II, and Type III WIM systems. This procedure requires that vehicles selected from the traffic stream at the WIM site pass over the WIM-system sensors and stop for reference-value weighing and measurement.

7.5.2 *Significance and Use*—The dynamic tire force which is measured by the WIM system results from a complex interaction among the vehicle components, the WIM-system sensors, and the road surface surrounding the sensors. Road-surface profiles and sensor installation are different at every WIM site, and every vehicle has unique tire, suspension, mass, and speed characteristics. Therefore, it is necessary to recognize the effects of these site-specific and vehicle-specific factors on WIM-system performance and attempt to compensate for them as much as is practicable via calibration. The calibration procedure shall be applied immediately after the initial installation of a Type I or Type II WIM system at any site. It should be applied again when a system is reinstalled or when site conditions have changed.

7.5.3 *Site for Weighing Static Vehicles*—The calibration procedure requires that vehicles processed over the WIM system stop for reference-value weighing and measurement. Apparatus for weighing static vehicles and their use are described in 7.1.1 and 7.1.2. A suitable site for making these

TABLE 7 Composition of Test Unit for Calibration Loading of WIM Systems

Vehicle Class	Number of Selected Vehicles
23	2
31	3
51	5
71	3

static measurements must be available within a reasonable distance from the WIM site so that specific vehicles can be identified at both locations. Appropriate safety and traffic control measures shall be considered in selecting and operating the static-measurement site. In all cases, traffic control procedures shall be approved in advance by the public authority which has jurisdiction over the site. For Type I and Type II WIM systems, a paved shoulder or a barricaded traffic lane may be considered if a more suitable area is not available. For Type III WIM systems, weighing apparatus will be in place at the weight-enforcement station.

7.5.4 *Test Unit for Calibration Loading*—The test unit for calibration loading shall consist of vehicles selected in random order from the traffic stream at the WIM site and shall, as a minimum, include the numbers and classes of vehicles shown in Table 7. Additional vehicles may be included in the test unit for calibration loading; this is particularly appropriate if a significant number of vehicles of a class(s) not represented in Table 7 are operating at the WIM site.

7.5.5 *Procedure*—The following steps are involved in the on-site calibration process:

7.5.5.1 Adjust all WIM-system settings to vendor's recommendations or to a best estimate of the proper setting based upon previous experience.

7.5.5.2 Select the required number of vehicles that have passed over the WIM-system sensors, or will later pass over them, from the traffic stream in random order and stop these vehicles for static weighing and measuring at the nearby site, using approved traffic-control measures (preferably including a uniformed law-enforcement officer). With a calibrated radar speed meter or by some other means (such as wheelbase/time) that is acceptable to both the user (or a recognized representative of user's interests) and the vendor, measure the speed of each selected vehicle as it passes over the WIM-system sensors.

7.5.5.3 Measure tire loads of the static vehicles as described in 7.1.1 and 7.1.2. Also, measure axle spacings of the static vehicles and record all data for reference values.

7.5.5.4 Calculate the difference in the WIM-system estimate and the respective reference value for each speed, wheel-load, axle-load, axle-group-load, gross-vehicle-weight, and axle-spacing measurement, express the difference in percent (see 7.2.7.2), and find a mean value for the differences for each set of measurements.

7.5.5.5 Make the necessary adjustments to the WIM-system settings which will make the mean of the respective differences for each basic measurement equal zero. For WIM systems which estimate wheel load, the adjustment will be to wheel-load estimates on each side of the vehicles, separately. For the systems which estimate axle loads only, the adjustment will be for axle loads. Some WIM systems allow calibration factors to be entered for selected wheels, axles, or axle groups with respect to their respective location on the vehicle or combination. Adjustment to the speed setting will probably affect axle-spacing estimates.

7.5.6 *Calculation*—In addition to the calculations described in 7.5.5.4 and 7.5.5.5, calculations should be made to determine whether the calibrated WIM system can be expected to perform within specification tolerances at this site. Adjust each calculated difference, as described in 7.5.5.4, by an amount equal to the amount that the mean of the differences varied from zero. Then calculate the percent of these adjusted differences that exceeded the tolerance shown in Table 2 by the method described in 7.2.7.2.

7.5.7 *Interpretation of Results*—If a large number of the adjusted differences for any applicable data item exceeded the specified tolerance shown in Table 2, the WIM system will probably not perform within tolerances at this site.

7.5.8 *Precision and Bias*—No justifiable statement concerning precision and bias of this procedure can be made at this time because there is no experience yet.

8. Keywords

8.1 loading; pavement and bridge; traffic; vehicle; weighing in highways; weigh-in-motion; WIM

ANNEX

(Mandatory Information)

A1. COMPUTATION OF EQUIVALENT SINGLE-AXLE LOADS (ESALs) BY WIM SYSTEMS

A1.1 Equivalency Factors

A1.1.1 Most pavement design procedures which are now in general use are based on theoretical considerations of materials behavior coupled with a complementary evaluation of the cumulative effects of traffic loading. Many of these procedures define the design thickness of a pavement in terms of the number of applications of a standard single-axle load. To use this concept, the damaging effect of each axle load in a mixed traffic stream must be expressed in terms of the equivalent number of repetitions of a selected standard single-axle load. The numerical factors that define the number of passes of a standard single-axle load which would cause pavement damage equivalent to that caused by one pass of a given axle load are called equivalent single-axle load (ESAL) factors.

A1.1.2 The equivalency factors that were derived from the AASHO Road Test[5] are perhaps the most commonly used equivalency factors for pavement design and analysis. These were derived from a statistical analysis of the AASHO (now AASHTO) Road Test data.[6] The standard axle load used by AASHO is an 18 000-lb (8.2-Mg) single-axle load. Analysis of the AASHO Road Test design equations[7] permits the determination of equivalency factors for both flexible and rigid pavements. These factors can be computed with the following equations.

A1.2 Flexible Pavement Equivalency Factors

A1.2.1 The design equations for flexible pavements presented in the AASHTO Interim Guide[7] are:

$$\log W_t = 5.93 + 9.36 \log(\overline{SN} + 1) - 4.79 \log(L_1 + L_2) + 4.33 \log L_2 + \frac{G_t}{\beta} \quad (A1.1)$$

and

$$\beta = 0.40 + \frac{0.081(L_1 + L_2)^{3.23}}{(\overline{SN} + 1)^{5.19} L_2^{3.23}} \quad (A1.2)$$

where:

W_t = number of axle load applications at the end of time t for axle sets with dual tires,

$\overline{SN}$ = structural number, an index number derived from an analysis of traffic, roadbed soil conditions, and regional factor which may be converted to a thickness of flexible pavement layers through the use of suitable layer coefficients that are related to the type of material being used in each layer of the pavement structure,

L_1 = load on one single axle, or on one tandem-axle set for dual tires, kips [1 kip = 1000 lb (1 kip = 4.536 × 10⁻¹ Mg)],

L_2 = axle code (one for single axle, and two for tandem axle sets),

P_t = serviceability at the end of time t (Serviceability is the ability of a pavement at the time of observation to serve high-speed, high-volume automobile and truck traffic.),

G_t = a function (the logarithm) of the ratio of loss in serviceability at time t to the potential loss taken to a point where P_t = 1.5, or

$G_t = \log\left[\frac{4.2 - P_t}{4.2 - 1.5}\right]$, and

β = a function of design and load variables that influences the shape of the P-versus-W serviceability curve.

A1.2.2 As indicated above, for this design method the number of axle load repetitions to failure is expressed in terms of a pavement stiffness or rigidity value which is represented by Structural Number, $\overline{SN}$, load characteristics denoted by L_1 and L_2, and the terminal level of serviceability selected as the pavement failure point, P_t. Values commonly used to define terminal serviceability, P_t, are 2.0 and 2.5.

A1.2.3 The relationship between the number of applications, $W_{t_{18}}$, of an 18 000-lb (8.2-Mg) single-axle load and the number of applications, W_{t_i}, of any other single or tandem axle load, L_i, to cause the same potential damage to a flexible pavement can be found from the following equation:

$$E_i = \frac{W_{t_{18}}}{W_{t_i}} = \left[\frac{(L_i + L_2)^{4.79}}{(18 + 1)^{4.79}}\right]\left[\frac{10^{G_t/\beta_{18}}}{(10^{G_t/\beta_i})L_2^{\ 4.331}}\right] \quad (A1.3)$$

A1.2.4 The ratio shown in Eq A1.3 is defined as an equivalence factor, and is evaluated by solving the equation with any given axle load L_i. This factor defines the number of 18 000-lb (8.2-Mg) single-axle load applications that would be needed to cause damage to the pavement structure equivalent to one application of the given axle load. Because the term β is a function of $\overline{SN}$ as well as L_i, the equivalence factor varies with $\overline{SN}$.

A1.3 Rigid Pavement Equivalency Factors

A1.3.1 The basic equations for rigid pavements developed from the AASHO Road Test are:

$$\log W_t = 5.85 + 7.35 \log(D + 1) - 4.62 \log(L_1 + L_2) + 3.28 \log L_2 + \frac{G_t}{\beta} \quad (A1.4)$$

and

$$\beta = 1.0 + \frac{3.63(L_1 + L_2)^{5.20}}{(D + 1)^{8.46} L_2^{3.52}} \quad (A1.5)$$

where:

D = thickness of rigid pavement slab, in. (mm), and

$G_t = \log\left[\frac{(4.5 - P_t)}{(4.5 - 1.5)}\right]$.

A1.3.2 As can be seen from analyzing Eqs A1.4 and A1.5, the pavement rigidity or stiffness value is expressed in terms of the pavement thickness, D.

A1.3.3 The relationship between the number of applications, $W_{t_{18}}$, of an 18 000-lb (8.2-Mg) single-axle load and the number of applications, W_{t_i}, of any other single or tandem axle load, L_i, to cause the same potential damage to a rigid pavement can be found from the following equation:

$$E_i = \frac{W_{t_{18}}}{W_{t_i}} = \left[\frac{(L_i + L_2)^{4.62}}{(18 + 1)^{4.62}}\right]\left[\frac{10^{G_t/\beta_{18}}}{(10^{G_t/\beta_i})(L_2^{3.28})}\right] \quad (A1.6)$$

A1.3.4 The ratio is defined as an equivalency factor, and is evaluated by solving Eq A1.6 with any given axle load, L_i. This factor gives the number of 18 000-lb (8.2-Mg) single-axle load applications that would be needed to cause damage to the pavement structure equivalent to one application of the given axle load. Because the term β is a function of D as well as L_i, the equivalency factor varies with D.

[5] Highway Research Board, "The AASHO Road Test," Report 5, Pavement Research, *Highway Research Board Special Report 61E*, 1962.

[6] Highway Research Board, "The AASHTO Road Test," Proceedings of a conference held May 16–18, 1962, St. Louis, Missouri, *Special Report 73*, Washington, DC 1962.

[7] "AASHTO Interim Guide for Design of Pavement Structure—1972," American Association of State Highway and Transportation Officials, Washington, DC 1974.

A1.1 CONVERSION FACTORS

To Convert From	To	Multiply By
pound (lb avoirdupois)	kilogram (kg)	4.536×10^{-1}
pound (lb avoirdupois)	megagram (Mg)	4.536×10^{-4}
kip (1000 lb avoirdupois)	megagram (Mg)	4.536×10^{-1}
inch	millimetres (mm)	25.4

APPENDIX B

Example of Raw Data for Mayagüez WIM Station - Km. 147.8

```
---------------------------------------------------------------------------
-
Date : 06/01/1997  Time  : 10:57:26    Lane  :  4          Ref No. : 13157
Class: F08         Length: 13.0 ft     Speed :  47 mph     Headway :      sec
Axle Mass   1)  1.62KIP   2)  0.52KIP   3)  5.49KIP   4)  6.36KIP
Axle Space  1)   7.6ft    2) 808.6ft    3)  10.9ft
Axle Group  1)  2.14KPS   2) 11.85KPS
Gross Vehicle Mass :  13.99klb          SF :  7  9900 105.0
Violations : None.
---------------------------------------------------------------------------
-
Date : 06/01/1997  Time  : 10:58:43    Lane  :  1          Ref No. : 13158
Class: F08         Length: 10.3 ft     Speed :  48 mph     Headway :      sec
Axle Mass   1)  1.44KIP   2)  0.86KIP   3)  3.44KIP   4)  3.35KIP
Axle Space  1)   7.6ft    2)1852.8ft    3)   7.9ft
Axle Group  1)  2.30KPS   2)  6.79KPS
Gross Vehicle Mass :   9.10klb          SF :  1  8600 105.0
Violations : None.
---------------------------------------------------------------------------
-
Date : 06/01/1997  Time  : 10:59:47    Lane  :  4          Ref No. : 13159
Class: F08         Length: 11.0 ft     Speed :  49 mph     Headway :      sec
Axle Mass   1)  0.50KIP   2)  3.97KIP   3)  3.67KIP
Axle Space  1) 672.1ft    2)   8.8ft
Axle Group  1)  0.50KPS   2)  7.64KPS
Gross Vehicle Mass :   8.13klb          SF :  7  9900 105.0
Violations : None.
---------------------------------------------------------------------------
-
Date : 06/01/1997  Time  : 11:00:28    Lane  :  2          Ref No. : 13160
Class: F08         Length:  9.0 ft     Speed :  57 mph     Headway :      sec
Axle Mass
Axle Space  1)   7.7ft    2)  13.3ft
Axle Group  1)  0.00KPS
Gross Vehicle Mass :   0.00klb          SF :  3 10000 105.0
Violations : None.
---------------------------------------------------------------------------
-
Date : 06/01/1997  Time  : 11:01:14    Lane  :  1          Ref No. : 13161
Class: F08         Length:  9.7 ft     Speed :  56 mph     Headway :      sec
Axle Mass   1)  3.61KIP   2)  2.24KIP   3)  1.38KIP
Axle Space  1)   7.6ft    2)  27.4ft
Axle Group  1)  5.85KPS   2)  1.38KPS
Gross Vehicle Mass :   7.22klb          SF :  1  8600 105.0
Violations : None.
---------------------------------------------------------------------------
-
Date : 06/01/1997  Time  : 11:01:15    Lane  :  1          Ref No. : 13162
Class: F08         Length: 169.0 ft    Speed : 255 mph     Headway :  0.6 sec
Axle Mass   1)  1.04KIP   2)  0.71KIP   3)  3.76KIP   4)  3.76KIP
Axle Space  1)  91.3ft    2)3007.1ft    3)  99.2ft
Axle Group  1)  1.04KPS   2)  0.71KPS   3   3.76KPS   4   3.76KPS
Gross Vehicle Mass :   9.28klb          SF :  1  8600 105.0
Violations : LT 99%, HW 40%, OS 99%
---------------------------------------------------------------------------
-
Date : 06/01/1997  Time  : 11:01:25    Lane  :  1          Ref No. : 13163
Class: F08         Length:  9.3 ft     Speed :  46 mph     Headway : 10.1 sec
Axle Mass   1)  2.35KIP   2)  0.86KIP   3)  3.35KIP   4)  2.92KIP
Axle Space  1)   7.3ft    2) 146.9ft    3)   7.3ft
Axle Group  1)  3.21KPS   2)  6.28KPS
Gross Vehicle Mass :   9.49klb          SF :  1  8600 105.0
Violations : None.
---------------------------------------------------------------------------
-
Date : 06/01/1997  Time  : 11:01:28    Lane  :  4          Ref No. : 13164
Class: F08         Length: 29.3 ft     Speed :  43 mph     Headway :      sec
```

Axle Group 1) 1.10KPS 2) 0.93KPS
Gross Vehicle Mass : 1.93klb SF : 7 9900 105.0
Violations : LT 99%, OS 78%

Date : 06/01/1997 Time : 10:33:45 Lane : 4 Ref No. : 13150
Class: F08 Length: 0.3 ft Speed : 50 mph Headway : sec
Axle Mass 1) 4.62KIP 2) 5.37KIP 3) 0.96KIP
Axle Space 1) 9.8ft 2) 13.1ft
Axle Group 1) 10.95KPS
Gross Vehicle Mass : 10.95klb SF : 7 9900 105.0
Violations : None.

Date : 06/01/1997 Time : 10:33:51 Lane : 4 Ref No. : 13151
Class: F04 Length: 87.0 ft Speed : 255 mph Headway : 5.8 sec
Axle Mass 1) 1.10KIP 2) 1.05KIP
Axle Space 1) 44.2ft
Axle Group 1) 1.10KPS 2) 1.05KPS
Gross Vehicle Mass : 2.15klb SF : 7 9900 105.0
Violations : LT 99%, OS 99%

Date : 06/01/1997 Time : 10:34:33 Lane : 1 Ref No. : 13152
Class: F08 Length: 11.7 ft Speed : 46 mph Headway : sec
Axle Mass 1) 2.17KIP 2) 1.81KIP 3) 2.24KIP 4) 3.27KIP
Axle Space 1) 9.0ft 2) 253.3ft 3) 8.5ft
Axle Group 1) 3.97KPS 2) 5.50KPS
Gross Vehicle Mass : 9.48klb SF : 1 8600 105.0
Violations : None.

Date : 06/01/1997 Time : 10:41:55 Lane : 1 Ref No. : 13153
Class: F08 Length: 14.7 ft Speed : 48 mph Headway : sec
Axle Mass 1) 1.72KIP 2) 1.38KIP 3) 3.44KIP 4) 2.24KIP
Axle Space 1) 8.3ft 2) 120.1ft 3) 9.4ft
Axle Group 1) 3.09KPS 2) 5.68KPS
Gross Vehicle Mass : 8.77klb SF : 1 8600 105.0
Violations : None.

Date : 06/01/1997 Time : 10:53:39 Lane : 1 Ref No. : 13154
Class: F08 Length: 13.0 ft Speed : 53 mph Headway : sec
Axle Mass 1) 1.72KIP 2) 0.86KIP 3) 4.13KIP 4) 3.78KIP
Axle Space 1) 7.5ft 2) 50.8ft 3) 10.2ft
Axle Group 1) 2.58KPS 2) 7.91KPS
Gross Vehicle Mass : 10.49klb SF : 1 8600 105.0
Violations : None.

Date : 06/01/1997 Time : 10:54:17 Lane : 1 Ref No. : 13155
Class: F08 Length: 10.0 ft Speed : 48 mph Headway : 37.8 sec
Axle Mass 1) 2.17KIP 2) 1.81KIP 3) 4.56KIP 4) 3.44KIP
Axle Space 1) 11.0ft 2) 158.9ft 3) 9.2ft
Axle Group 1) 3.97KPS 2) 8.00KPS
Gross Vehicle Mass : 11.97klb SF : 1 8600 105.0
Violations : None.

Date : 06/01/1997 Time : 10:55:17 Lane : 4 Ref No. : 13156
Class: F04 Length: 143.3 ft Speed : 255 mph Headway : sec
Axle Mass 1) 2.28KIP 2) 2.55KIP
Axle Space 1) 76.0ft
Axle Group 1) 2.28KPS 2) 2.55KPS
Gross Vehicle Mass : 4.83klb SF : 7 9900 105.0
Violations : LT 99%, OS 99%

```
--------------------------------------------------------------------------------
-
Date : 06/01/1997  Time  : 10:20:00    Lane  :  4          Ref No. : 13135
Class: F08         Length:  8.7 ft     Speed :  49 mph     Headway : 46.1 sec
Axle Mass    1)  3.22KIP   2)  2.38KIP   3)  0.99KIP
Axle Space   1)   7.4ft    2)  26.1ft
Axle Group   1)  5.60KPS   2)  0.99KPS
Gross Vehicle Mass :   6.59klb         SF :  7  9900 105.0
Violations : None.
--------------------------------------------------------------------------------
-
Date : 06/01/1997  Time  : 10:20:01    Lane  :  4          Ref No. : 13136
Class: F04         Length: 145.3 ft    Speed : 255 mph     Headway :  0.6 sec
Axle Mass    1)  3.07KIP   2)  2.18KIP
Axle Space   1) 437.0ft
Axle Group   1)  3.07KPS   2)  2.18KPS
Gross Vehicle Mass :   5.25klb         SF :  7  9900 105.0
Violations : LT 99%, HW 40%, OS 99%
--------------------------------------------------------------------------------
-
Date : 06/01/1997  Time  : 10:20:10    Lane  :  4          Ref No. : 13137
Class: F04         Length: 39.0 ft     Speed : 195 mph     Headway :  9.5 sec
Axle Mass    1)  1.50KIP   2)  1.95KIP
Axle Space   1)  30.2ft
Axle Group   1)  1.50KPS   2)  1.95KPS
Gross Vehicle Mass :   3.45klb         SF :  7  9900 105.0
Violations : LT 99%, OS 63%
--------------------------------------------------------------------------------
-
Date : 06/01/1997  Time  : 10:20:45    Lane  :  4          Ref No. : 13138
Class: F09         Length: 42.0 ft     Speed :  36 mph     Headway : 34.8 sec
Axle Mass    1) 13.61KIP   2) 17.88KIP   3)  9.84KIP   4) 13.14KIP   5)
13.28KIP
Axle Space   1)  10.7ft    2)   4.1ft    3)  27.2ft    4)   3.8ft
Axle Group   1) 41.33KPS   2) 26.43KPS
Gross Vehicle Mass :  67.75klb         SF :  7  9900 105.0
Violations : LT 99%, US 10%, RL 11%, AL 99%, AG 97%, GV 81%
--------------------------------------------------------------------------------
-
Date : 06/01/1997  Time  : 10:21:11    Lane  :  4          Ref No. : 13139
Class: F05         Length: 18.7 ft     Speed :  39 mph     Headway : 26.1 sec
Axle Mass    1)  1.50KIP   2)  1.58KIP
Axle Space   1)  14.4ft
Axle Group   1)  3.07KPS
Gross Vehicle Mass :   3.07klb         SF :  7  9900 105.0
Violations : LT  2%, US  3%
--------------------------------------------------------------------------------
-
Date : 06/01/1997  Time  : 10:24:28    Lane  :  4          Ref No. : 13140
Class: F09         Length: 39.3 ft     Speed :  51 mph     Headway :      sec
Axle Mass    1) 14.78KIP   2) 14.39KIP   3) 12.62KIP   4)  6.65KIP   5
9.75KIP
Axle Space   1)  11.4ft    2)   3.9ft    3)  24.9ft    4)   3.8ft
Axle Group   1) 41.79KPS   2) 16.40KPS
Gross Vehicle Mass :  58.19klb         SF :  7  9900 105.0
Violations : LT 99%, AL 99%, AG 99%, GV 56%
--------------------------------------------------------------------------------
-
Date : 06/01/1997  Time  : 10:25:15    Lane  :  2          Ref No. : 13141
Class: F04         Length: 12.0 ft     Speed :  66 mph     Headway :      sec
Axle Mass
Axle Space   1)   4.6ft    2)1010.8ft    3)  10.3ft
Axle Group   1)  0.00KPS   2)  0.00KPS
Gross Vehicle Mass :   0.00klb         SF :  3 10000 105.0
Violations : None.
--------------------------------------------------------------------------------
-
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--------------------------------------------------------------------------------
Date : 06/01/1997  Time  : 10:14:28    Lane  :  1          Ref No. : 13127
Class: F08         Length: 13.3 ft     Speed :  52 mph     Headway :       sec
Axle Mass   1)  1.26KIP   2)  3.87KIP   3)  3.01KIP
Axle Space  1) 349.5ft    2)  11.2ft
Axle Group  1)  1.26KPS   2)  6.88KPS
Gross Vehicle Mass :   9.14klb         SF :  1  8600 105.0
Violations : None.
--------------------------------------------------------------------------------
Date : 06/01/1997  Time  : 10:14:47    Lane  :  4          Ref No. : 13128
Class: F05         Length: 20.3 ft     Speed :  23 mph     Headway :       sec
Axle Mass   1)  0.79KIP   2)  1.20KIP
Axle Space  1)  14.2ft
Axle Group  1)  1.99KPS
Gross Vehicle Mass :   1.99klb         SF :  7  9900 105.0
Violations : LT 11%, US 43%
--------------------------------------------------------------------------------
Date : 06/01/1997  Time  : 10:15:23    Lane  :  1          Ref No. : 13129
Class: F08         Length: 10.0 ft     Speed :  49 mph     Headway : 55.0 sec
Axle Mass   1)  2.62KIP   2)  1.38KIP   3)  3.87KIP   4)  2.49KIP
Axle Space  1)    7.9ft   2) 149.9ft    3)    8.0ft
Axle Group  1)  3.99KPS   2)  6.36KPS
Gross Vehicle Mass :  10.36klb         SF :  1  8600 105.0
Violations : None.
--------------------------------------------------------------------------------
Date : 06/01/1997  Time  : 10:16:51    Lane  :  1          Ref No. : 13130
Class: F08         Length:  6.3 ft     Speed :  34 mph     Headway : 88.1 sec
Axle Mass   1)  2.62KIP   2)  2.24KIP   3)  3.87KIP   4)  1.20KIP
Axle Space  1)    7.9ft   2)  79.5ft    3)    6.4ft
Axle Group  1)  4.85KPS   2)  5.07KPS
Gross Vehicle Mass :   9.93klb         SF :  1  8600 105.0
Violations : US 15%
--------------------------------------------------------------------------------
Date : 06/01/1997  Time  : 10:17:35    Lane  :  1          Ref No. : 13131
Class: F08         Length: 75.7 ft     Speed : 255 mph     Headway : 43.9 sec
Axle Mass   1)  0.82KIP   2)  1.35KIP   3)  1.35KIP
Axle Space  1) 333.8ft    2) 267.3ft
Axle Group  1)  0.82KPS   2)  1.35KPS   3)  1.35KPS
Gross Vehicle Mass :   3.52klb         SF :  1  8600 105.0
Violations : LT 99%, OS 99%
--------------------------------------------------------------------------------
-
Date : 06/01/1997  Time  : 10:17:35    Lane  :  2          Ref No. : 13132
Class: F08         Length: 31.7 ft     Speed :  21 mph     Headway :       sec
Axle Mass
Axle Space  1) 305.3ft    2)  18.3ft
Axle Group  1)  0.00KPS   2)  0.00KPS
Gross Vehicle Mass :   0.00klb         SF :  3 10000 105.0
Violations : LT 73%, US 48%
--------------------------------------------------------------------------------
-
Date : 06/01/1997  Time  : 10:18:39    Lane  :  4          Ref No. : 13133
Class: F05         Length: 23.0 ft     Speed :  25 mph     Headway :       sec
Axle Mass   1)  0.79KIP   2)  1.05KIP
Axle Space  1)  14.2ft
Axle Group  1)  1.84KPS
Gross Vehicle Mass :   1.84klb         SF :  7  9900 105.0
Violations : LT 25%, US 38%
--------------------------------------------------------------------------------
-
Date : 06/01/1997  Time  : 10:19:11    Lane  :  4          Ref No. : 13134
Class: F04         Length: 114.3 ft    Speed : 255 mph     Headway : 35.6 sec
Axle Mass   1)  1.65KIP   2)  2.33KIP
Axle Space  1)  53.2ft
Axle Group  1)  1.65KPS   2)  2.33KPS
Gross Vehicle Mass :   3.98klb         SF :  7  9900 105.0
Violations : LT 99%, OS 99%
```

APPENDIX C

Example of Worksheet Used to Filter and Analyze WIM Data

Mayagüez WIM Station: Km. 147.8

June 2nd, 1997

LANE4

From file named: D:\JAVIER\THESIS\Datos de WIM\Junio\mayaguez\Mg970602.trf

Time	Lane	Ref. No.	Length (ft)	Speed (Mph)	Headway	Axle Mass 1	Axle Mass 2 (Kip)	Axle Space	GVM (Klb)	
2:49:39 AM	4	13710	15.3	47	0	12.43	21.79	14.9	34.22	Overweighted
2:52:54 AM	4	13711	25.3	46	0	14.52	21	19.2	35.52	Overweighted
										Overweighted
										Overweighted
										Overweighted
3:44:22 AM										Overweighted
3:51:53 AM										Overweighted
3:52:02 AM										Overweighted
										Overweighted
										Overweighted
										Overweighted
4:01:10 AM	4	13748	19.7	55	0	6.77	12.47	17.9	19.24	
4:09:30 AM	4	13753	16	68	0	11.02	13.58	14.5	24.6	
										Overweighted
4:23:32 AM	4	13769	16.7	51	0	10.68	18.87	14.9	29.55	
										Overweighted
4:41:04 AM	4	13778	18	40	0	12.26	22.19	16.9	34.44	Overweighted
										Overweighted
										Overweighted
										Overweighted
										Overweighted
										Overweighted
4:53:09 AM	4	13788	19.7	41	0	14.2	22.19	17.2	36.39	Overweighted
4:56:35 AM	4	13793	15.3	154	0	1.1	0.75	18.6	1.85	
5:01:19 AM	4	13796	19.3	46	0	14.42	18.92	16.8	33.34	
										Overweighted
										Overweighted
										Overweighted
5:09:27 AM	4	13805	22	44	0	17.05	25.25	18.6	42.29	Overweighted
										Overweighted
5:18:08 AM	4	13817	19	40	0	8.73	17.33	17.4	26.06	
										Overweighted
5:18:22 AM	4	13819	24	51	0	13.85	16.52	13.6	30.38	
5:21:43 AM										
										Overweighted
5:22:52 AM	4	13825	24	43	0	11.05	20.85	18.6	31.9	

From file named: D:\JAVIER\THESIS\Datos de WIM\Junio\mayaguez\Mg970602.trf

Class	Lane	Ref. No.	Length (ft)	Speed (Mph) (Mph))	Headway (sec)	Axle Mass 1 (Kip)	Axle Mass 2 (Kip)	Axle Space 1 (ft)	GVM (Klb)
5	1	MIN	15	27	0	0.99	0.95	12.3	1.94
		MAX	38.7	63	0	20.41	21.93	19.8	44.32
		AVG	20.669	44.37037037	0	12.64453704	17.5181481	16.48888889	30.2599074
		COUNT	216	216	216	216	216	216	216
		STDEV	3.3022	6.820751636	0	3.498554222	3.75243218	1.82801625	6.538552
	4	MIN	15	25	0	1.1	0.75	10.8	1.85
		MAX	40	154	0	21.1	25.25	19.9	78.92
		AVG	19.653	46.02083333	0	10.85713542	16.6078646	16.7046875	28.6973958
		COUNT	192	192	192	192	192	192	192
		STDEV	3.136	9.76582262	0	3.553641539	4.038306	1.645882982	10.0347558

Within Limits Lane 1	144
Overweighted Lane 1	72
% Overweighted	50
Within Limits Lane 4	156
Overweighted Lane 4	36
% Overweighted	23.077

TOTAL FILES	621
FILES OK	481
ERROR	140
% ERROR	22.5442834

LANE1

From file named: D:\JAVIER\THESIS\Datos de WIM\Junio\mayaguez\Mg970602.trf

Time	Lane	Ref. No.	Length (ft)	Speed (Mph)	Headway	Axle Mas:	Axle Mass 2 (Kip)	Axle Space 1	GVM (Klb)	
										Overweight(
2:59:13 AM	1	13714	17.7	31	0	9.57	17.46	15	27.03	
3:05:35 AM	1	13718	22.7	50	0	20.41	21.93	17.8	42.34	Overweight(
3:32:29 AM	1	13727	24.7	55	0	14	21.93	19.4	35.93	Overweight(
3:37:41 AM	1	13728	22	52	0	10.2	16.6	19.4	26.8	
										Overweight(
										Overweight(
										Overweight(
3:52:47 AM	1	13740	26.3	51	0	16.98	21.93	19.3	38.91	Overweight(
3:53:38 AM	1	13741	23	45	0	17.16	21.93	17.7	39.09	Overweight(
										Overweight(
										Overweight(
4:13:24 AM	1	13757	17.3	49	0	13.54	15.48	14.8	29.03	
										Overweight(
4:38:57 AM	1	13777	21.3	42	0	17.61	21.93	17.5	39.54	Overweight(
										Overweight(
4:43:38 AM	1	13779	23	46	0	12.1	21.93	16.3	34.03	Overweight(
4:50:11 AM	1	13784	15	60	0	10.57	8.34	13.3	18.91	
4:50:44 AM	1	13785	22.3	42	0	14.72	21.93	17.7	36.65	Overweight(
										Overweight(
4:52:45 AM	1	13787	19	27	0	14	21.93	14.8	35.93	Overweight(
										Overweight(
										Overweight(
										Overweight(
5:01:32 AM	1	13798	22	35	0	11.83	21.93	17.9	33.76	
										Overweight(
5:08:45 AM	1	13803	19.7	51	0	17.79	21.93	14.2	39.72	Overweight(
										Overweight(
										Overweight(
										Overweight(
5:18:19 AM	1	13818	17	52	0	11.74	12.99	14.5	24.72	
										Overweight(
										Overweight(
										Overweight(

From file named: D:\JAVIER\THESIS\Datos de WIM\Junio\mayaguez\Mg970602.trf

Time	Lane	Ref. No.	Length (ft)	Speed (Mph)	Headway	Axle Mass 1	Axle Mass 2	Axle Space	GVM (Klb)	
2:49:39	4	13710	15.3	47	0	12.43	21.79	14.9	34.22	OK
2:52:54	4	13711	25.3	46	0	14.52	21	19.2	35.52	OK
2:59:13	1	13714	17.7	31	0	9.57	17.46	15	27.03	OK
3:05:35	1	13718	22.7	50	0	20.41	21.93	17.8	42.34	OK
3:32:29	1	13727	24.7	55	0	14	21.93	19.4	35.93	OK
3:37:41	1	13728	22	52	0	10.2	16.6	19.4	26.8	OK
3:44:22	4	13732	12.3	30	0	8.45	17.88	15.2	26.33	ERROR
3:51:53	4	13738	13.3	56	0	12.05	19.66	14.7	31.71	ERROR
3:52:02	4	13739	13.7	49	0	10.38	18.92	13.5	29.29	ERROR
3:52:47	1	13740	26.3	51	0	16.98	21.93	19.3	38.91	OK
3:53:38	1	13741	23	45	0	17.16	21.93	17.7	39.09	OK
4:01:10	4	13748	19.7	55	0	6.77	12.47	17.9	19.24	OK
4:09:30	4	13753	16	68	0	11.02	13.58	14.5	24.6	OK
4:13:24	1	13757	17.3	49	0	13.54	15.48	14.8	29.03	OK
4:23:32	4	13769	16.7	51	0	10.68	18.87	14.9	29.55	OK
4:38:57	1	13777	21.3	42	0	17.61	21.93	17.5	39.54	OK
4:41:04	4	13778	18	40	0	12.26	22.19	16.9	34.44	OK
4:43:38	1	13779	23	46	0	12.1	21.93	16.3	34.03	OK
4:50:11	1	13784	15	60	0	10.57	8.34	13.3	18.91	OK
4:50:44	1	13785	22.3	42	0	14.72	21.93	17.7	36.65	OK
4:51:51	3	13786	18.3	34	0		0	0	14.8	OK
4:52:45	1	13787	19	27	0	14	21.93	14.8	35.93	OK
4:53:09	4	13788	19.7	41	0	14.2	22.19	17.2	36.39	OK
4:56:35	4	13793	15.3	154	0	1.1	0.75	18.6	1.85	OK
5:01:19	4	13796	19.3	46	0	14.42	18.92	16.8	33.34	OK
5:01:32	1	13798	22	35	0	11.83	21.93	17.9	33.76	OK
5:08:42	2	13802	19.7	56	0		0	0	14	OK
5:08:45	1	13803	19.7	51	0	17.79	21.93	14.2	39.72	OK
5:09:27	4	13805	22	44	0	17.05	25.25	18.6	42.29	OK
5:14:03	3	13815	21.3	48	0		0	0	17.2	OK
5:18:08	4	13817	19	40	0	8.73	17.33	17.4	26.06	OK
5:18:19	1	13818	17	52	0	11.74	12.99	14.5	24.72	OK
5:18:22	4	13819	24	51	0	13.85	16.52	13.6	30.38	OK
5:21:43	4	13823	14.3	61	0	8.28	7.89	13.3	16.17	ERROR
5:22:52	4	13825	24	43	0	11.05	20.85	18.6	31.9	OK

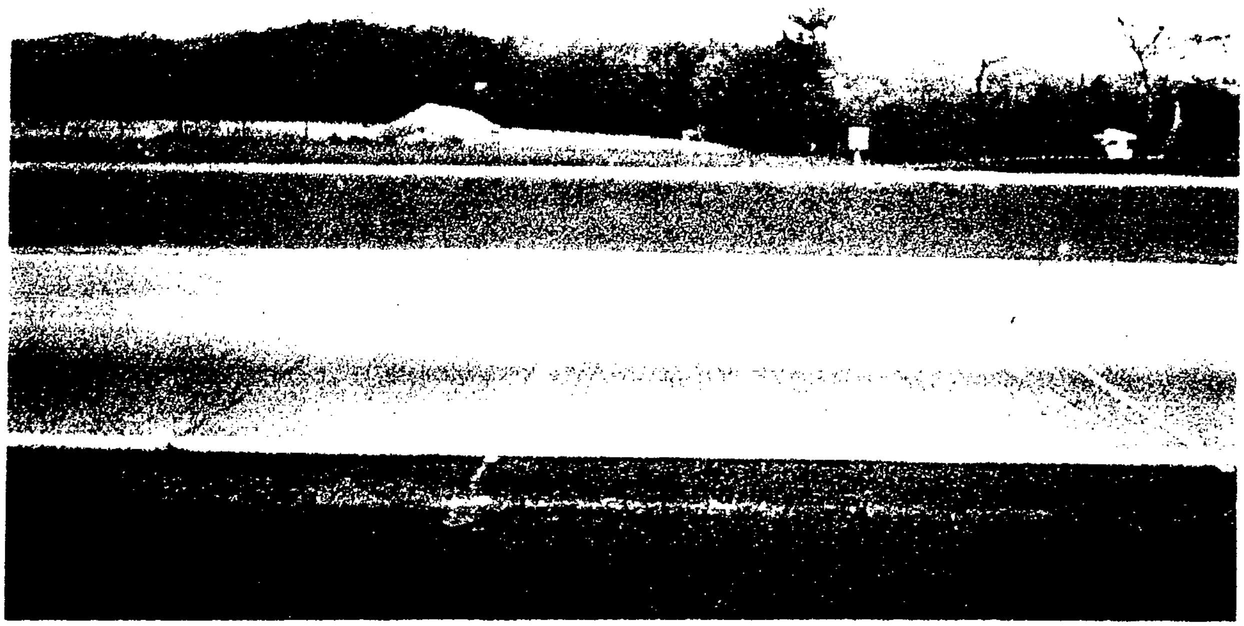
APPENDIX D

Photographs of WIM Station

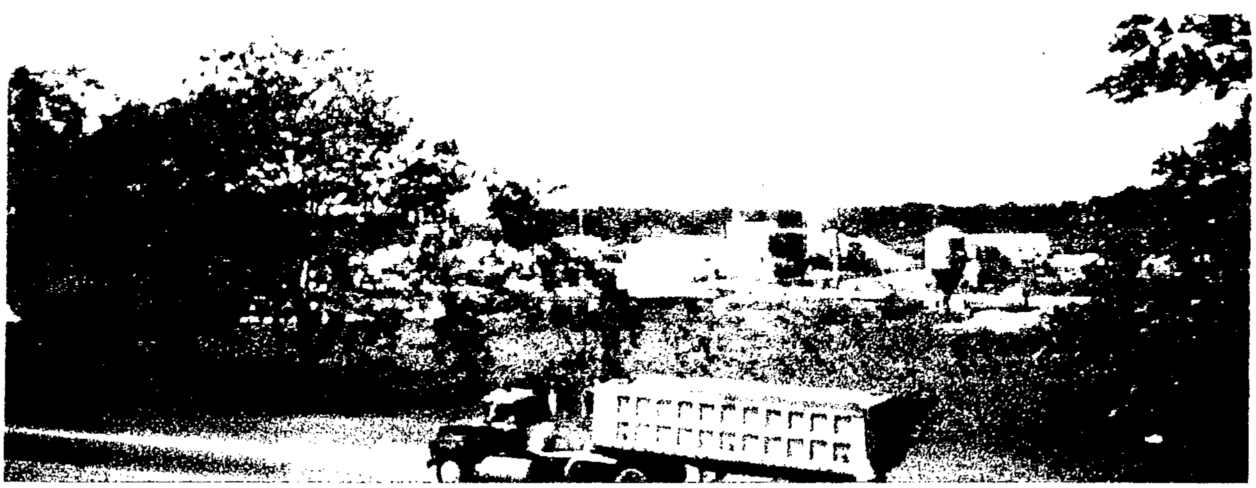
Arecibo Station (Rigid Pavement)
Location: PR 22 km 69.8

a) Westbound View

b) Eastbound View



c) WIM Setup and Data Collection Box

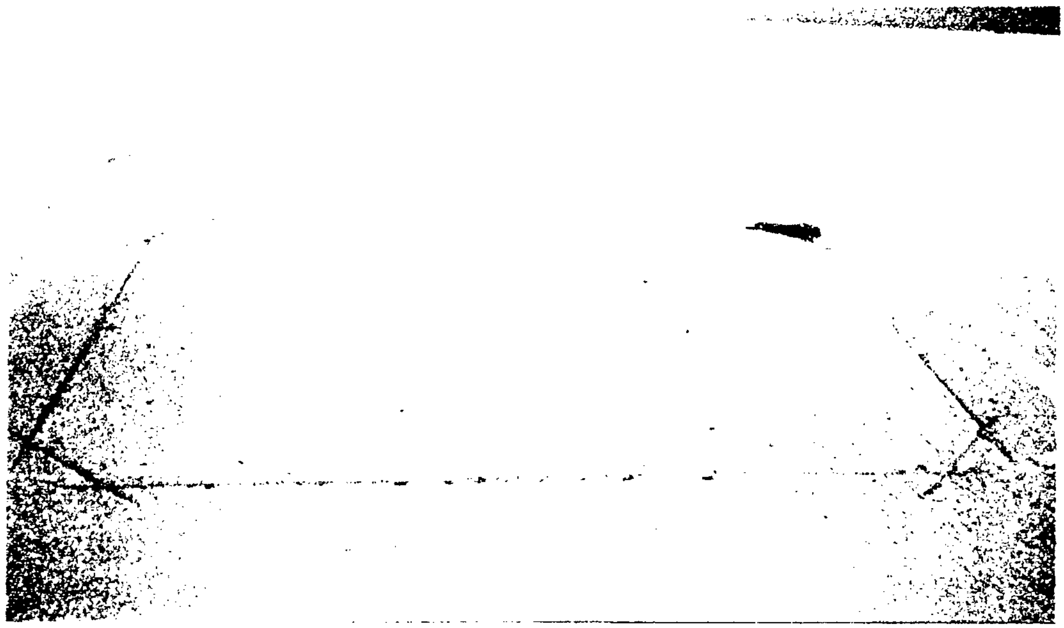


d) Concrete Mix Plant Near WIM Station

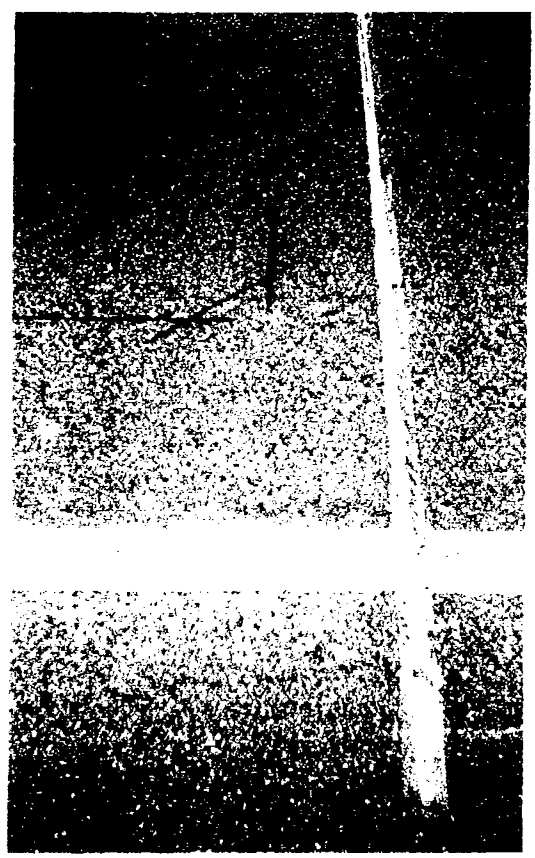
Arecibo Station (Flexible Pavement)
Location: PR 22 km 71.75

a) Westbound View

b) Eastbound View



c) Pothole at WIM Sensor

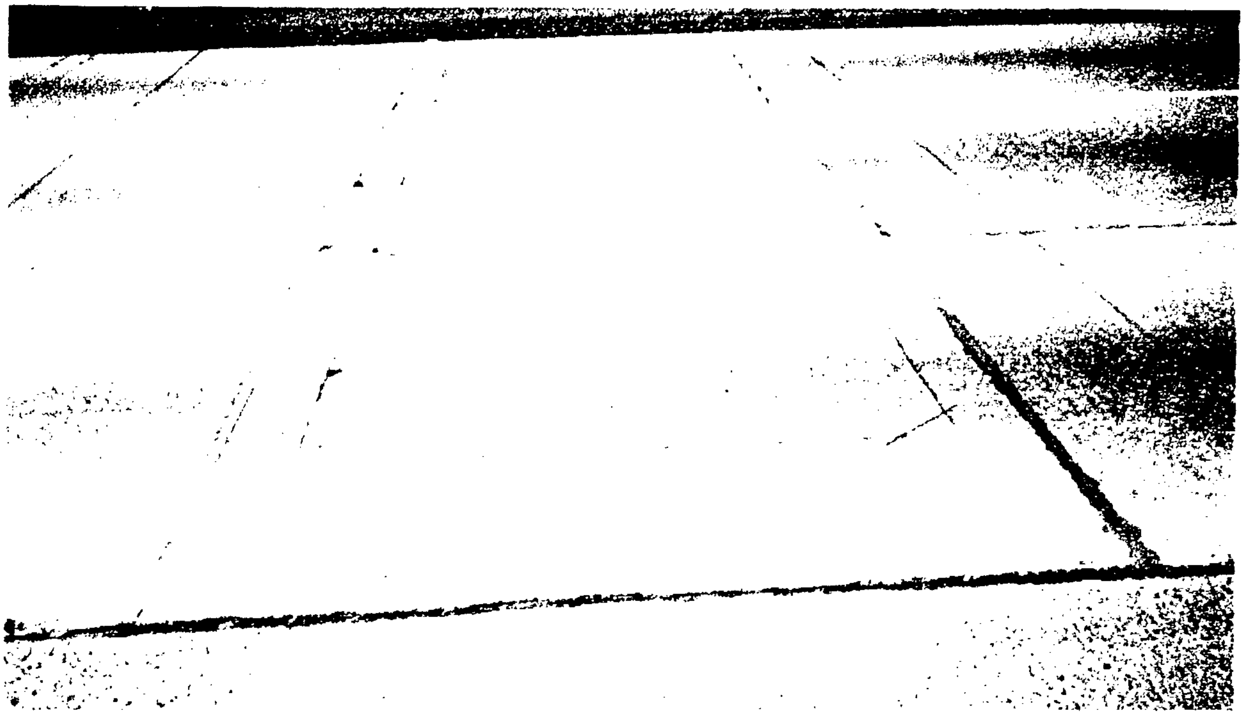


d) Piezoelectric Deterioration

Caguas Station
Location: PR 52 km 6.7

a) Southbound View

b) Northbound View

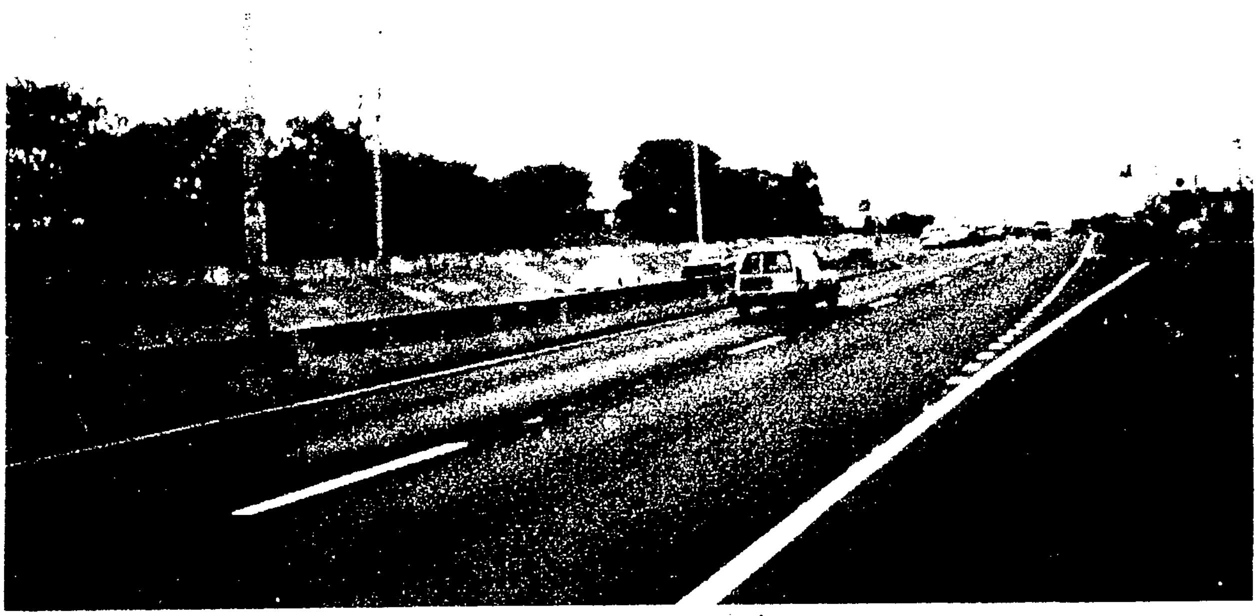


c) WIM Setup

d) Data Collection Box

Hatillo Station
Location: PR 2 km 84.6

a) Eastbound View



b) Westbound View

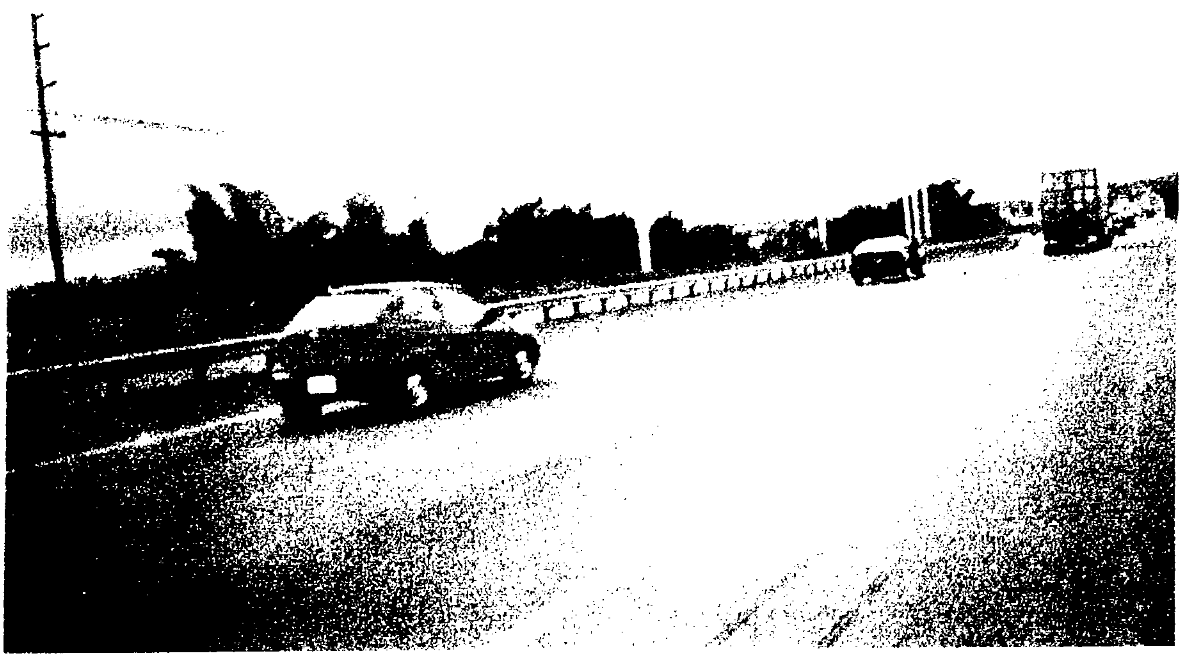
Gurabo Station
Location: PR 30 km 9.4

a) Eastbound View

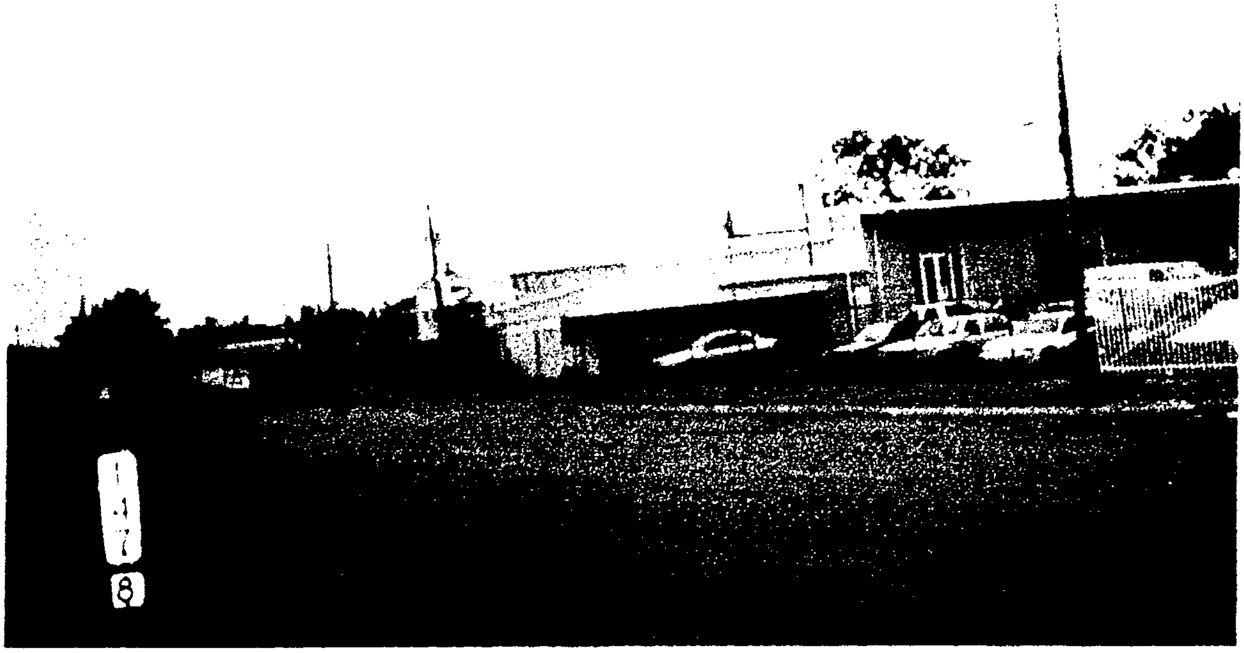
b) Westbound View

Mayagüez Station
Location: PR 2 km 147.8

a) Northbound View



b) Southbound View



c) Industries Near WIM Station

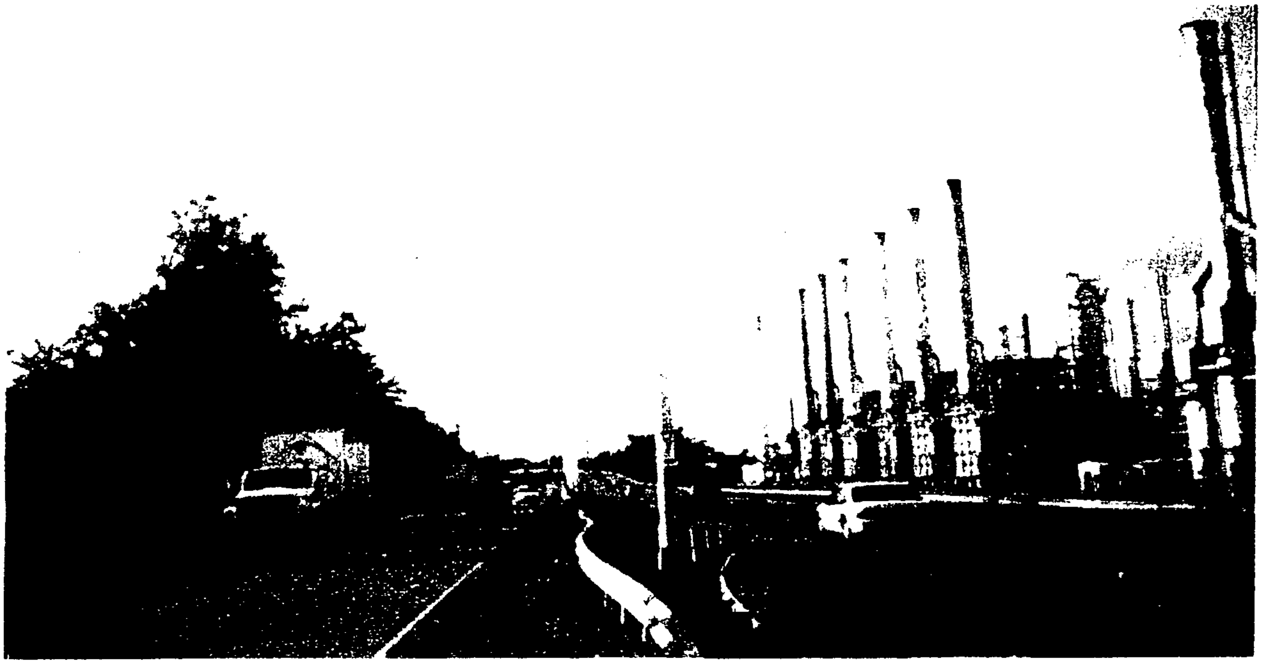
d) Data Collection Box and WIM Setup

Río Grande Station
Location: PR 3 km 26.8

a) Eastbound View

b) Westbound View

Peñuelas Station
Location: PR 3 km 26.8



a) Eastbound View (Petroleum Industries to the Right)

b) Westbound View

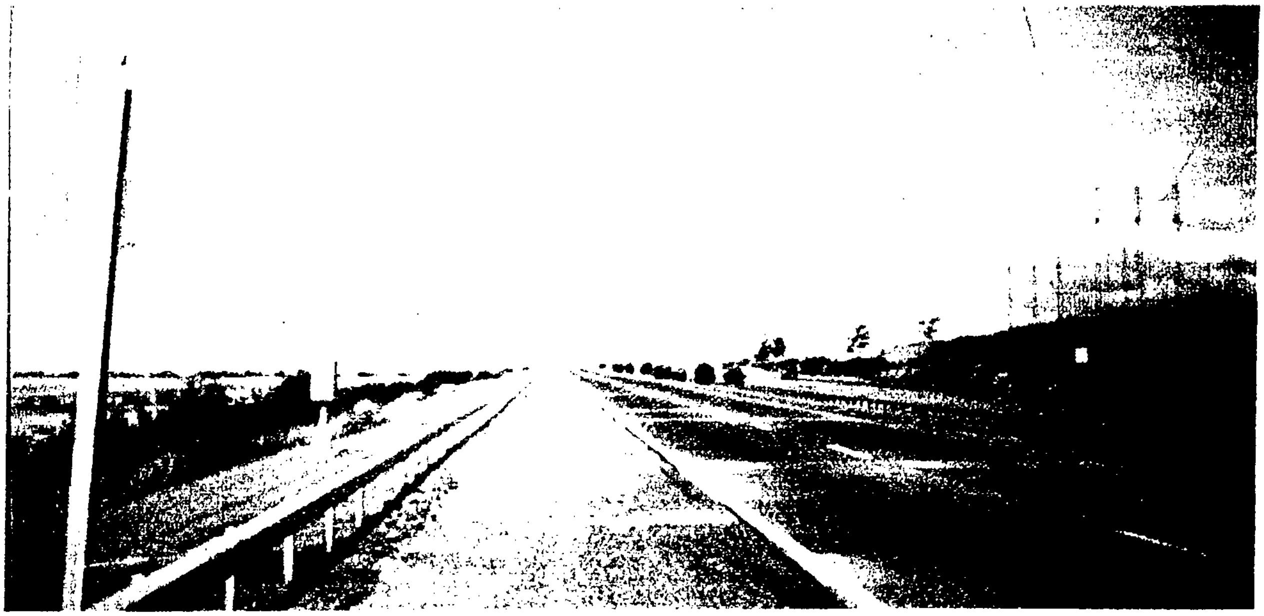
Guayama Station
Location: PR 53 km 88.7

a) Westbound View

a) Northbound View

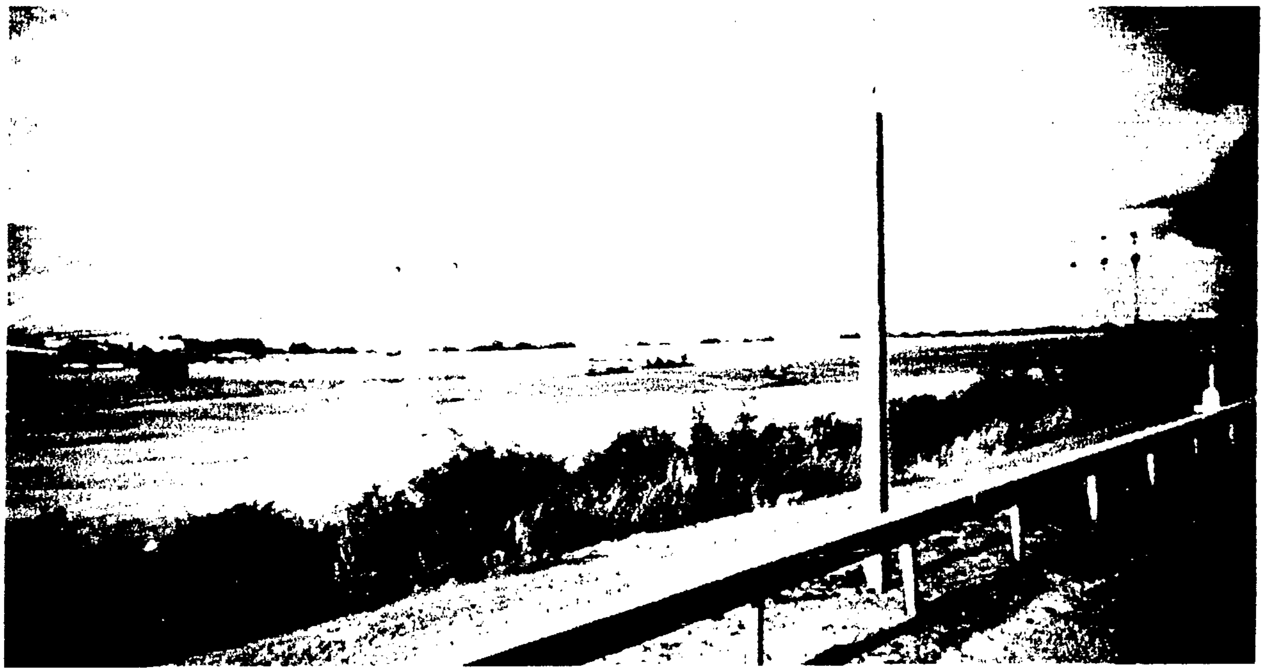
c) Guayama's Industries

Salinas Station
Location: PR 52 km 70.3



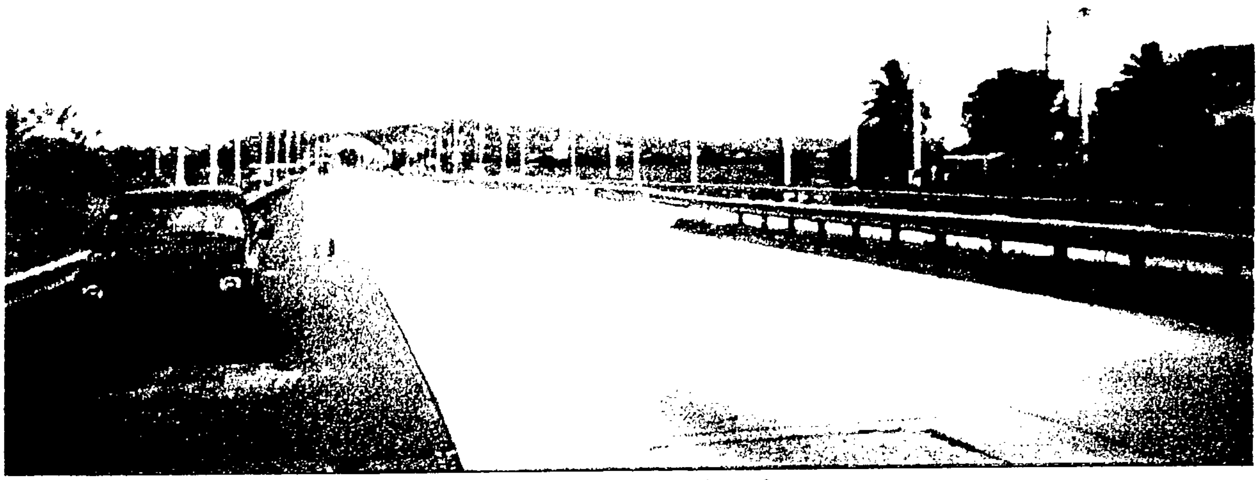
a) Westbound View

b) Eastbound View

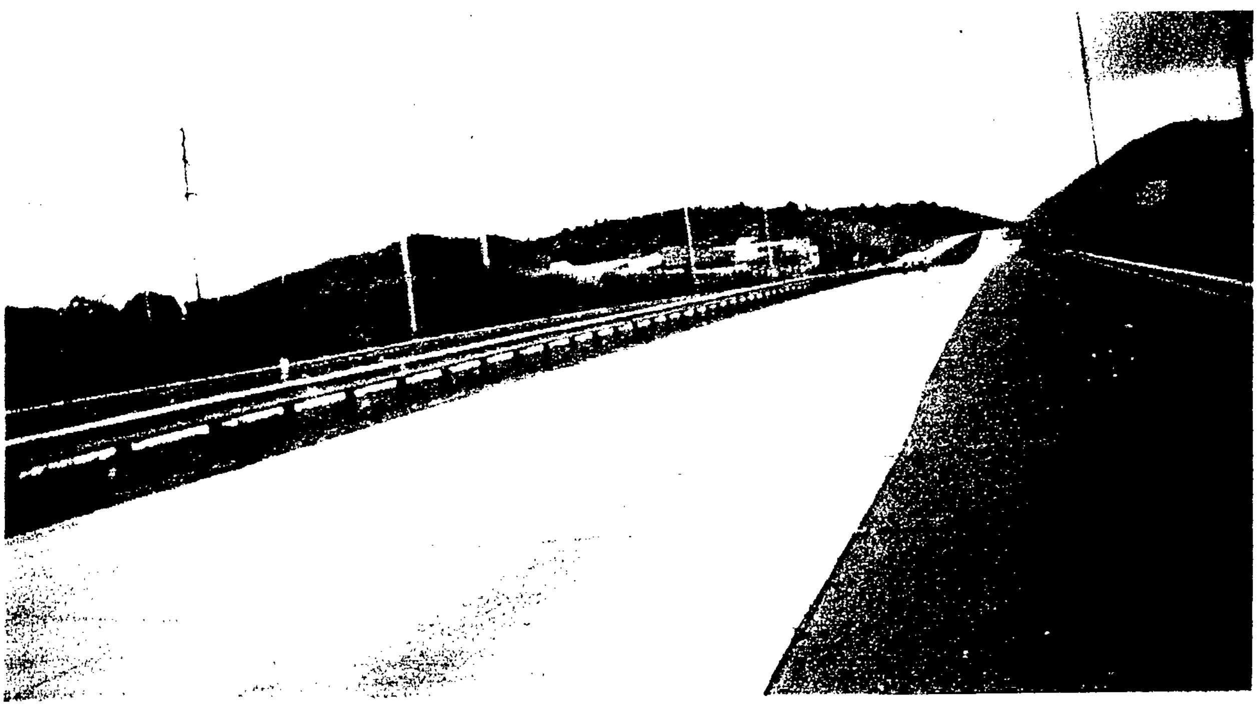


c) Land Use Near WIM Station

Ceiba Station
Location: PR 53 km 1.1



a) Northbound View



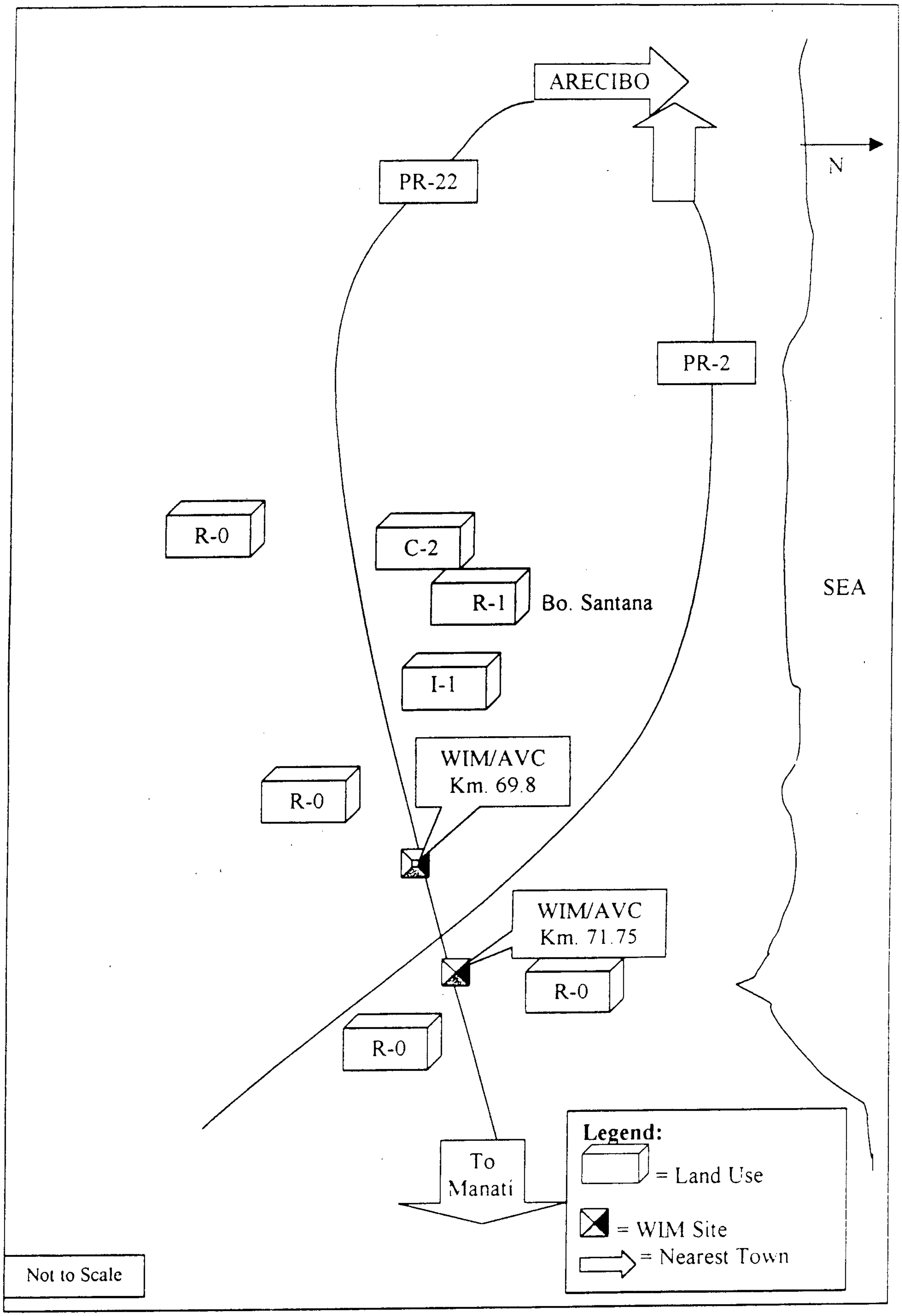
b) Southbound View

APPENDIX E

Land Use Schematics

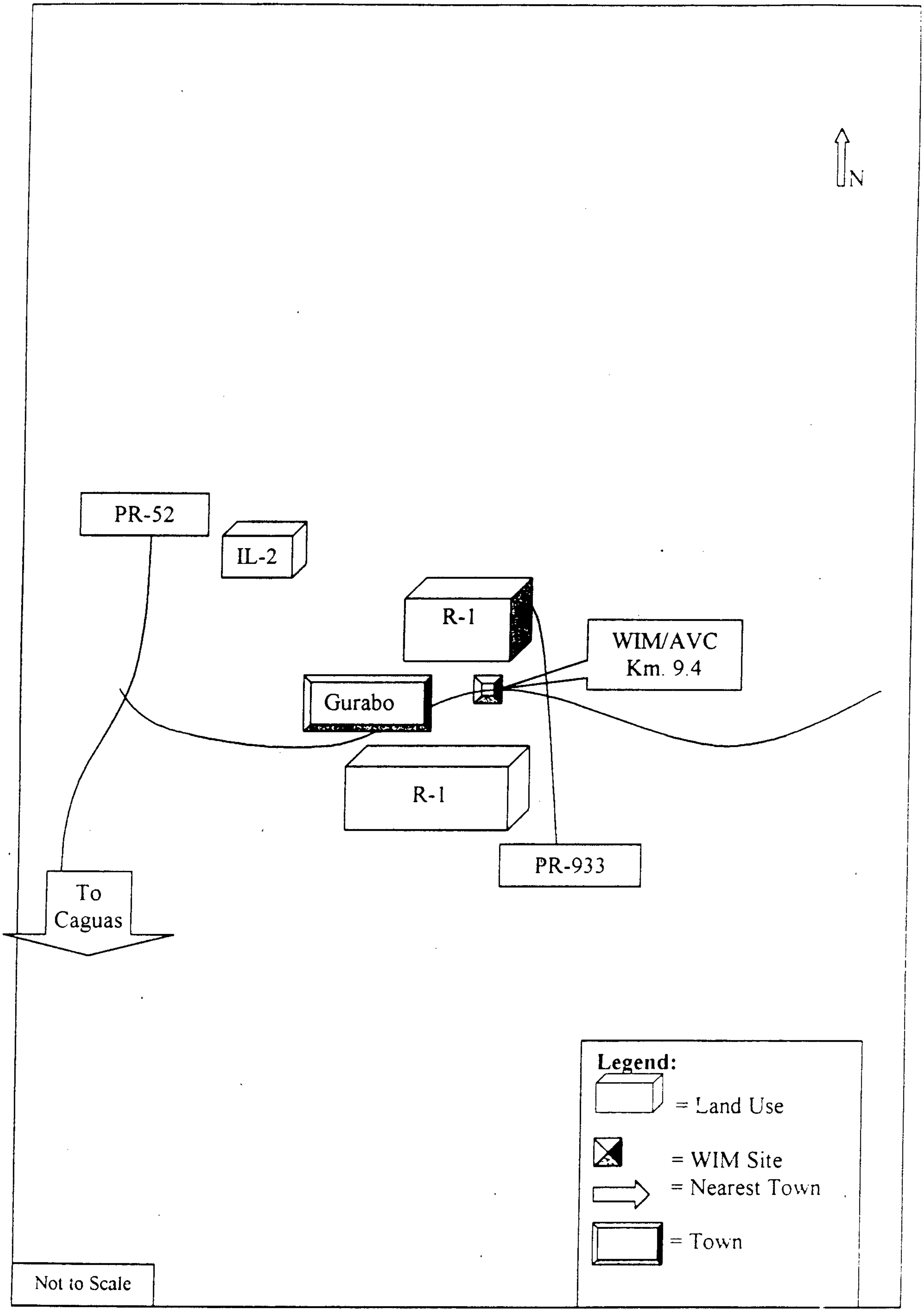
LAND USE MAP

WIM/AVC STATIONS: Arecibo 001 PR-22 Km. 69.8, Arecibo 002 PR-22 Km 71.75



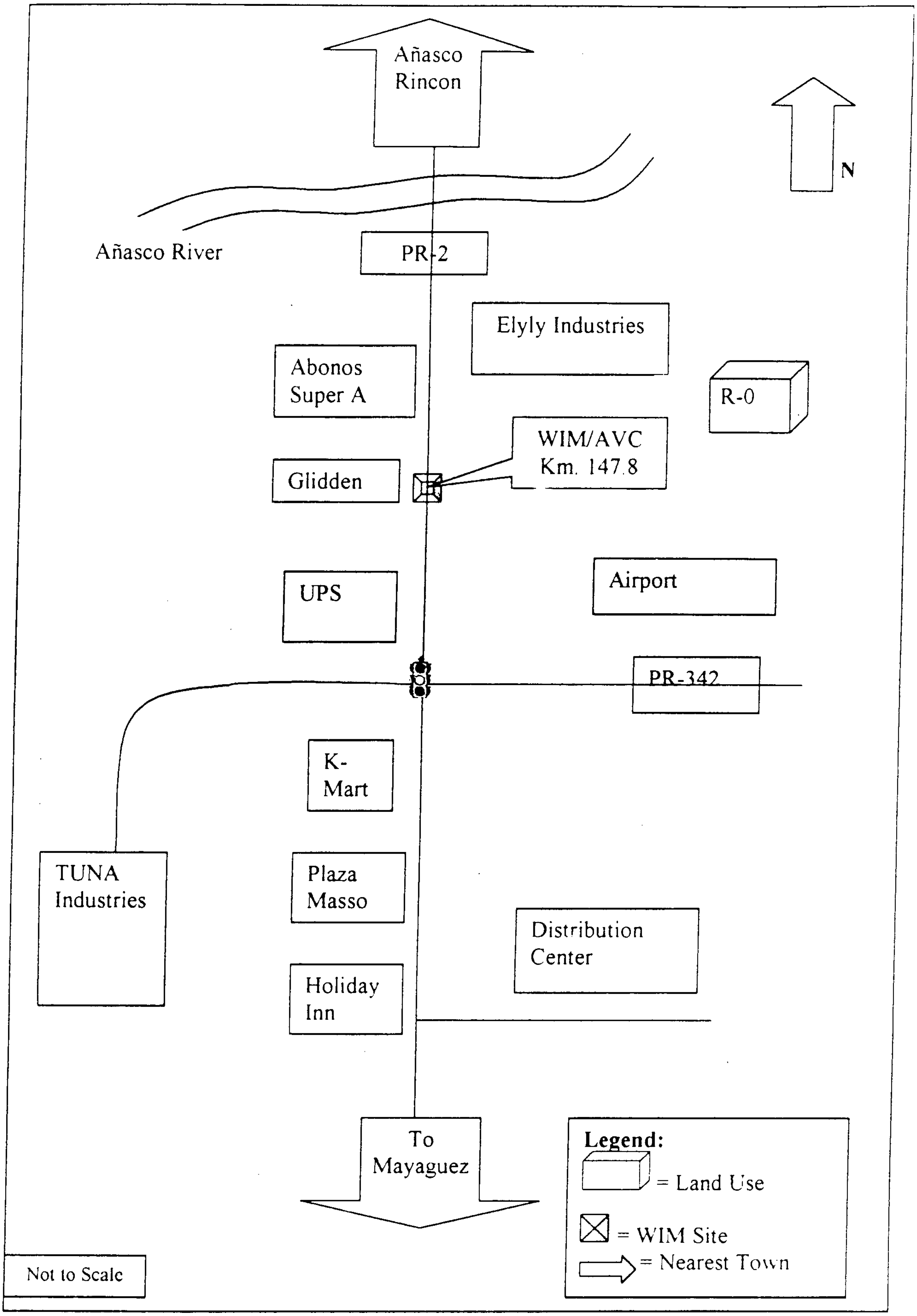
LAND USE MAP

WIM/AVC STATIONS: Gurabo 005 PR-30 Km 9.4



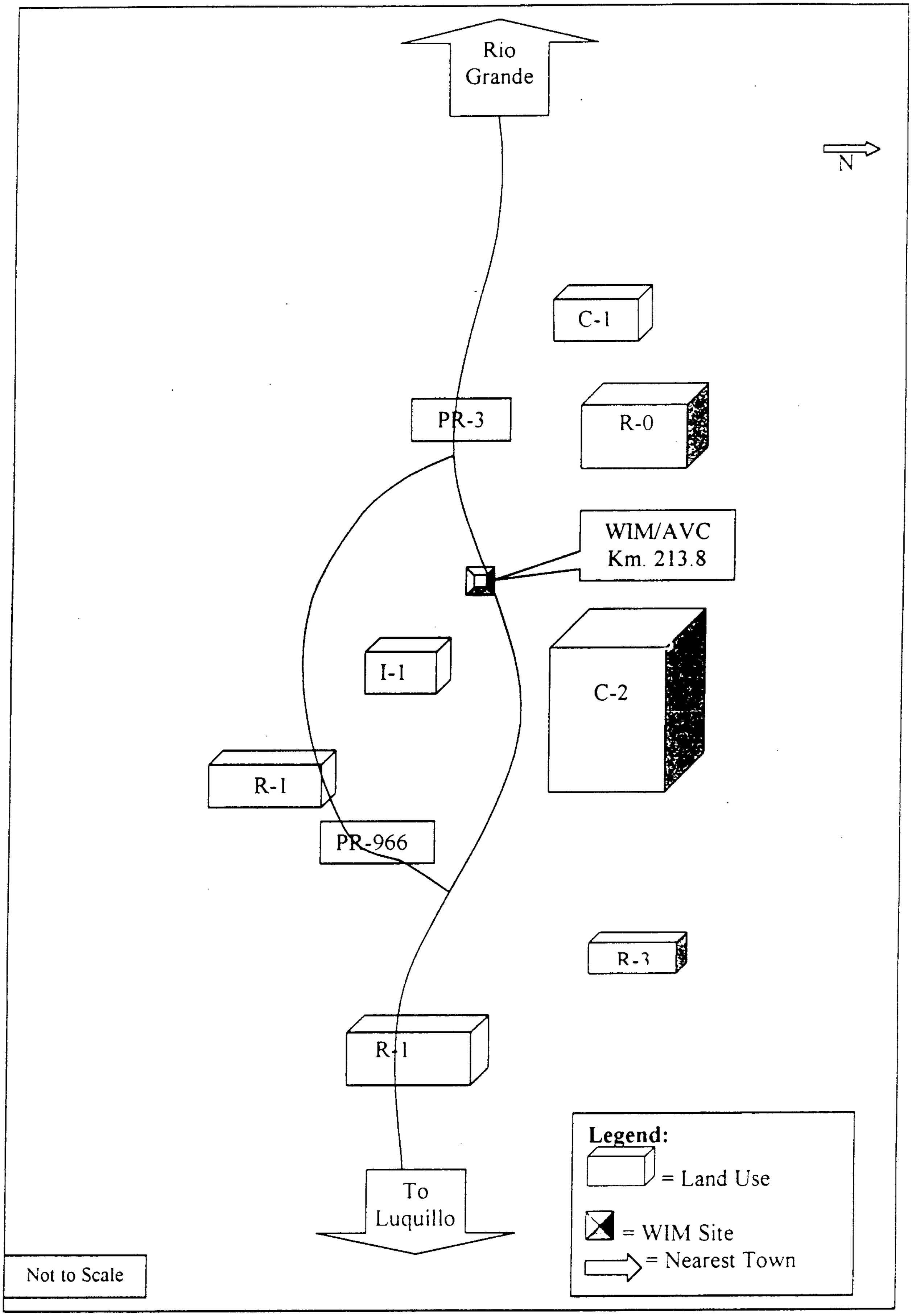
LAND USE MAP

WIM/AVC STATIONS: Mayaguez 006 PR-2 Km. 147 8



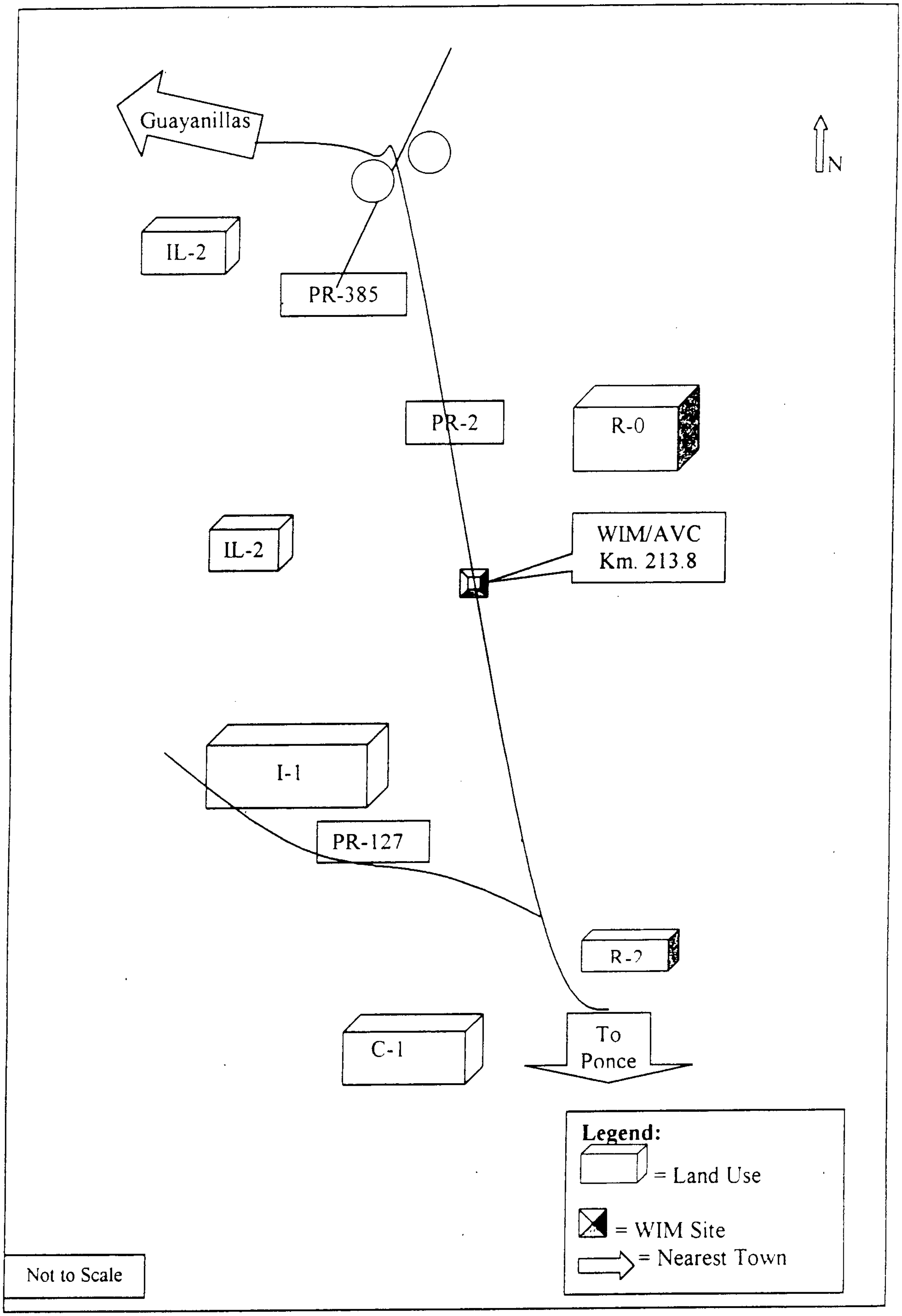
LAND USE MAP

WIM/AVC STATIONS: Rio Grande 007 PR-2 Km. 26 8



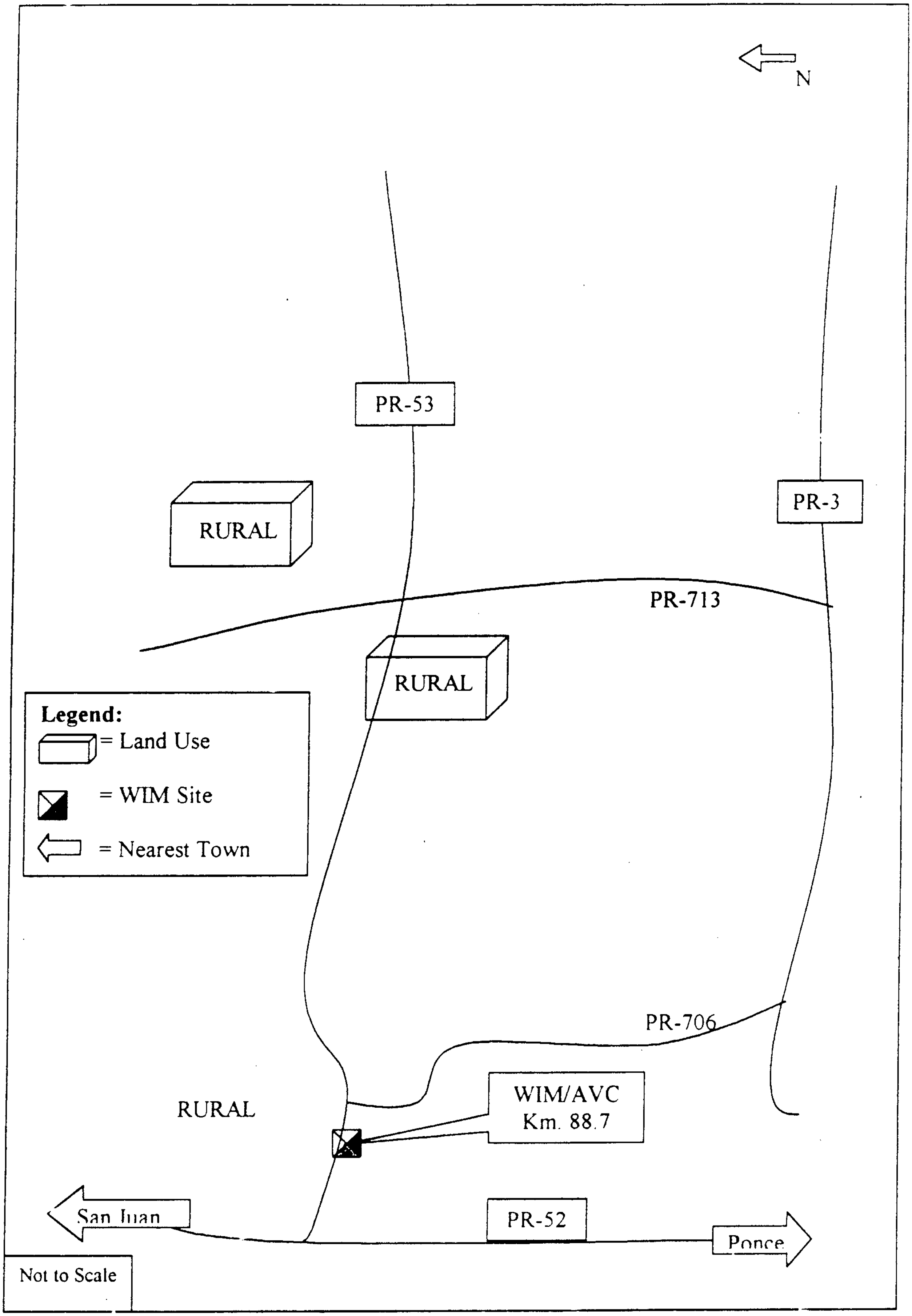
LAND USE MAP

WIM/AVC STATIONS: Peñuelas 008 PR-2 Km 213.8



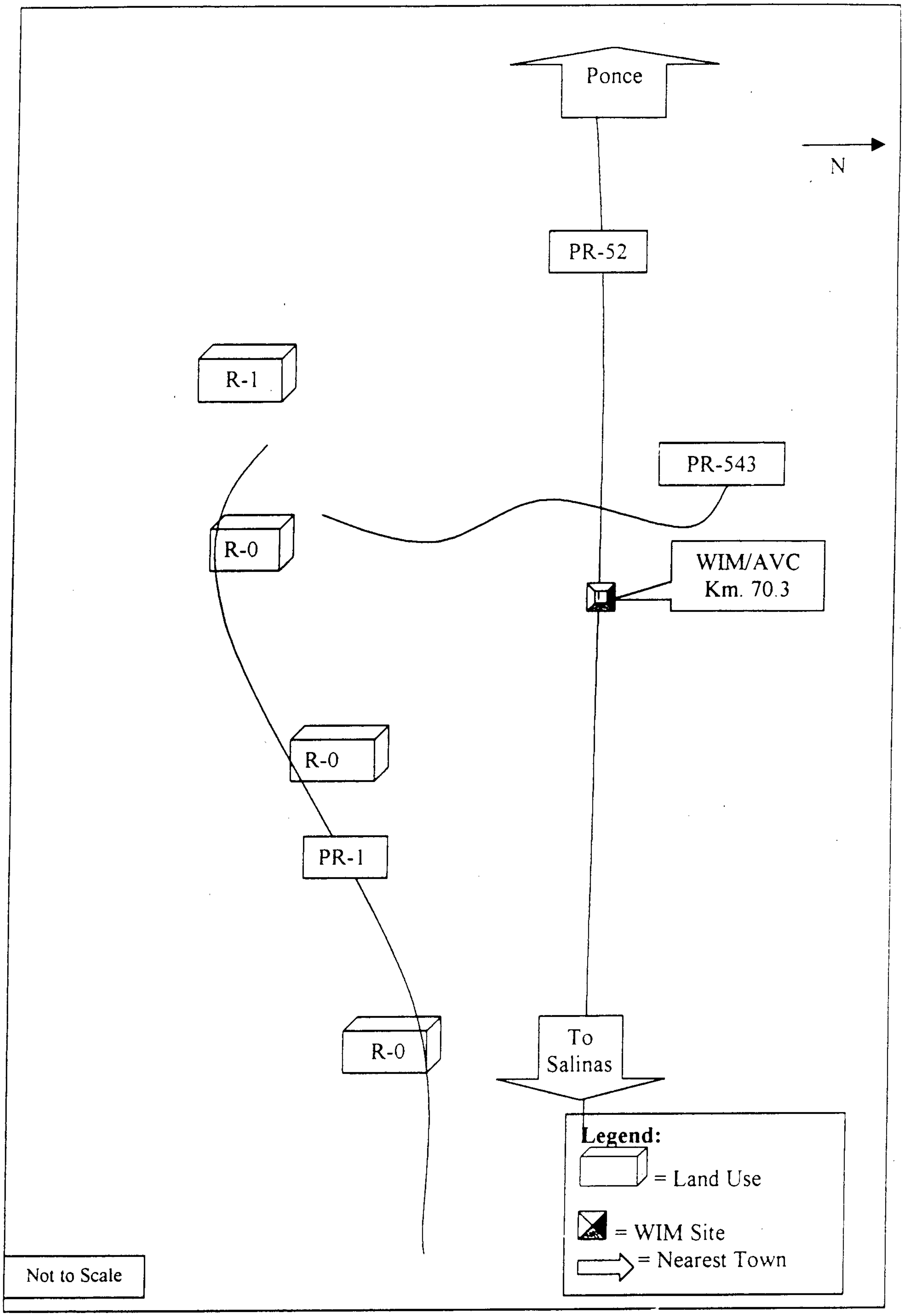
LAND USE MAP

WIM/AVC STATION: Guayama PR-53 Km. 88.7



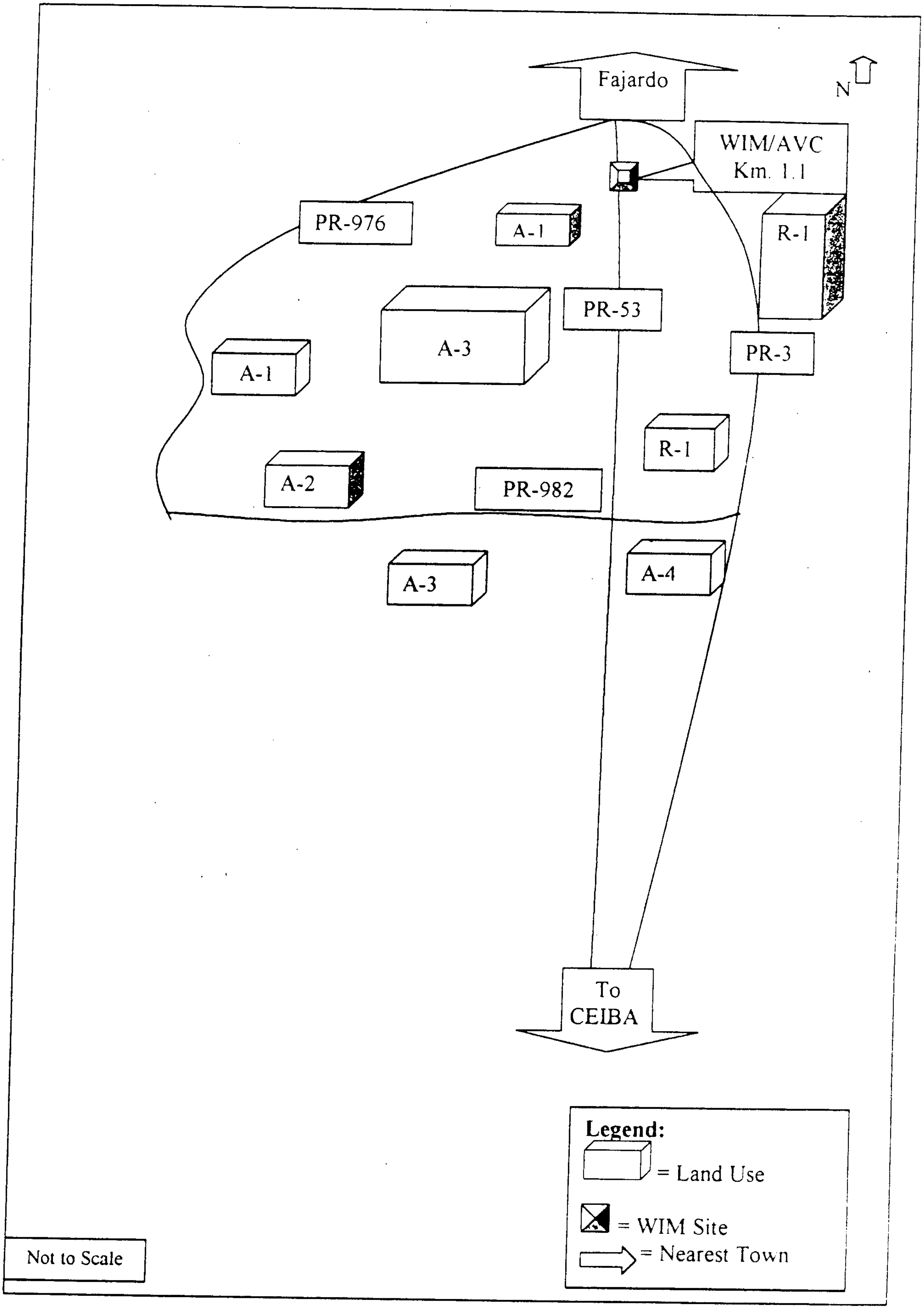
LAND USE MAP

WIM/AVC STATIONS: Salinas 010 PR-52 Km. 70.3



LAND USE MAP

IM/AVC STATIONS: Ceiba 011 PR-53 Km. 1.1

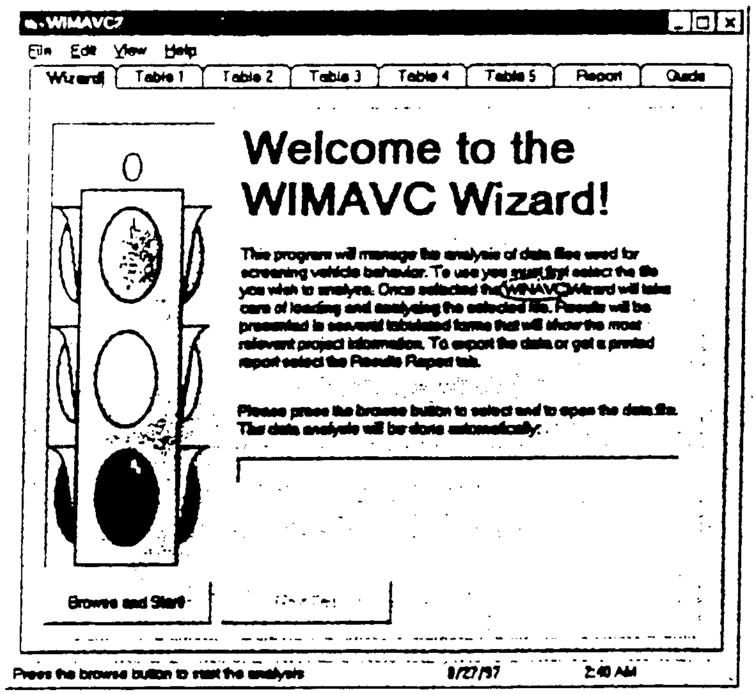


APPENDIX F

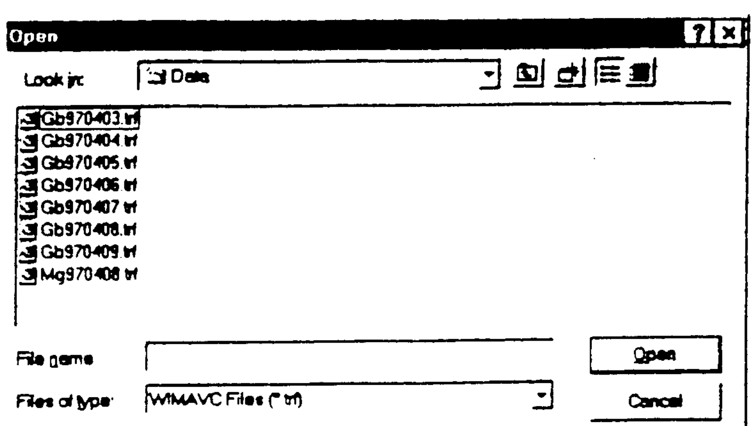
Quick Reference Guide to WIMAVC 2.0

Quick Reference Guide to WIMAVC 2.0 Beta

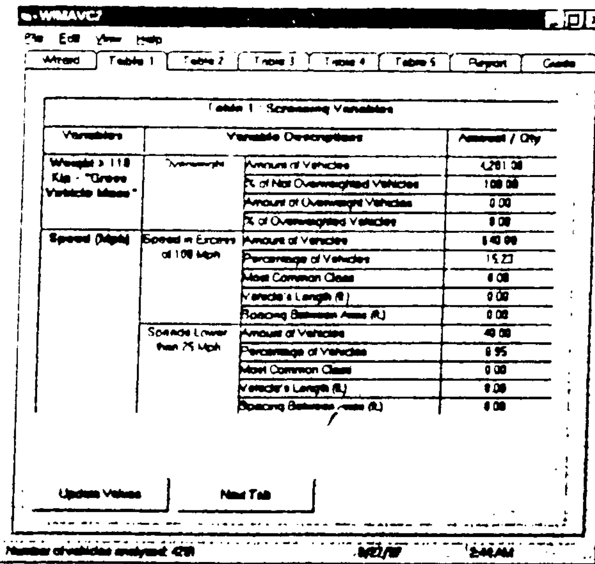
The WIMAVC application is basically a converter and analyzer of raw data obtained from measuring instruments used to monitor vehicle behavior in terms of weight, speed and others physical characteristics. This raw data is presented in ASCII text file format. These files end with the *.trw extension. The WIMAVC program actually reads the data from the source, gets the necessary information and processes it to deliver an ordered report.

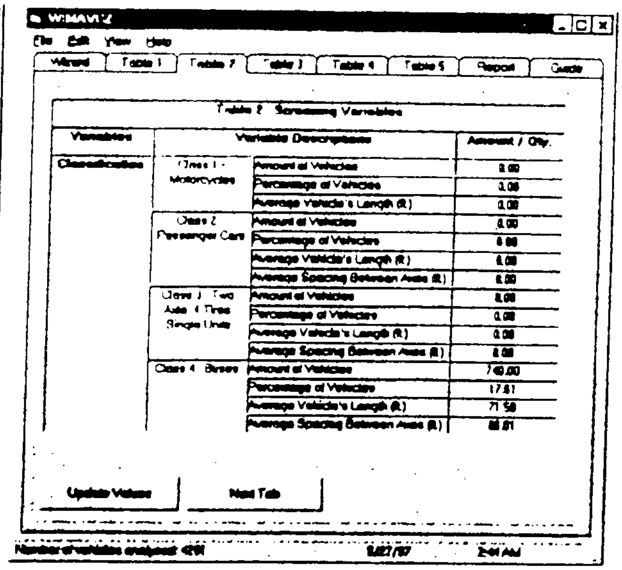


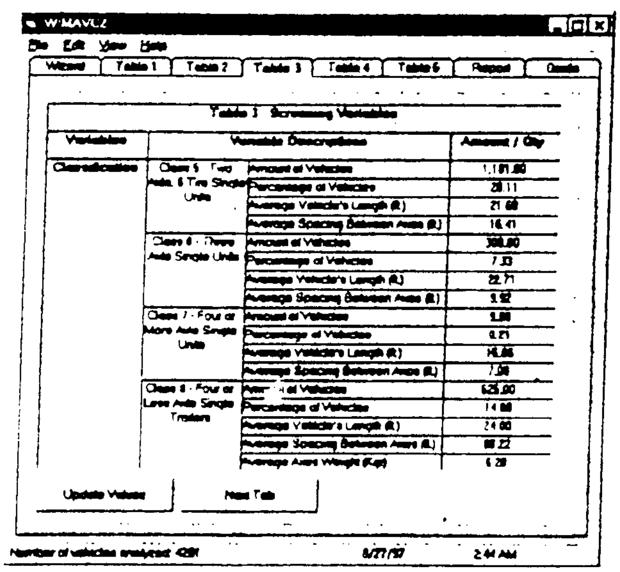
To use this application you must first select the file you wish to analyze. For this task simple press Open in the menu area or press the Browse and Start button in the first form. Once selected the WIMAVC application will manage this data accordingly.

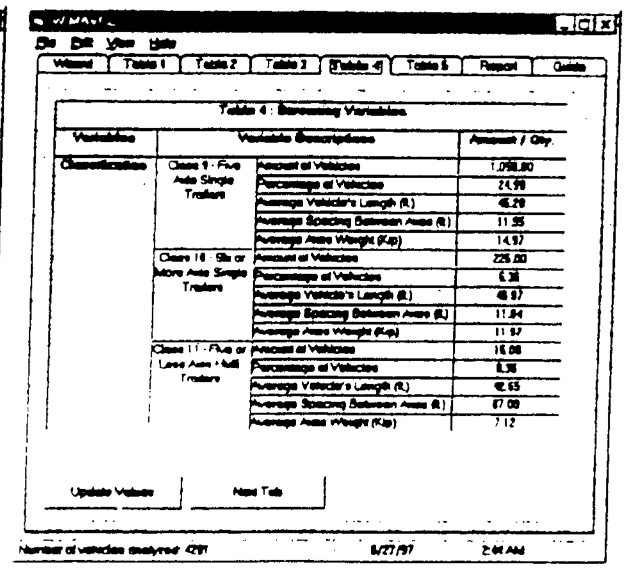


Press the Next button to move to the next form or simply select the corresponding Tab from this form and you will be able to examine the tabulated forms that will show the most relevant project information. If you wish to print or export any data to any other application go to the Report Tab. There you will find any material as required.

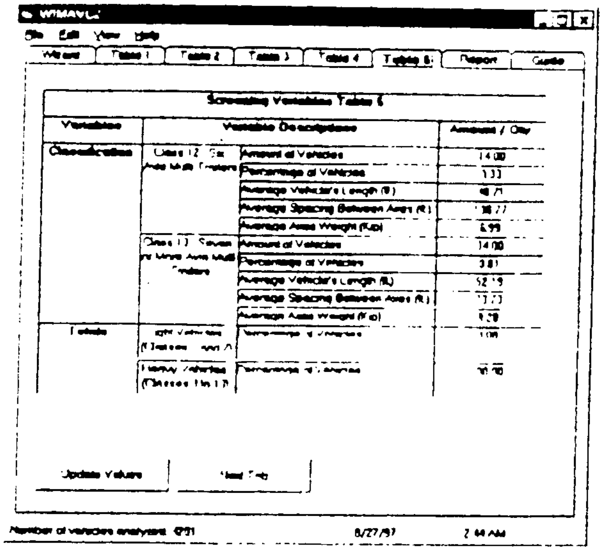


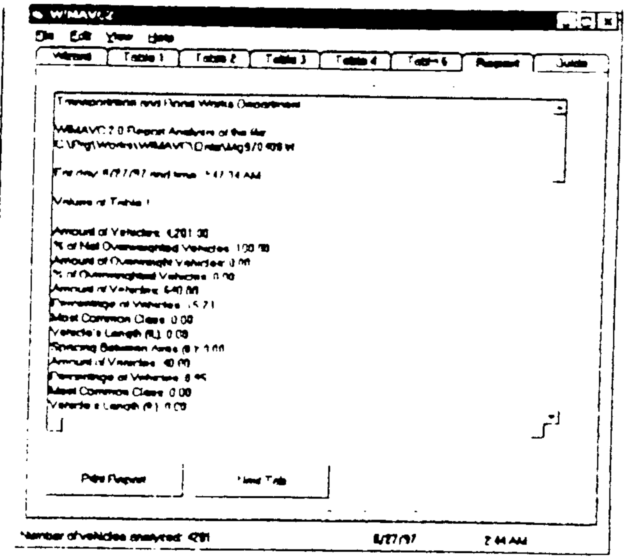




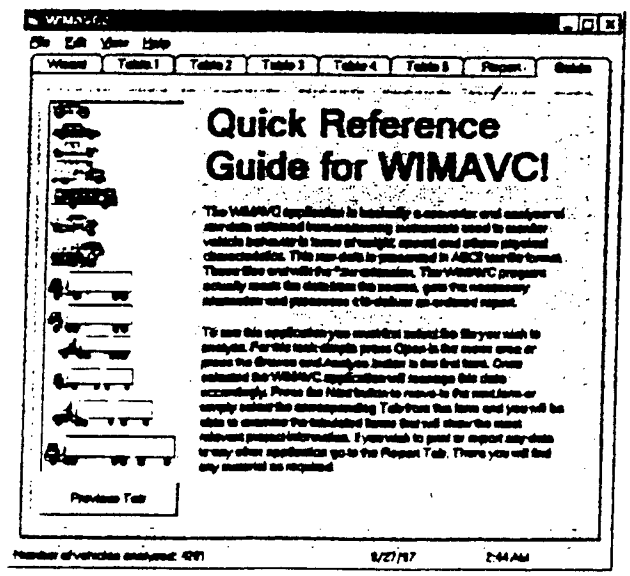


By pressing the Next Tab button in table 5 form the program will generate a report which will be shown in the Reports form as shown next.



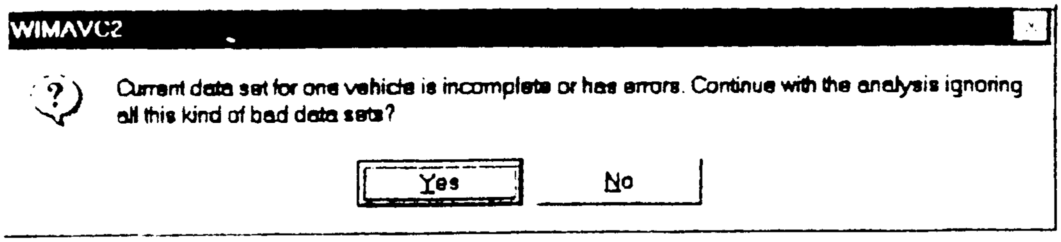


The last form in the application is used as a short guide on how to use the WIMAVC application and is shown next.



A few notes on this version:

This application is still in development. If there is something you might want to add or correct feel free to do so. Implementation will be as soon as possible. If the following screen or form appears while loading a truck it is OK. It is simply an indication that some files might not be complete. Answer Yes to continue and not worry about competition.



If you do not press Yes this form will always appear as soon as an error occurs. It is strongly recommended that you press Yes since the size of the files been evaluated is generally, extremely big.

Installation:

To install this application, simply place it in a floppy disk (preferably A). Run the Setup.exe program which will install the application. Follow the screen instructions. If you have any doubts press Yes to everything and let the program install itself.

APPENDIX G

Weekly Results for the Analysis Class 5, 6, and 9

Arecibo (Flexible) Station
Class 5, Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)		0.39	0.39	0.39	1.99	4.08		0.39
Max GVM		55.79	55.42	45.79	47.12	68.97		68.97
Avg. GVM		18.754	19.752	19.821	19.374	18.344		19.209
Within Limits		502	540	550	562	542		2696
Overweighted		28	23	26	21	18		116
% Overweighted		5.577	4.259	4.727	3.737	3.321		4.324
Lane 4								
Min GVM (Klb)		0.96	1.06	1.81	0.68	0.78		0.68
Max GVM		46.22	46.17	56.16	47.5	51.4		56.16
Avg. GVM		17.384	18.2352	19.066	18.785	18.538		18.402
Within Limits		570	570	531	617	557		2845
Overweighted		7	6	9	7	14		43
% Overweighted		1.23	1.053	1.69	1.13	2.51		1.52
General								
TOTAL FILES		1375	1383	1381	1493	1424		7056
FILES OK		1339	1352	1346	1450	1389		6876
ERROR		44	31.00	37	43	35		190
% ERROR		3.20	2.24	2.68	2.88	2.46		2.69

Gurabo Station
Class 5. Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)		2.09	0.99	3.88	1.6	1.19		0.99
Max GVM		59.38	53.46	50.710	47.27	45.25		53.46
Avg. GVM		20.685	22.497	21.51	20.313	19.753		21.018
Within Limits		371	346	390	458	466		1660
Overweighted		17	35	34	26	15		110
% Overweighted		4.582	10.115	8.717	5.676	3.218		6.932
Lane 4								
Min GVM (Klb)		3.25	4.63	4.43	5.09	4.26		4.26
Max GVM		47.46	38.1	43.59	46.62	37.61		46.62
Avg. GVM		16.942	17.29	18.537	16.954	17.500		17.570
Within Limits		443	471	484	465	481		1901
Overweighted		3	4	5	4	1		14
% Overweighted		0.677	0.849	1.03	0.86	0.21		0.74
General								
TOTAL FILES		1060	1090	1141	1175	1202		4608
FILES OK		1040	1073	1130	1164	1195		4562
ERROR		20	17.00	11	11	7		46
% ERROR		1.89	1.56	0.96	0.94	0.58		1.00

Class 5, Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)		1.94	11.54	1.51	1.81	1.51	8.5	1.51
Max GVM		44.32	61.52	67.83	65.08	66.93	44.96	67.83
Avg. GVM		30.260	28.850	29.975	28.987	29.887	29.202	29.527
Within Limits		144	174	190	215	178	56	957
Overweighted		72	77	95	84	102	23	453
% Overweighted		50.000	44.253	50.000	39.069	57.303	41.071	46.949
Lane 4								
Min GVM (Klb)		7.85	1.25	0.62	0.62	2.46	2.57	0.62
Max GVM		79.92	68.39	68.03	73.95	74.27	55.35	79.92
Avg. GVM		28.697	26.238	26.789	26.478	27.918	24.452	26.762
Within Limits		156	217	218	219	203	67	1080
Overweighted		36	29	38	30	34	9	176
% Overweighted		23.08	13.36	17.43	13.70	16.75	13.43	16.29
General								
TOTAL FILES		621	683	719	703	715	211	3652
FILES OK		481	609	627	625	597	180	3119
ERROR		140	74	92	78	118	31	533
% ERROR		22.54	10.83	12.79	11.09	16.50	14.69	14.59

Peñuelas Station
Class 5, Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)		2.64	0.49	1.23	0.97	5.2		0.49
Max GVM		44.1	60.41	47.82	40.35	46.64		60.41
Avg. GVM		25.116	29.059	26.966	24.958	24.411		26.102
Within Limits		138	182	208	159	231		918
Overweighted		24	69	61	28	30		212
% Overweighted		17.391	37.912	29.326	17.610	12.987		23.045
Lane 4								
Min GVM (Klb)		5.7	0.69	1.45	5.7	0.69		0.69
Max GVM		54	68.56	50.41	44.24	56.59		68.56
Avg. GVM		25.103	25.064	24.479	23.960	23.937		24.509
Within Limits		143	206	241	145	234		969
Overweighted		19	28	29	18	30		124
% Overweighted		13.86	13.592	12.03	12.41	12.82		12.94
General								
TOTAL FILES		376	582	633	437	641		2669
FILES OK		367	566	615	424	616		2588
ERROR		9	16.00	18	13	25		81
% ERROR		2.39	2.75	2.84	2.97	3.90		3.03

Guayama Station
Class 5, Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)		0.47	2.66	2.74	3.56	0.83	0.83	0.47
Max GVM		43.58	39.6	44.8	36.04	49.76	46.2	49.76
Avg. GVM		12.712	13.311	13.700	14.286	15.540	13.947	13.916
Within Limits		153	132	166	156	154	58	819
Overweighted		3	1	2	2	11	4	23
% Overweighted		1.961	0.757	1.205	1.282	7.143	6.897	3.207
Lane 4								
Min GVM (Klb)		0.72	3.11	2.95	4.43	2.87	3.69	0.72
Max GVM		29.38	41	31.86	32.29	37.41	27.86	41
Avg. GVM		14.926	16.121	16.174	16.339	16.008	14.210	15.630
Within Limits		150	130	161	150	143	53	787
Overweighted		0	1	0	0	2	0	3
% Overweighted		0.00	0.77	0.00	0.00	1.40	0.00	0.36
General								
TOTAL FILES		348	304	368	346	370	131	1867
FILES OK		344	301	364	345	362	128	1844
ERROR		4	3	4	1	8	3	23
% ERROR		1.15	0.99	1.09	0.29	2.16	2.29	1.23

Salinas Station
Class 5, Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)		1.21	9.03	6.26	0.41	1.31	1.21	0.41
Max GVM		15.38	65.63	63.19	25.79	52.46	27.89	65.63
Avg. GVM		9.003	22.096	19.880	5.892	18.700	9.135	14.118
Within Limits		10	79	117	10	90	11	317
Overweighted		0	8	2	0	2	0	12
% Overweighted		0.000	10.127	1.709	0.000	2.222	0.000	2.343
Lane 4								
Min GVM (Klb)		6.67	0	4.52	1.13	1.21	1.65	0
Max GVM		46.76	0	68.66	44.36	43.93	61.82	68.66
Avg. GVM		19.148	0.000	20.195	17.464	17.964	16.689	15.243
Within Limits		113	0	147	113	189	51	613
Overweighted		3	0	6	4	2	2	17
% Overweighted		2.65	0.00	4.08	3.54	1.06	3.92	2.54
General								
TOTAL FILES		234	207	374	251	421	121	1608
FILES OK		206	183	352	228	403	108	1480
ERROR		28	24	22	23	18	13	128
% ERROR		11.97	11.59	5.88	9.16	4.28	10.74	7.96

Ceiba Station
Class 5, Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)	3.7	2.06	0.98	2.6	0.58	2.7	7.02	0.58
Max GVM	32.58	33.76	31.74	32.46	35.02	43.62	29.92	43.62
Avg. GVM	13.8557	17.333	16.085	16.229	17.160	17.122	15.202	16.141
Within Limits	14	117	130	120	136	129	25	671
Overweighted	0	0	0	1	1	3	0	5
% Overweighted	0	0.000	0.000	0.833	0.735	2.326	0.000	0.556
Lane 4								
Min GVM (Klb)	10.46	8.86	8.05	0.32	8.35	9.35	0.96	0.32
Max GVM	32.45	60.35	56.43	60.27	59.6	60.04	34.83	60.35
Avg. GVM	17.699	24.475	24.294	24.360	25.180	25.333	21.959	23.329
Within Limits	10	110	129	143	121	130	26	669
Overweighted	0	16	22	32	27	24	3	124
% Overweighted	0	14.55	17.05	22.38	22.31	18.46	11.54	15.184
General								
TOTAL FILES	28	273	326	342	333	328	70	1700
FILES OK	28	267	310	333	327	320	63	1648
ERROR	0	6	16	9	6	8	7	52
% ERROR	0.00	2.20	4.91	2.63	1.80	2.44	10.00	3.06

Arecibo (Flexible) Station
Class 6, Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)		17.56	13.1	18.13	15.95	16.74		13.1
Max GVM		72.19	73.83	76.22	71	76.22		76.22
Avg. GVM		43.490	44.919	44.172	47.585	44.730		44.979
Within Limits		200	207	149	119	193		868
Overweighted		47	56	39	61	63		266
% Overweighted		19.028	21.293	20.745	33.889	24.609		23.913
Lane 4								
Min GVM (Klb)		19.55	18.42	19.94	15.51	15.56		15.51
Max GVM		67.68	75.73	67.68	65.61	73.11		75.73
Avg. GVM		42.280	42.853	39.518	38.149	42.320		41.024
Within Limits		181	219	169	147	199		915
Overweighted		47	53	15	11	52		178
% Overweighted		20.61	19.485	8.15	6.96	20.72		15.18
General								
TOTAL FILES		520	575	413	369	545		2422
FILES OK		516	566	409	359	534		2384
ERROR		4	9.00	4	10	11		38
% ERROR		0.77	1.57	0.97	2.71	2.02		1.57

Gurabo Station
Class 6, Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)		19.05	4.37	3.52	25.14	19.61		3.52
Max GVM		77.61	80.01	84	85.52	84		85.52
Avg. GVM		51.071	51.041	53.081	52.880	52.266		52.068
Within Limits		131	98	110	94	104		537
Overweighted		70	75	100	71	79		395
% Overweighted		35.149	43.353	47.619	43.030	43.169		42.464
Lane 4								
Min GVM (Klb)		12.04	13.54	20.07	17.78	14.42		12.04
Max GVM		75.32	65.46	65.24	68.06	63.35		75.32
Avg. GVM		44.502	44.294	45.272	44.021	44.209		44.460
Within Limits		173	188	183	156	167		867
Overweighted		44	35	37	26	28		170
% Overweighted		20.28	15.695	16.82	14.29	14.36		16.29
General								
TOTAL FILES		465	436	465	394	413		2173
FILES OK		457	430	463	347	378		2075
ERROR		8	6.00	2	47	35		98
% ERROR		1.72	1.38	0.43	11.93	8.47		4.51

Class 6, Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)		36.19	20.26	22.08	22.27	36.2	35.52	20.26
Max GVM		66.89	66.89	66.89	66.89	66.89	55.79	66.89
Avg. GVM		52.549	50.624	53.043	52.642	54.241	45.084	51.364
Within Limits		42	32	29	34	31	13	181
Overweighted		24	40	33	33	34	1	165
% Overweighted		36.364	55.556	53.226	49.254	52.308	7.143	42.308
Lane 4								
Min GVM (Klb)		13.79	19.95	9.99	17.78	24.08	26	9.99
Max GVM		66.26	67.02	70.55	71.28	70.55	69.2	71.28
Avg. GVM		42.182	42.939	41.926	43.677	44.101	44.053	43.146
Within Limits		48	52	55	53	46	8	262
Overweighted		10	17	5	11	13	2	58
% Overweighted		17.24	24.64	8.33	17.19	22.03	20.00	18.24
General								
TOTAL FILES		148	163	142	155	146	29	783
FILES OK		137	150	130	145	141	28	731
ERROR		11	13	12	10	5	1	52
% ERROR		7.43	7.98	8.45	6.45	3.42	3.45	6.64

Peñuelas Station
Class 6. Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)		21.77	26.94	17.58	27.89	23.98		17.58
Max GVM		77.26	73.61	78.06	78.58	78.55		78.58
Avg. GVM		52.733	54.471	53.017	52.810	49.739		52.554
Within Limits		34	32	36	22	56		180
Overweighted		30	33	40	26	32		161
% Overweighted		46.875	50.769	52.630	54.167	36.364		48.161
Lane 4								
Min GVM (Klb)		31.56	24.89	23.04	21.85	23.23		21.85
Max GVM		88.19	77.73	80.12	76.99	79.91		88.19
Avg. GVM		52.225	45.752	46.729	47.496	48.206		48.081
Within Limits		30	51	61	38	63		243
Overweighted		27	18	18	15	25		103
% Overweighted		47.37	26.087	22.78	28.30	28.41		30.59
General								
TOTAL FILES		131	143	170	112	194		750
FILES OK		126	138	165	112	192		733
ERROR		5	5.00	5	0	2		17
% ERROR		3.82	3.50	2.94	0.00	1.03		2.27

Guayama Station
Class 6, Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)		16.11	13.08	13.27	15.7	12.04	12.88	12.04
Max GVM		76.89	78.5	77.81	78.39	85.55	40.6	85.55
Avg. GVM		40.059	37.760	41.796	40.295	41.857	26.541	38.051
Within Limits		25	23	27	22	30	8	135
Overweighted		5	3	9	5	7	1	30
% Overweighted		16.667	11.538	25.000	18.518	18.918	11.111	16.959
Lane 4								
Min GVM (Klb)		22.41	17.73	13.92	14.59	14.11	32.53	13.92
Max GVM		56.22	58.64	56.09	55.59	66.33	59.41	66.33
Avg. GVM		42.250	38.936	36.658	36.950	37.291	43.602	39.281
Within Limits		30	24	40	31	35	8	168
Overweighted		3	2	1	2	3	2	13
% Overweighted		9.09	7.69	2.44	6.06	7.89	20.00	8.86
General								
TOTAL FILES		64	53	81	60	78	20	356
FILES OK		63	53	80	60	77	20	353
ERROR		1	0	1	0	1	0	3
% ERROR		1.56	0.00	1.23	0.00	1.28	0.00	0.84

Salinas Station
Class 6, Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)		2.73	5.51	2.13	2.131	7.02	6.28	2.13
Max GVM		22.8	54.03	46.39	22.34	46.07	27.2	54.03
Avg. GVM		13.517	21.975	23.850	12.499	18.608	14.320	17.461
Within Limits		39	55	62	34	55	21	266
Overweighted		1	1	0	1	0	0	3
% Overweighted		2.500		0.000	2.857	0.000	0.000	1.071
Lane 4								
Min GVM (Klb)		8.36	0	4.07	6.78	1.71	7.75	0
Max GVM		50.37	0	58.26	70.22	51.11	61.88	70.22
Avg. GVM		24.146	0.000	29.896	24.376	24.625	24.665	21.284
Within Limits		72	0	68	79	69	18	306
Overweighted		0	0	4	2	1	2	9
% Overweighted		0.00	0.00	5.55	2.47	1.43	10.00	3.24
General								
TOTAL FILES		128	68	160	135	142	47	680
FILES OK		126	65	151	125	137	44	648
ERROR		2	3	9	10	5	3	32
% ERROR		1.56	4.41	5.63	7.41	3.52	6.38	4.71

Ceiba Station
Class 6, Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)	27.48	19.61	24.46	13.9	21.83	17.74	36.05	13.9
Max GVM	31.41	61.13	57.43	62.22	62.22	58.02	54.06	62.22
Avg. GVM	29.213	42.348	39.488	39.662	40.876	39.627	43.427	39.234
Within Limits	2	27	51	67	51	55	5	258
Overweighted	1	5	4	8	8	5	2	33
% Overweighted	33.333	15.625	7.273	10.667	13.559	8.333	28.570	16.766
Lane 4								
Min GVM (Klb)	37.42	30.63	13.24	13.15	15.75	30.53	42.35	13.15
Max GVM	37.42	61.99	61.79	63	59.65	61.3	58.45	63
Avg. GVM	37.42	47.111	43.669	45.425	45.581	47.254	48.850	45.044
Within Limits	1	29	35	39	36	28	3	171
Overweighted	0	11	10	13	6	15	1	56
% Overweighted	0	27.50	22.22	25.00	14.29	34.88	25.00	21.270
General								
TOTAL FILES	5	78	112	135	113	120	12	575
FILES OK	5	77	109	133	111	119	11	565
ERROR	0	1	3	2	2	1	1	10
% ERROR	0	1.28	2.68	1.48	1.77	0.83	8.33	1.74

Arecibo (Flexible) Station
Class 9, Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)		22.8	26.71	23.83	26.64	20.54		20.54
Max GVM		112.41	113.54	113.34	116.32	113.34		116.32
Avg. GVM		58.645	58.698	58.597	61.001	59.831		59.354
Within Limits		297	329	330	302	324		1582
Overweighted		14	12	14	21	22		83
% Overweighted		4.501	3.519	4.069	6.501	6.358		4.990
Lane 4								
Min GVM (Klb)		24.8	23.77	25.38	15.07	22.89		15.07
Max GVM		98.1	103.15	105.54	104.06	106.01		106.01
Avg. GVM		60.084	59.606	59.571	58.443	61.022		59.745
Within Limits		266	287	284	244	254		1335
Overweighted		1	4	5	2	4		16
% Overweighted		0.37	1.374	1.73	0.81	1.55		1.17
General								
TOTAL FILES		678	719	720	660	709		3486
FILES OK		645	697	694	638	673		3347
ERROR		33	22.00	26	22	36		139
% ERROR		4.87	3.06	3.61	3.33	5.08		3.99

Gurabo Station
Class 9, Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)		21.37	37.24	32.84	21.03	31.43		21.03
Max GVM		104.87	130.57	126.39	127.74	123.69		130.57
Avg. GVM		69.279	76.152	74.971	73.011	72.310		74.111
Within Limits		181	161	164	153	168		646
Overweighted		6	18	12	21	18		69
% Overweighted		3.208	10.055	6.818	12.068	9.677		9.655
Lane 4								
Min GVM (Klb)		24.9	28.25	31.42	25.25	27.23		25.25
Max GVM		95.64	107.43	110.37	105.14	100.87		110.37
Avg. GVM		60.533	60.178	62.791	59.308	62.191		61.117
Within Limits		191	189	180	176	211		756
Overweighted		0	7	6	4	4		21
% Overweighted		0	3.571	3.23	2.22	1.86		2.72
General								
TOTAL FILES		456	457	423	429	488		1797
FILES OK		434	423	400	405	461		1689
ERROR		22	34.00	23	24	27		108
% ERROR		4.82	7.44	5.44	5.59	5.53		6.01

Mayaguez Station
Class 9. Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)		45.58	40.54	37.11	27.56	26.8	44.53	26.8
Max GVM		110.75	110.75	108.31	107.32	108.31	110.75	110.75
Avg. GVM		84.620	83.824	82.836	81.918	83.474	85.731	83.734
Within Limits		189	189	219	201	183	65	1046
Overweighted		50	54	48	44	60	31	287
% Overweighted		20.920	22.200	17.977	17.959	24.690	32.292	22.673
Lane 4								
Min GVM (Klb)		33.75	24.91	7.97	32.96	31.53	18.49	7.97
Max GVM		105.63	105.4	113.63	112.14	104.67	118.55	118.55
Avg. GVM		70.900	73.337	71.660	70.937	71.539	66.957	70.888
Within Limits		151	162	175	171	166	56	881
Overweighted		10	19	17	12	18	7	83
% Overweighted		6.21	10.50	8.85	6.56	9.78	11.11	8.83
General								
TOTAL FILES		443	469	508	470	485	178	2553
FILES OK		417	452	479	447	460	168	2423
ERROR		26	17	29	23	25	10	130
% ERROR		5.87	3.62	5.71	4.89	5.15	5.62	5.09

Peñuelas Station
Class 9, Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)		33.03	32.6	29.83	43.33	32.53		29.83
Max GVM		122.86	121.24	140.77	100.95	131		140.77
Avg. GVM		73.923	82.950	81.743	71.226	78.213		77.611
Within Limits		74	80	91	65	83		393
Overweighted		5	16	25	2	20		68
% Overweighted		6.329	16.667	21.552	2.985	19.417		13.390
Lane 4								
Min GVM (Klb)		39.08	41.33	34.71	37.19	37.62		34.71
Max GVM		145.51	140.68	124.04	136.86	140.97		145.51
Avg. GVM		70.315	71.15196	63.347	66.783	71.049		68.529
Within Limits		79	85	97	64	106		431
Overweighted		11	17	8	7	13		56
% Overweighted		12.22	16.667	7.62	9.85	10.92		11.46
General								
TOTAL FILES		209	244	300	174	278		1205
FILES OK		187	217	248	151	251		1054
ERROR		22	27.00	52	23	27		151
% ERROR		10.53	11.07	17.33	13.22	9.71		12.53

Guayama Station
Class 9, Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)		22.91	20.43	24.19	22.02	16.88	22.92	16.88
Max GVM		126.29	119.61	110.32	131.37	132.99	130.22	132.99
Avg. GVM		53.264	53.237	50.330	56.270	52.380	55.117	53.433
Within Limits		67	52	63	49	54	34	319
Overweighted		7	5	4	7	9	7	39
% Overweighted		9.454	8.770	5.970	12.500	14.286	17.070	11.342
Lane 4								
Min GVM (Klb)		18.72	31.04	15.14	26.01	21.26	27.73	15.14
Max GVM		99.61	109.85	83.77	82.9	80.28	104.7	109.85
Avg. GVM		56.856	63.670	60.250	57.925	60.780	68.781	61.377
Within Limits		54	56	50	38	46	30	274
Overweighted		1	3	0	0	0	1	5
% Overweighted		1.82	5.08	0.00	0.00	0.00	3.22	1.69
General								
TOTAL FILES		148	138	135	110	136	85	752
FILES OK		137	125	127	100	122	79	690
ERROR		11	13	8	10	14	6	62
% ERROR		7.43	9.42	5.92	9.09	10.29	7.06	8.24

Salinas Station
Class 9, Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)		17.41	13.41	22.01	21.71	12.71	18.1	12.71
Max GVM		82.81	77.76	81.93	39.12	75.77	68.65	82.81
Avg. GVM		33.539	46.792	45.568	30.415	44.588	34.266	39.195
Within Limits		10	43	39	2	26	5	125
Overweighted		0	0	0	0	0	0	0
% Overweighted		0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lane 4								
Min GVM (Klb)		28.22	0	15.55	26.47	14.7	23.65	0
Max GVM		111.54	0	85.36	96.5	111.94	77.61	111.94
Avg. GVM		54.325	0.000	57.968	50.360	55.184	52.367	45.034
Within Limits		69	0	158	71	142	31	471
Overweighted		2	0	0	1	1	0	4
% Overweighted		2.82	0.00	0.00	1.39	0.70	0.00	0.82
General								
TOTAL FILES		275	190	393	288	369	114	1629
FILES OK		140	106	272	165	247	58	988
ERROR		135	84	121	107	200	56	703
% ERROR		49.09	44.21	30.79	37.15	54.20	49.12	43.16

Ceiba Station
Class 9. Weekly

	Sunday	Monday	Tuesday	Wenesday	Thursday	Friday	Saturday	Weekly
Lane 1								
Min GVM (Klb)	0	30.88	28.98	30.41	27.93	31.94	31.21	0
Max GVM	0	95.04	93.22	91.77	94.7	91.67	49.17	95.04
Avg. GVM	0	56.030	55.545	55.834	53.715	57.502	42.248	45.839
Within Limits	0	27	40	40	25	34	4	170
Overweighted	0	0	0	0	0	0	0	0
% Overweighted	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lane 4								
Min GVM (Klb)	68.44	48.17	41.99	43.78	28	29.7	56.52	28
Max GVM	74.6	95.02	95.69	95.96	93.45	96.16	71.88	96.16
Avg. GVM	71.52	68.134	67.386	67.870	68.922	62.769	63.973	67.225
Within Limits	2	29	34	39	26	30	3	163
Overweighted	0	0	0	0	0	1	0	1
% Overweighted	0	0.00	0.00	0.00	0.00	3.23	0.00	0.461
General								
TOTAL FILES	4	65	93	100	68	81	11	422
FILES OK	2	59	76	82	55	66	7	347
ERROR	2	6	17	18	13	15	4	75
% ERROR	50.00	9.23	18.28	18.00	19.12	18.52	36.36	17.77

APPENDIX H

Worksheets with Vehicles OK and Errors

VEHICLES FILTERED BY CLASS

Arecibo	Class 4	5	6	7	8	9	10	11	12	13	DTT
Monday	71	1339	516	8	200	645	16	1	0	1	2797
Tuesday	77	1352	566	11	202	697	28	6	1	0	2940
Wednesday	90	1346	409	5	134	694	19	2	0	1	2700
Thursday	103	1450	359	9	249	638	15	4	0	0	2827
Friday	134	1389	534	2	252	673	24	4	2	0	3014
Average	95	1375	477	7	207	669	20	3	1	0	2856
Std-Dev	25	46	88	4	48	27	6	2	1	1	123
Coef. of Var.	0.26	0.03	0.19	0.51	0.23	0.04	0.27	0.57	1.49	1.37	0.04

Percent of Each Class

Arecibo	Class 4	5	6	7	8	9	10	11	12	13
Monday	2.54	47.87	18.45	0.29	7.15	23.06	0.57	0.04	0.00	0.04
Tuesday	2.62	45.99	19.25	0.37	6.87	23.71	0.95	0.20	0.03	0.00
Wednesday	3.33	49.85	15.15	0.19	4.96	25.70	0.70	0.07	0.00	0.04
Thursday	3.64	51.29	12.70	0.32	8.81	22.57	0.53	0.14	0.00	0.00
Friday	4.45	46.08	17.72	0.07	8.36	22.33	0.80	0.13	0.07	0.00

Gurabo	Class 4	5	6	7	8	9	10	11	12	13	DTT
Monday	61	1040	457	7	107	434	29	1	1	2	2139
Tuesday	106	1073	430	1	112	423	65	1	0	0	2211
Wednesday	114	1130	463	5	123	400	35	0	0	0	2270
Thursday	106	1164	347	1	117	405	48	2	0	2	2192
Friday	94	1195	378	1	143	461	54	0	1	0	2327
Average	96	1120	415	3	120	425	46	1	0	1	2228
Std-Dev	21	64	51	3	14	25	14	1	1	1	73
Coef. of Var.	0.22	0.06	0.12	0.94	0.12	0.06	0.31	1.05	1.37	1.37	0.03

Percent of Each Class

Gurabo	Class 4	5	6	7	8	9	10	11	12	13
Monday	2.85	48.62	21.37	0.33	5.00	20.29	1.36	0.05	0.05	0.09
Tuesday	4.79	48.53	19.45	0.05	5.07	19.13	2.94	0.05	0.00	0.00
Wednesday	5.02	49.78	20.40	0.22	5.42	17.62	1.54	0.00	0.00	0.00
Thursday	4.84	53.10	15.83	0.05	5.34	18.48	2.19	0.09	0.00	0.09
Friday	4.04	51.35	16.24	0.04	6.15	19.81	2.32	0.00	0.04	0.00

VEHICLES FILTERED BY CLASS

Mayaguez	Class 4	5	6	7	8	9	10	11	12	13	DTT
Monday	17	481	137	0	82	417	12	1	0	4	1151
Tuesday	34	609	150	1	87	452	16	1	1	4	1355
Wednesday	34	627	130	0	105	479	17	2	1	4	1399
Thursday	28	625	145	3	84	447	13	3	0	0	1348
Friday	32	597	141	3	94	460	20	2	0	1	1350
Average	29	588	141	1	90	451	16	2	0	3	1321
Std-Dev	7	61	8	2	9	23	3	1	1	2	97
Coef. of Var.	0.25	0.10	0.05	1.08	0.10	0.05	0.21	0.46	1.37	0.75	0.07

Percent of Each Class

Mayaguez	Class 4	5	6	7	8	9	10	11	12	13
Monday	1.48	41.79	11.90	0.00	7.12	36.23	1.04	0.09	0.00	0.35
Tuesday	2.51	44.94	11.07	0.07	6.42	33.36	1.18	0.07	0.07	0.30
Wednesday	2.43	44.82	9.29	0.00	7.51	34.24	1.22	0.14	0.07	0.29
Thursday	2.08	46.36	10.76	0.22	6.23	33.16	0.96	0.22	0.00	0.00
Friday	2.37	44.22	10.44	0.22	6.96	34.07	1.48	0.15	0.00	0.07

Peñuelas	Class 4	5	6	7	8	9	10	11	12	13	DTT
Monday	28	367	126	0	74	187	8	1	0	1	792
Tuesday	48	485	134	1	74	151	21	0			914
Wednesday	20	539	155	3	88	221	13	0			1039
Thursday	29	350	101	1	53	138	5	0			677
Friday	40	495	176	1	88	222	10	0			1032
Average	33	447	138	1	75	184	11	0	0	1	891
Std-Dev	11	84	29	1	14	39	6	0			156
Coef. of Var.	0.33	0.19	0.21	0.91	0.19	0.21	0.54	2.24			0.18

Percent of Each Class

Peñuelas	Class 4	5	6	7	8	9	10	11	12	13
Monday	3.54	46.34	15.91	0.00	9.34	23.61	1.01	0.13	0.00	0.13
Tuesday	5.25	53.06	14.66	0.11	8.10	16.52	2.30	0.00	0.00	0.00
Wednesday	1.92	51.88	14.92	0.29	8.47	21.27	1.25	0.00	0.00	0.00
Thursday	4.28	51.70	14.92	0.15	7.83	20.38	0.74	0.00	0.00	0.00
Friday	3.88	47.97	17.05	0.10	8.53	21.51	0.97	0.00	0.00	0.00

VEHICLES FILTERED BY CLASS

Guayama	Class 4	5	6	7	8	9	10	11	12	13	DTT
Monday	56	344	63	1	42	137	20	1	0	0	664
Tuesday	24	301	53	1	37	125	22	2	0	1	566
Wednesday	31	364	80	0	39	127	14	2	0	1	658
Thursday	35	345	60	2	33	100	17	1	0	0	593
Friday	47	362	77	0	52	122	15	0	0	1	676
Average	39	343	67	1	41	122	18	1	0	1	631
Std-Dev	13	25	12	1	7	14	3	1	0	1	49
Coef. of Var.	0.33	0.07	0.17	1.05	0.18	0.11	0.19	0.70		0.91	0.08

Percent of Each Class

Guayama	Class 4	5	6	7	8	9	10	11	12	13
Monday	8.43	51.81	9.49	0.15	6.33	20.63	3.01	0.15	0.00	0.00
Tuesday	4.24	53.18	9.36	0.18	6.54	22.08	3.89	0.35	0.00	0.18
Wednesday	4.71	55.32	12.16	0.00	5.93	19.30	2.13	0.30	0.00	0.15
Thursday	5.90	58.18	10.12	0.34	5.56	16.86	2.87	0.17	0.00	0.00
Friday	6.95	53.55	11.39	0.00	7.69	18.05	2.22	0.00	0.00	0.15

Salinas	Class 4	5	6	7	8	9	10	11	12	13	DTT
Monday	42	206	126	1	45	140	33	0	2	39	634
Tuesday	55	183	65	1	18	106	21	0	1	44	494
Wednesday	17	352	151	0	75	272	45	0	0	57	969
Thursday	19	228	125	1	53	165	36	0	2	38	667
Friday	40	403	137	1	85	247	39	0	0	40	992
Average	35	274	121	1	55	186	35	0	1	44	751
Std-Dev	16	97	33	0	26	71	9	0	1	8	219
Coef. of Var.	0.47	0.35	0.27	0.56	0.48	0.38	0.26		1.00	0.18	0.29

Percent of Each Class

Salinas	Class 4	5	6	7	8	9	10	11	12	13
Monday	6.62	32.49	19.87	0.16	7.10	22.08	5.21	0.00	0.32	6.15
Tuesday	11.13	37.04	13.16	0.20	3.64	21.46	4.25	0.00	0.20	8.91
Wednesday	1.75	36.33	15.58	0.00	7.74	28.07	4.64	0.00	0.00	5.88
Thursday	2.85	34.18	18.74	0.15	7.95	24.74	5.40	0.00	0.30	5.70
Friday	4.03	40.63	13.81	0.10	8.57	24.90	3.93	0.00	0.00	4.03

VEHICLES FILTERED BY CLASS

Ceiba	Class 4	5	6	7	8	9	10	11	12	13	DTT
Monday	17	267	77	2	41	59	21	0	0	1	485
Tuesday	17	310	109	4	41	76	20	0	0	3	580
Wednesday	20	311	133	7	32	82	22	0	1	3	611
Thursday	25	327	111	1	27	55	27	0	0	4	577
Friday	26	320	119	6	43	66	26	0	0	1	607
Average	21	307	110	4	37	68	23	0	0	2	572
Std-Dev	4	23	21	3	7	11	3	0	0	1	51
Coef. of Var.	0.20	0.08	0.19	0.64	0.19	0.17	0.13		2.24	0.56	0.09

Percent of Each Class

Ceiba	Class 4	5	6	7	8	9	10	11	12	13
Monday	3.51	55.05	15.88	0.41	8.45	12.16	4.33	0.00	0.00	0.21
Tuesday	2.93	53.45	18.79	0.69	7.07	13.10	3.45	0.00	0.00	0.52
Wednesday	3.27	50.90	21.77	1.15	5.24	13.42	3.60	0.00	0.16	0.49
Thursday	4.33	56.67	19.24	0.17	4.68	9.53	4.68	0.00	0.00	0.69
Friday	4.28	52.72	19.60	0.99	7.08	10.87	4.28	0.00	0.00	0.16

Vehicles Unfiltered Reported and Calculated Error

Arecibo	Class 4	5	6	7	8	9	10	11	12	13	DTT
Monday	754	1375	520	12	450	678	33	5	3	13	3843
Tuesday	741	1383	575	18	451	719	44	8	6	14	3959
Wednesday	704	1381	413	8	460	720	38	5	2	14	3745
Thursday	747	1493	369	12	507	660	27	6	4	16	3841
Friday	909	1424	545	6	518	709	41	6	7	22	4187
Average	771	1411	484	11	477	697	37	6	4	16	3915
STD-DEV	80	50	89	5	33	27	7	1	2	4	170
Coef. of Var	0.10	0.04	0.18	0.41	0.07	0.04	0.18	0.20	0.47	0.23	0.04

Total Error	
Monday	**27.218**
Tuesday	**25.739**
Wednesday	**27.904**
Thursday	**26.399**
Friday	**28.015**
Average	**27.055**

Gurabo	Class 4	5	6	7	8	9	10	11	12	13	DTT
Monday	573	1060	465	11	603	456	54	10	2	14	3248
Tuesday	596	1090	436	23	645	457	91	5	0	28	3371
Wednesday	603	1141	465	17	545	423	62	2	3	8	3269
Thursday	624	1175	394	15	605	429	69	5	4	13	3333
Friday	646	1202	413	12	663	488	79	4	1	19	3527
Average	608	1134	435	16	612	451	71	5	2	16	3350
STD-DEV	28	59	31	5	46	26	14	3	2	8	111
Coef. of Var	0.05	0.05	0.07	0.31	0.07	0.06	0.20	0.57	0.79	0.46	0.03

Total Error	
Monday	**34.144**
Tuesday	**34.411**
Wednesday	**30.56**
Thursday	**34.233**
Friday	**34.023**
Average	**33.474**

Vehicles Unfiltered Reported and Calculated Error

Mayaguez	Class 4	5	6	7	8	9	10	11	12	13	DTT
Monday	287	621	148	5	614	443	54	5	1	19	2197
Tuesday	287	683	163	4	581	469	58	4	2	22	2273
Wednesday	312	719	142	5	614	508	63	5	1	12	2381
Thursday	300	703	155	9	614	470	58	8	5	17	2339
Friday	327	715	146	8	612	485	64	8	7	16	2388
Average	303	688	151	6	607	475	59	6	3	17	2316
STD-DEV	17	40	8	2	15	24	4	2	3	4	81
Coef. of Var	0.06	0.06	0.05	0.35	0.02	0.05	0.07	0.31	0.84	0.22	0.03

Total Error	
Monday	**47.61**
Tuesday	**40.387**
Wednesday	**41.243**
Thursday	**42.369**
Friday	**43.467**
Average	**43.015**

Peñuelas	Class 4	5	6	7	8	9	10	11	12	13	DTT
Monday	504	376	131	3	208	209	22	8	2	9	1472
Tuesday	664	582	143	2	444	244	35	4	4	12	2134
Wednesday	390	633	170	3	463	300	19	1	4	13	1996
Thursday	476	437	112	2	208	174	20	4	7	11	1451
Friday	586	641	194	2	515	278	31	7	7	16	2277
Average	524	534	150	2	368	241	25	5	5	12	1866
STD-DEV	105	120	32	1	148	51	7	3	2	3	382
Coef. of Var	0.20	0.23	0.22	0.23	0.40	0.21	0.28	0.58	0.45	0.21	0.20

Total Error	
Monday	**46.196**
Tuesday	**57.17**
Wednesday	**47.946**
Thursday	**53.343**
Friday	**54.677**
Average	**51.866**

Vehicles Unfiltered Reported and Calculated Error

Guayama	Class 4	5	6	7	8	9	10	11	12	13	DTT
Monday	208	348	64	1	242	148	26	7	5	5	1054
Tuesday	127	304	53	1	201	138	27	5	3	7	866
Wednesday	174	368	81	0	199	135	17	7	6	10	997
Thursday	163	346	60	2	219	110	19	6	6	8	939
Friday	220	370	78	1	242	136	21	3	3	8	1082
Average	178	347	67	1	221	133	22	6	5	8	988
STD-DEV	37	27	12	1	21	14	4	2	2	2	87
Coef. of Var	0.21	0.08	0.18	0.71	0.10	0.11	0.20	0.30	0.33	0.24	0.09

Total Error	
Monday	**37.002**
Tuesday	**34.642**
Wednesday	**34.002**
Thursday	**36.848**
Friday	**37.523**
Average	**36.003**

Salinas	Class 4	5	6	7	8	9	10	11	12	13	DTT
Monday	665	234	128	1	1339	275	336	21	27	645	3671
Tuesday	807	207	68	15	733	190	201	0	19	427	2667
Wednesday	590	374	160	24	1220	393	350	13	24	614	3762
Thursday	538	251	135	21	970	288	359	0	24	690	3276
Friday	634	421	142	24	1003	369	311	11	23	555	3493
Average	647	297	127	17	1053	303	311	9	23	586	3374
STD-DEV	102	94	35	10	235	81	64	9	3	102	437
Coef. of Var	0.16	0.32	0.28	0.57	0.22	0.27	0.21	1.00	0.12	0.17	0.13

Total Error	
Monday	**82.73**
Tuesday	**81.477**
Wednesday	**74.242**
Thursday	**79.64**
Friday	**71.6**
Average	**77.938**

Vehicles Unfiltered Reported and Calculated Error

Ceiba	Class 4	5	6	7	8	9	10	11	12	13	DTT
Monday	101	273	78	5	407	65	23	3	5	2	962
Tuesday	114	326	112	8	370	93	24	2	8	6	1063
Wednesday	107	322	135	13	364	100	27	6	3	6	1083
Thursday	115	333	113	11	402	68	33	9	5	8	1097
Friday	114	328	120	13	439	81	35	8	2	2	1142
Average	110	316	112	10	396	81	28	6	5	5	1069
STD-DEV	6	25	21	3	30	15	5	3	2	3	67
Coef. of Var	0.05	0.08	0.19	0.35	0.08	0.19	0.19	0.54	0.50	0.56	0.06

Total Error	
Monday	**49.584**
Tuesday	**45.437**
Wednesday	**43.583**
Thursday	**47.402**
Friday	**46.848**
Average	**46.571**

APPENDIX I

Development of Weigh Probability Distribution, ESAL, and T_f

Mayagüez and Gurabo

Mayagüez Station

Fitting Cumulative Distribution for Underloaded Trucks Class 9

$$F(w_1) = \exp\left(2.063392 - \frac{195594.259}{w_1}\right)$$

Probability Density Function (PDF) for Underloaded Trucks Class 9

$$f(w_1) = \frac{190637.679337}{w_1^2}\exp\left(2.063392 - \frac{195594.259}{w_1}\right)$$

Expected Value

$$\int_{5000}^{96000} f(w_1) w_1 dw_1 = 69{,}690 lbs$$

Fitting Cumulative Distribution for Overloaded Truck Class 9

$$F(w_2) = \left(-3.2797 + 3.7378 * 10^{-15} * w_2^3\right)^{1/2}$$

Probability Density Function (pdf) for Overloaded Truck Class 9

$$f(w_2) = \left(\frac{6.5308095157 * 10^{15}}{\left(-3.2797 - 3.7378 * 10^{-15} * w_2^3\right)^{1/2}}\right) w_2^2$$

Expected Value

$$\int_{96{,}000}^{105{,}000} w_2 f(w_2) d(w_2) = 99{,}510 lbs$$

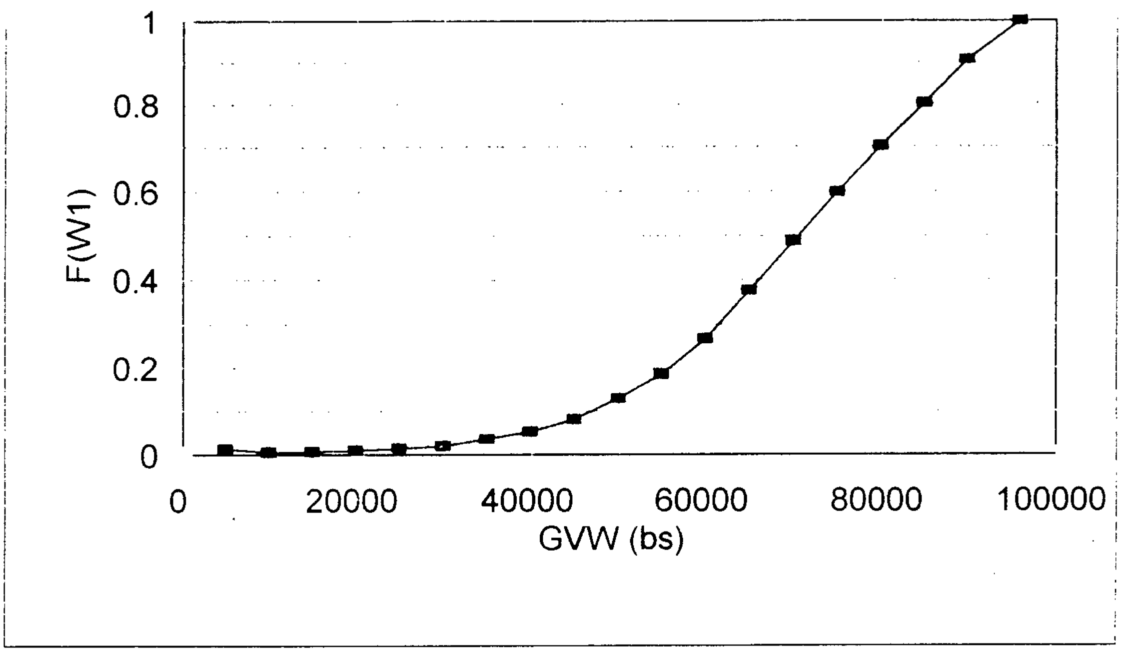


Figure 1 Cumulative Distribution for Underloaded Truck Class 9 (3S-2) for Mayagüez WIM Station

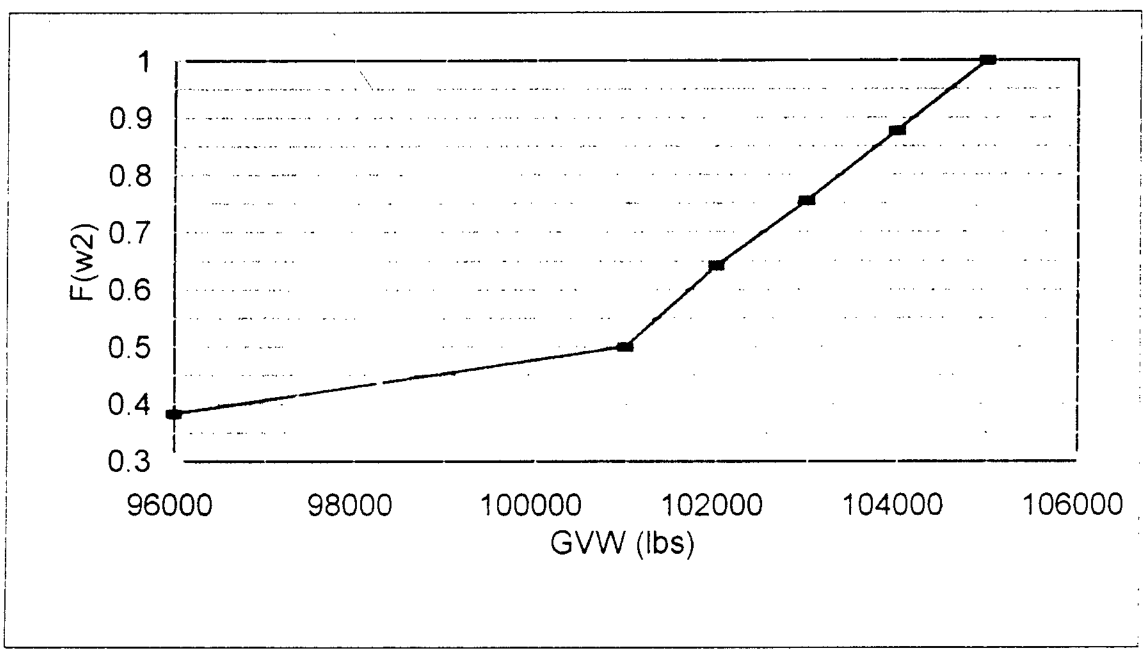


Figure 2 Cumulative Distribution for Overloaded Truck Class 9 (3S-2) for Mayagüez WIM Station

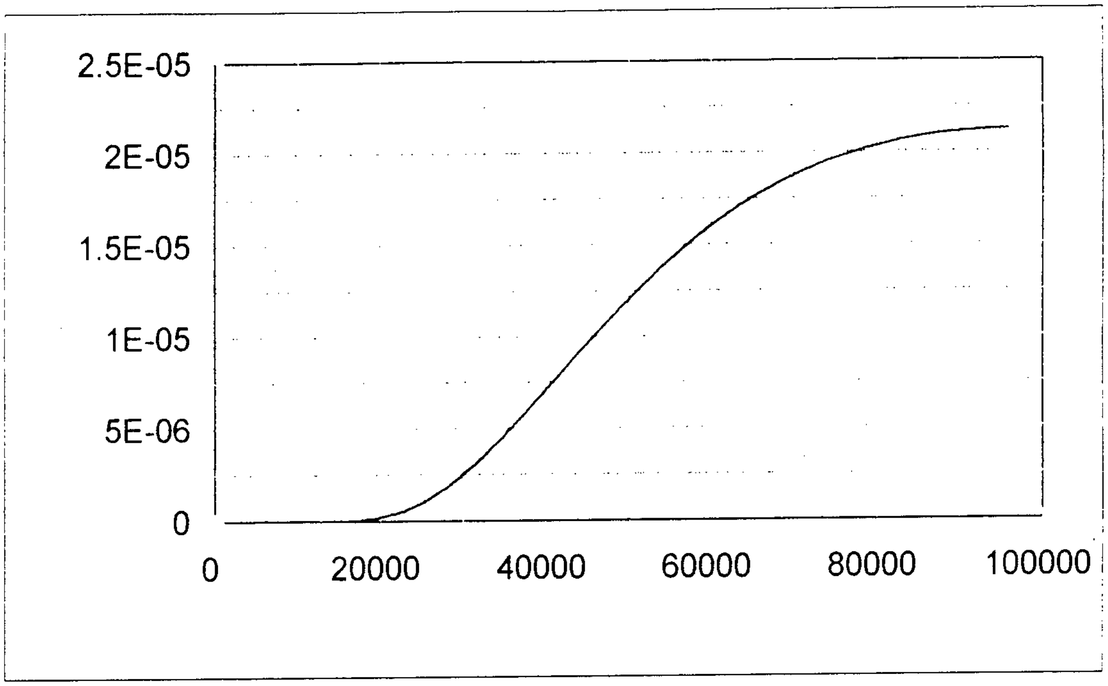


Figure 3 Weigh Probability Density Distribution for Underloaded Truck Class 9 (3S-2) for Mayagüez WIM Station

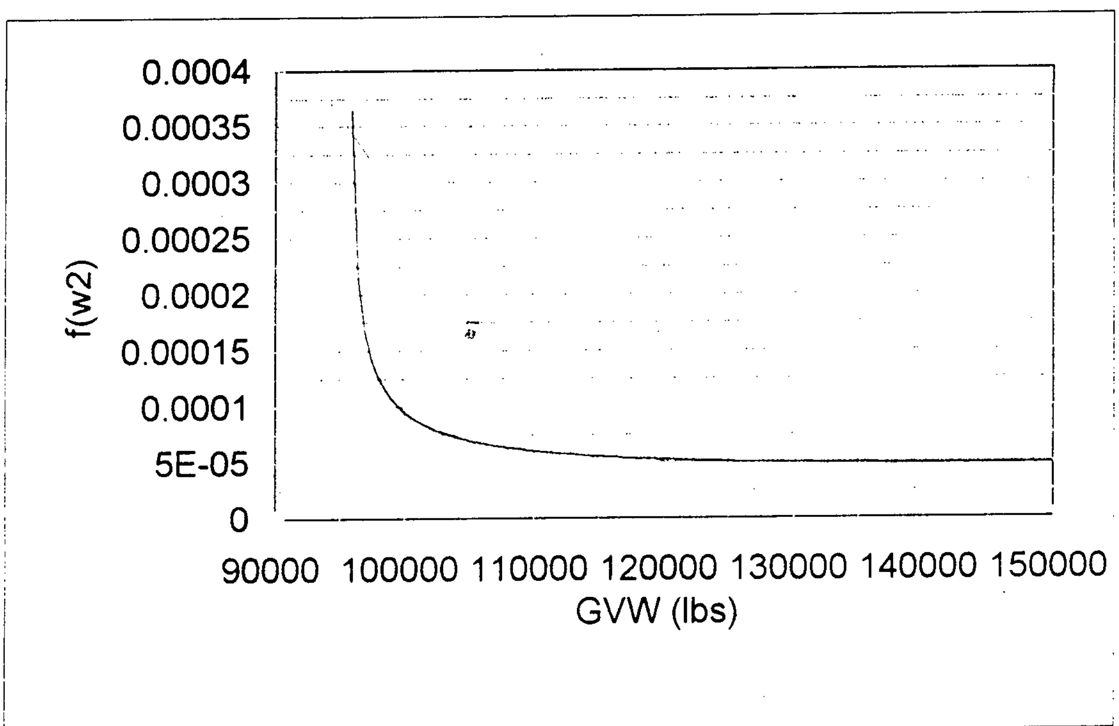


Figure 4 Weigh Probability Distribution for Overloaded Truck Class 9 (3S-2) for Mayagüez WIM Station

Regression Model:

$$Y_{9} = \exp\left(9074.0028x_1^{0.7} - 2.262139 * 10^{4} x_2^{0.7} - 0.00828x_1x_2^{1.5} + \varepsilon\right)$$

The following table shows the data that was used to develop non-linear regression model, and the estimated ESAL and Truck Factor for Mayagüez Station.

Table 1 Data Used for Non Linear Regression Model for Mayagüez Station

Date	TT/Lane	Pr{Type Truck}	Sj	Ej	Nj	K1j	K2j	W1j	W2j	X1	X2	Observed Esal	Estimated Esal	Estimated Tf
1-Apr	884	0.2246	199	0.1596	0.8404	167	32	69690	99510	11.6286	3.1528	680.071	512.430	2.5809
2-Apr	1991	0.2246	447	0.1596	0.8404	376	71	69690	99510	26.1906	7.1010	2166.268	2597.842	5.8094
3-Apr	2127	0.2246	478	0.1596	0.8404	401	76	69690	99510	27.9796	7.5860	2269.62	2190.403	4.5851
4-Apr	2207	0.2246	496	0.1596	0.8404	417	79	69690	99510	29.0320	7.8714	2310.683	1904.341	3.8418
5-Apr	1065	0.2246	239	0.1596	0.8404	201	38	69690	99510	14.0095	3.7984	673.635	956.702	3.9996
6-Apr	644	0.2246	145	0.1596	0.8404	122	23	69690	99510	8.4715	2.2969	37.908	178.760	1.2359
7-Apr	1970	0.2246	442	0.1596	0.8404	372	71	69690	99510	25.9144	7.0261	2064.116	2647.307	5.9832
8-Apr	942	0.2246	212	0.1596	0.8404	178	34	69690	99510	12.3915	3.3597	1379.333	635.668	3.0045

Gurabo Station

The Empirical Cummulative Distribution for Underloaded Trucks Class 9

$$F(w_1) = \exp\left(0.7424 - \frac{2.0558 * 10^7}{w_1^{1.5}}\right)$$

Probability Density Function (PDF) for Underloaded Trucks Class 9

$$f(w_1) = \frac{29284900.2849}{w_1^{2.5}} \exp\left(0.7424 - \frac{20558000}{w_1^{1.5}}\right)$$

Expected Value

$$\int_{5000}^{96000} f(w_1) w_1 dw_1 = 60,960 lbs$$

The Cumulative Distribution for Overloaded Truck Class 9

$$F(w_2) = 7.215908698 - \frac{2.1149 * 10^8}{w_2^{1.5}}$$

Probability Density Function (PDF) for Overloaded Truck Class 9

$$f(w_2) = \frac{354848993.288}{w_2^{2.5}}$$

Expected Value

$$\int_{96,000}^{105,000} w_2 . f(w_2) d(w_2) = 100,400 lbs$$

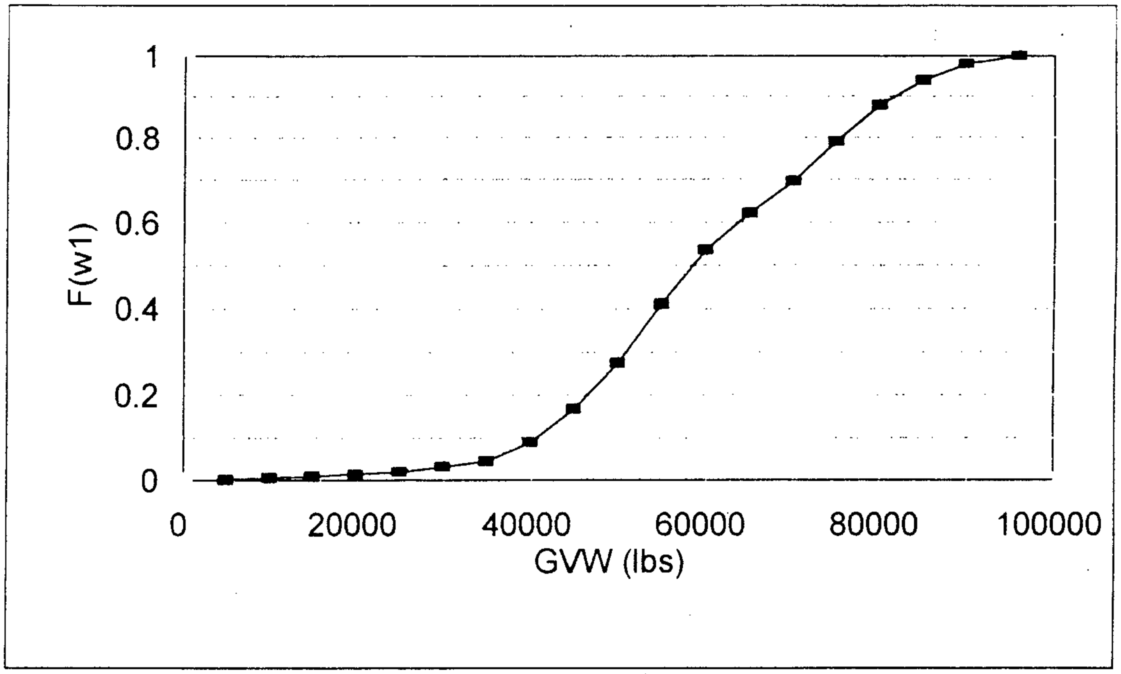


Figure 5 Cumulative Distribution for Underloaded Truck Class 9 (3S-2) for Gurabo WIM Station

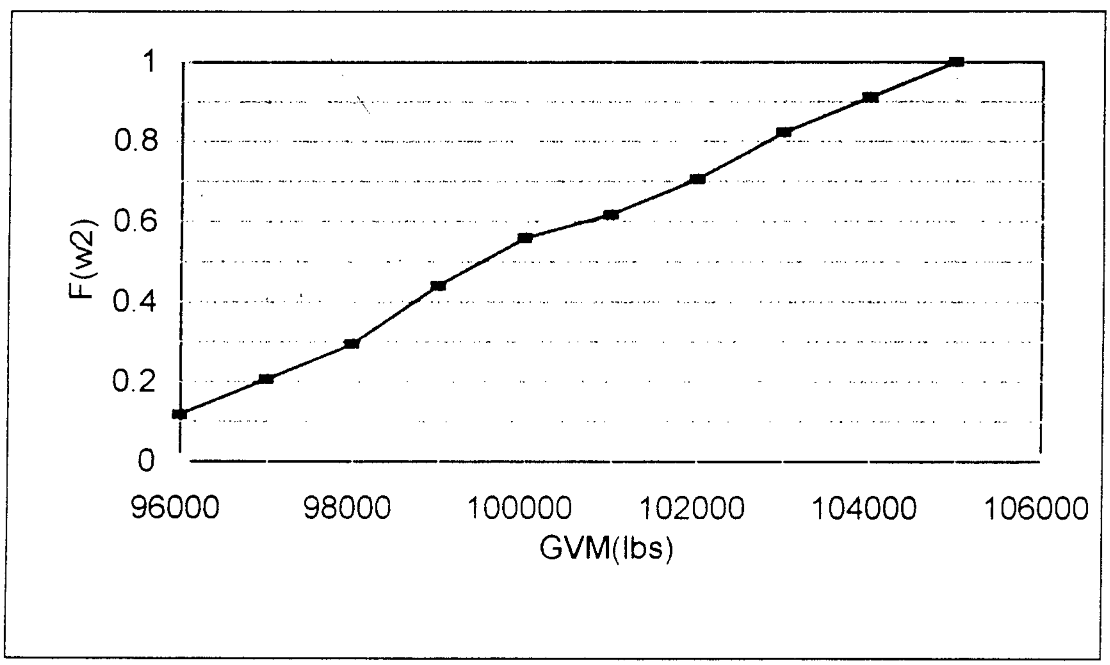


Figure 6 Cumulative Distribution for Overloaded Truck Class 9 (3S-2) for Gurabo WIM Station

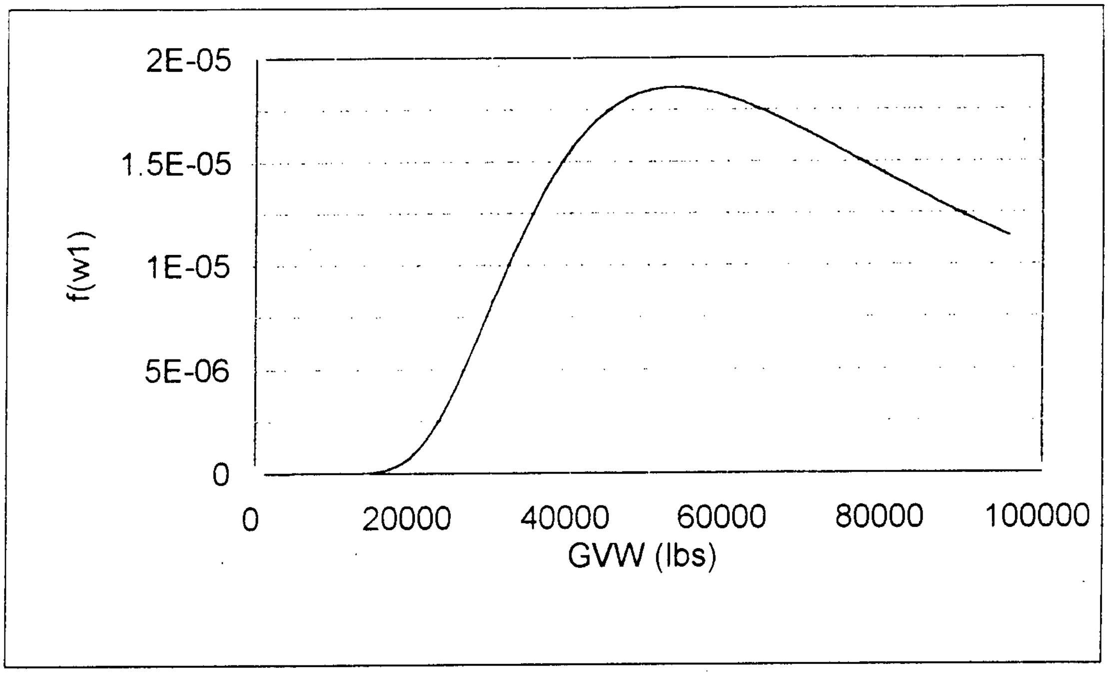


Figure 7 Weigh Probability Density Distribution for Underloaded Truck Class 9 (3S-2) for Gurabo WIM Station

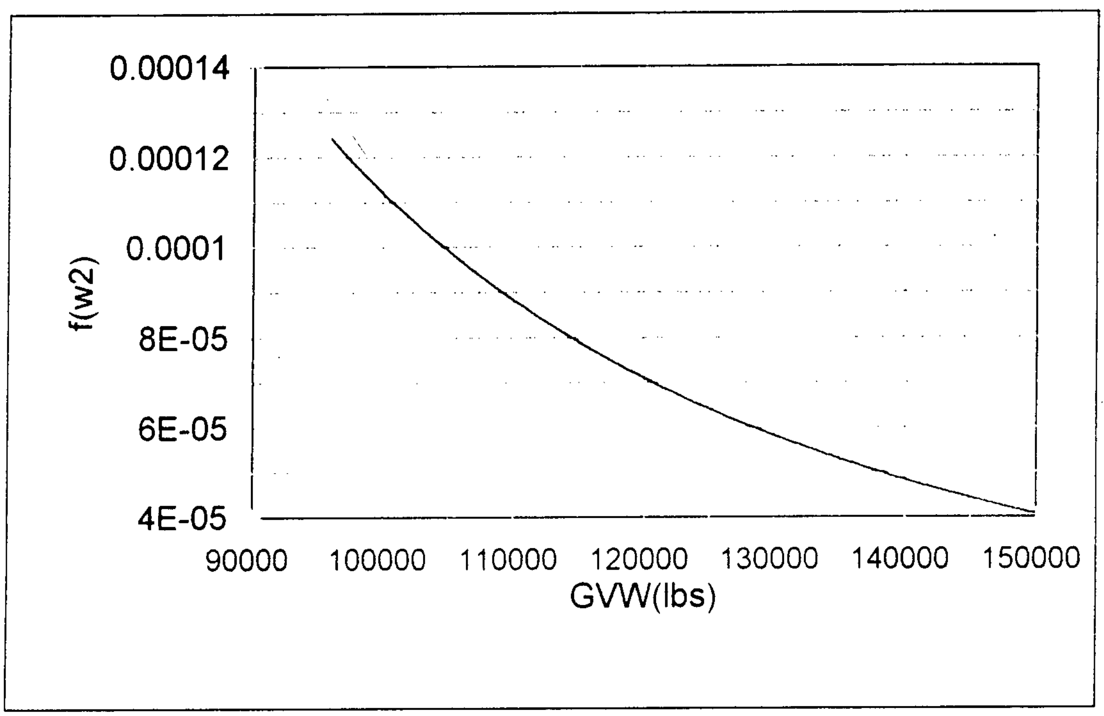


Figure 8 Weigh Probability Distribution for Overloaded Truck Class 9 (3S-2) for Gurabo WIM Station

Regression Model:

$$Y_9 = 3.412929x_1^{0.7} - 36.416737x_2^{0.7} - 0.007496x_1x_2^{1.5} + \varepsilon$$

Table 2, shows the data that was used to developed non linear regression model, and the estimated ESAL and Truck Factor for Gurabo Station.

Table 2 Data Used for Non Linear Regression Model for Gurabo Station

Date 4-97	TT Lane	Pr(Type Truck)	Sj	Ej	Nj	K1j	K2	W1j	W2j	X1	X2	Observed ESAL	Estimated ESAL	Estimated T_f
3	4277	0.22	941	0.015	0.984	926	15	60960	100400	56.456	1.5062	915.275	2357.3	2.51
4	13271	0.22	2920	0.015	0.984	2874	46	60960	100400	175.21	4.6187	898.891	856.5	0.29
5	1190	0.22	262	0.015	0.984	258	4	60960	100400	15.719	0.4014	271.803	58.3	0.22
6	677	0.22	149	0.013	0.986	147	2	60960	100400	8.9592	0.2008	141.402	49.4	0.33
7	2719	0.22	598	0.015	0.984	589	9	60960	100400	35.923	0.9040	859.742	1676.4	2.80
8	2787	0.22	613	0.016	0.983	603	10	60960	100400	36.774	1.0044	775.416	233.6	0.38
9	2714	0.22	597	0.015	0.984	588	9	60960	100400	35.856	0.9039	812.863	1594.4	2.67