EVALUATION OF TXDOT'S TRAFFIC DATA COLLECTION AND LOAD FORECASTING PROCESS

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16. Abstract

This study had two primary objectives: 1) compare current Texas Department of Transportation (TxDOT) procedures and protocols with the state-of-the-practice and the needs of its data customers; and 2) develop enhanced traffic collection, archival, analysis, forecasting, and reporting methodologies. TxDOT has been concerned about the process, consistency, accuracy, and timeliness of traffic load forecast estimates for pavement design. Elements not adequately accounted for in TxDOT's traffic load forecasting process included overweight vehicles, special permits, super single tires, and spread axles. There was also concern about adopting a proposed process for determining pavement damage based on load spectra as opposed to equivalent single axle loads. The research included a literature review and an evaluation of state-of-the-practice for traffic data collection equipment, data collection and archiving protocols, forecasting methodologies, and reporting methods.

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GLOSSARY

Axle	A shaft on which or with which two or more wheels on a vehicle revolve.
Axle Set	Two or more consecutive axles considered a single unit in determining their combined load effect on bridge or pavement structures.
ESAL	The damage per pass to a pavement caused by a specific axle load relative to the damage per pass of a standard 18,000 pound axle load moving on the same pavement.
Axle Load	The weight carried by one axle of a vehicle.
Axle Spacing	The distance between two consecutive axles of a truck or combination, usually measured from the point of ground contact of one tire to the same point on the other tire or from a point on an axle hub to the same point on the other axle hub.
Flexible Pavement	Road construction of a bituminous material, generally asphalt, which has little tensile strength.
Gross Weight	The weight of a vehicle and/or vehicle combination together with the weight of its load.
Overweight	Over the federal or state legal restrictions for single axle weight, tandem axle weight, or gross weight.
Rigid Pavement	Road construction of Portland cement concrete.
Semitrailer	A vehicle designed for carrying persons or property and drawn by another vehicle on which part of its weight and load rests.
Single Axle	An axle on a vehicle that is separated from any previous or succeeding axle by more than 96 inches.
Single Axle Weight	The total weight transmitted by all wheels whose centers may be included between two parallel transverse vertical planes 40 inches apart, extending across the full width of the vehicle.
Spread Tandem	Two axles that are articulated from a common attachment but are considered as two single axles rather than one tandem axle because they are separated by more than 96 inches.

GLOSSARY (Continued)

Steering Axle	The axle to which a vehicle's steering mechanism is affixed.
Tandem Axle	Two consecutive axles that are more than 40 inches but not more than 96 inches apart and are articulated from a common attachment.
Tandem Axle Weight	The total weight transmitted to the road by two or more consecutive axles whose centers may be included between parallel vertical planes spaced more than 40 inches and not more than 96 inches apart, extending across the full width of the vehicle.
Tractor	A vehicle designed and used primarily as the power unit for drawing a semitrailer or trailer.
Trailer	A vehicle without motive power designed to be drawn by another vehicle and so constructed that no part of its weight rests upon or is carried by the pulling unit.
Truck	A motor vehicle designed, used, or maintained primarily for the transportation of property.
Vehicle	Any conveyance of any type operated on a highway, whether self-propelled or drawn by another vehicle.
Weigh-in-Motion	An electronic system with pavement sensors that allows vehicle weights to be electronically recorded as the vehicle passes over the sensors without stopping.

CHAPTER 1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this study is to evaluate TxDOT's state-of-the-practice in traffic data collection and load forecasting for pavement design, identify shortcomings, and recommend improvements.

1.2 BACKGROUND

The American Association of State Highway Officials (AASHO) (now American Association of State Highway and Transportation Officials (AASHTO)) Road Test (1958 to 1960) evaluated the effects of axle loads and configurations on bridge and pavement performance *(1)*. The test dealt with flexible and rigid pavements and short-span bridges. Test vehicles traveled 16 million miles *(2)*, applying over 1.1 million equivalent single axle loads to each test section *(3)*. Test vehicles used both single and tandem axles forming 10 different axle arrangements *(1)*. Steering axle loads in the road test ranged from 2000 lb to 12,000 lb, single axle loads ranged from 2000 lb to 30,000 lb, and tandem axle loads ranged from 24,000 lb to 48,000 lb *(2)*. The *AASHTO Pavement Design Manual*, originally published in 1961, resulted from these tests, and subsequent pavement response research yielded revisions to this manual.

Both the frequency of truck loadings and truck weights have increased since the AASHO Road Test, and trucks are operating with significantly higher tire inflation pressures today *(3)*. The increase in trucks resulted from economic development, recent trade agreements, and successful competition with railroads for transporting goods. The increase in loads resulted from increases in legal weight limits since the time of the AASHO Road Test. Also, there are probably more overweight trucks on the transportation system due to agricultural and industrial exemptions and the presence of Mexican-registered trucks close to the border due to the North American Free Trade Agreement (NAFTA). Mexican trucking regulations allow higher single-axle load limits than Texas regulations allow. According to the U.S. Customs Service, from 1990 through 1999, the number of trucks crossing the Texas border from Mexico increased by an average of 19 percent per year. In 1999 alone, over 2.29 million trucks entered Texas from Mexico. This total reflects a daily average of 6274 trucks per day that entered the United States through Texas ports of entry *(4)*. As NAFTA creates new opportunities for international traffic, Texas highways will be subjected to additional truck traffic, some with higher axle and gross vehicle weights than are being seen today. Bridge and pavement engineers need better traffic load data to design new infrastructure and maintain the current infrastructure not designed to handle these increased loads.

With the advent of radial truck tires, inflation pressures have increased dramatically since the AASHO Road Test. There is now widespread use of radial tires because of their reduced rolling resistance, resulting in increased fuel mileage. New axle configurations and suspensions have increased truck load capacities. The AASHO equations do not account for the newer axle configurations (tridems, quads, and spread tandem axles) or lift axles that may not actually carry their share of the load. The fundamental question being asked by pavement designers today pertains to whether pavements are being under-designed or over-designed.

Several questions concerning the validity of the AASHO Road Test results have surfaced over the past 10 years. These questions not only center around the procedures and assumptions used to develop the pavement response equations, but also how changes in materials and equipment over time affect pavement performance. Also, advances in pavement engineering, traffic data collection, and traffic data analysis practices combined with changes in trucks hauling loads throughout the state and other traffic characteristics have created a need to revisit procedures used in TxDOT's traffic load forecasting process.

Optimum pavement design requires accurate and consistent traffic loading forecasts. Over the years, several deficiencies have been noted in the methods for collecting, analyzing, forecasting, and reporting traffic loads. Some deficiencies are:

- accounting for trends in transport technology such as super-single tires and the growing trend of spread-axle tandem trailers to increase axle loadings,
- accounting for the damaging effects of overloaded vehicles,
- enhancing forecasting capabilities such as forecasting trends by vehicle type,
- accounting for directional and lane distributions,
- improving correlations and consistency between the various vehicle classification systems (automatic and manual) and weigh-in-motion (WIM) systems,
- ensuring consistency between project-specific and statewide traffic load forecasts,
- improving the accuracy of traffic load forecasts, and
- using different design vehicle parameters for pavement and bridge design.

1.2.1 Traffic Load Data Collection

The accuracy of a traffic load forecast depends upon when and where truck weight data are collected. The procedures recommended in the *Traffic Monitoring Guide* (TMG) *(5)* provide system estimates. The TMG suggests that over a three-year period vehicle classifications (i.e., truck volume and type) should be randomly collected at 300 sites statewide, and that truck weights be randomly collected at 90 sites. These sites should be selected from the existing stratified random sample data collection sites in the Highway Performance Monitoring System (HPMS). Vehicle classification sites should be allocated throughout the HPMS sample strata by type of area, functional class, and volume groups based on the proportion of average vehicle distance traveled (AVDT) on those systems relative to other systems. The truck weighing sites are a subset of the vehicle classification sample, stratified by interstate (30 sites) and all other roads (60 sites), and allocated by annual vehicle distance traveled.

The basic processes involved in developing a pavement design year forecast include traffic load data collection, data archival, data analysis, forecasting, and reporting. The overall process is quite complex, requiring many different individuals who are members of different TxDOT divisions. Because of its complexity, it is likely that no one individual within the Transportation Planning and Programming Division (TPP) has a thorough working knowledge of all aspects of the process. Districts and other divisions know very little about the process. Therefore, there is a compelling need for an information source to assist in improving inter-departmental understanding to improve the effectiveness of the pavement design year forecast. One of the deliverables produced by this research is a Traffic Data Request Guide that is intended to fulfill this very need.

The pavement design process converts mixed traffic to an equivalent number of applications of the standard 18 kip single-axle load or equivalent single axle loads (ESALs) and load equivalence factors (LEFs). Pavement designers require this information to design pavements using the Texas Flexible Pavement System (FPS). The accuracy of these estimates is critical to the pavement design process. An inaccurate estimate may lead to an under-designed pavement that will fail prematurely or to an over-designed pavement that is not the most cost-effective use of limited funds. District personnel have expressed concerns about the accuracy, consistency, and timeliness of the 18 kip ESAL estimates used in TxDOT's traffic reporting system. In response to this need, TPP has now conducted two comprehensive surveys to determine how well its products and services meet the needs of its customers. TTI completed the first extensive interviews with TxDOT district, division, and administrative staff between 1989 and 1991. All of the interviewees thought that more resources (both labor and equipment) should be dedicated to the collection, analysis, and reporting of traffic data *(6)*. TTI conducted a second set of interviews as part of this research; findings are provided in Chapter 3 of this document.

1.2.2 Traffic Load Data Archival

Weight data collection from WIM sites currently occurs once each quarter. TxDOT then stores the data for further processing and reporting. It uses these point samples to derive system-wide traffic load estimates and for project-specific pavement design. Current WIM equipment used by TxDOT has the ability to continuously record traffic and store it for later use.

Daily traffic load information could provide many benefits to TxDOT. The department could use daily, weekly, monthly, or quarterly trends much like it currently uses the continuous Automatic Traffic Recorder (ATR) data for traffic volumes. If TxDOT collects and stores continuous WIM data, it must prepare for the large amount of data that will result.

1.2.3 Traffic Load Analysis

The two primary components of traffic data that TxDOT uses in the traffic load process are vehicle classification and weight. TxDOT does not have any rigorous analysis processes for reviewing either weight or classification data. TPP conducts a preliminary review of manual classification data to prevent gross errors by comparing with historical trends. TPP is working to remove inconsistencies in automated classification data through improvements in their automated equipment algorithms. TPP does little office analysis on weight data, simply reviewing the data for anomalous events, then forwarding it for use in the traffic load forecasting processes.

1.2.4 Traffic Load Forecasting

TxDOT uses a computer program, RDTEST68, to calculate the total ESAL and the design lane ESAL forecasts for pavement design. The base year Average Daily Traffic (ADT) comes from volume counts near the project site. ADT is the only input variable that varies through the design period. The "percent truck" factor comes from vehicle classification data collected at or near the project location or from sites on roadways with similar characteristics. Design assumes the truck factor to remain constant through the design period (i.e., total traffic and truck traffic grow at the same rate) *(7)*.

The RDTEST68 program creates axle weight distribution tables for each permanent WIM station, and it also creates a combined statewide average. The process uses the most recent distribution table of a particular WIM station if the station is located on the same roadway as the project. It uses the statewide distribution if no WIM stations exist on the project roadway. The selection of a representative axle weight distribution table to represent the traffic load pattern at a particular highway segment is critical.

In TxDOT research project 0-1235, TTI identified the key assumptions for the TxDOT traffic forecasting model as follows *(7)*:

- annual traffic growth follows a linear model,
- percent trucks remains constant over the design period,
- the truck traffic stream makeup remains constant over the design period, and
- the average load equivalency factor per truck remains constant over the design period.

1.3 OBJECTIVES

This study had two primary objectives: 1) compare current TxDOT procedures and protocols with the state-of-the-practice and the needs of its data customers; and 2) develop enhanced traffic collection, archival, analysis, forecasting, and reporting methodologies.

1.4 ORGANIZATION OF THE REPORT

This research report consists of nine chapters organized by topic. Chapter 2 provides a summary of the literature findings conducted at the beginning of this research. Chapter 3 presents the results of an extensive customer needs assessment with TxDOT districts, divisions, and the Department of Public Safety regarding the use and expectations of traffic and project-level data supplied by the Transportation Planning and Programming Division. Chapter 4 details the TxDOT traffic load forecast process, from data collection procedures to computer forecasting programs. Chapter 5 presents several discussions regarding considerations for changing forecasting processes. These discussions include growth of a unique truck configuration and its impacts to forecasting, trends in overweight trucks, and effects of steering axles. Chapter 6 covers issues in accommodating continuously collected weight data, from data storage requirements to database environments. Chapter 7 presents the national traffic load forecasting state-of-the-practice covering data collection equipment and processes, as well as forecasting procedures from several states. Chapter 8 discusses the results of interviews with state transportation departments regarding their use of geographic information systems (GIS) in their traffic load forecasting process. Finally, Chapter 9 presents the conclusions and recommendations developed from this research for each phase of the load forecast process.

CHAPTER 2.0 LITERATURE FINDINGS

2.1 INTRODUCTION

The need for accurate, consistent, and timely traffic load collection and forecasting is a critical issue in the design and maintenance of roadways. More specifically, this type of information has varying degrees of importance in the cost-effective design of pavements and bridges. Pavement design life may be 20 to 30 years, whereas bridges may be designed for a 50-year or longer life. The actual service life of these structures depends on the traffic loading applied to them over their life. An important consideration in design is the forecasted traffic loading expected to be applied over the facility's design life. Pavement design utilizes traffic loading by axles of different weights and/or configurations equated to an 18,000 lb single-axle reference *(7)*. This reference measures pavement stress in terms of this reference axle through ESALs. One ESAL is a single-axle load with dual tires inflated to 70 psi at a weight of 18,000 lb *(3)*.

The purpose of pavement design is to develop a pavement that can withstand the repeated application of variable loading. The primary loading factors *(8)* that are important in pavements are magnitude of axle loads, volume and composition of axle loads, and tire pressure and contact area. Legal limits commonly control the magnitude of maximum loading, with exemptions allowed to exceed the statutory maximum loading. Traffic load forecasting uses traffic data collection, including coverage counts, vehicle classifications, and weight, to predict the relative magnitude and frequency of the various loading to which a pavement will be subjected. The accurate prediction of the total traffic that will use the facility is difficult but very important to the task of pavement design.

The Federal Highway Administration's *Traffic Monitoring Guide (5, 9)* espouses requirements pertaining to traffic monitoring on the nation's highways. These requirements pertain to both the number of sites to be monitored in each state and the accuracy requirements of the equipment. The guidelines presented in the TMG represent minimum specifications, which can be expanded and supplemented to any degree desired by the states. It promotes the use of portable automatic equipment as the most effective means of achieving statistical validity. The TMG states that the truck weight sample must consist of 90 measurements taken over a three-year cycle, with one-third of the sample being taken from the Interstate system.

2.2 METHODOLOGY

Research staff conducted a comprehensive literature search to identify publications concerning the improved systems for traffic data collection and the state-of-the-practice for traffic load data processes. This search, using key words and phrases, encompassed the following catalogs and databases: Texas A&M University's Sterling C. Evans Library NOTIS (the local library database), Wilson's Periodical Database, FirstSearch, National Technical Information System (NTIS), and Transportation Research Information Service (TRIS). Key words and key-word combinations served as input to conduct a systematic search of the above databases. Some of the key words and key-word combinations included: traffic data collection, data collection protocols, traffic loads, traffic load reporting, truck loads and pavement wear, truck weighing methods, trucks weights and pavement wear, weigh-in-motion, bending plate, portable weigh scales, weight data, traffic load forecasting, traffic load analysis, and traffic load estimates. In addition, researchers searched various web sites and reviewed ongoing TxDOT projects relevant to the proposed study.

2.3 FINDINGS

Pavement design requires the collection of truck volumes, classifications or axle spacing, and weight data. Bridge design depends upon selection of a design vehicle (e.g., HS-20); however, researchers anticipate that bridge fatigue performance could be forecast more accurately with improved histories of vehicular loading. Traffic data collection equipment can be grouped by its intended use. In general, there are traffic volume counters, vehicle classifiers, and WIM systems; however, almost every piece of traffic data collection equipment collects some combination of traffic volumes, vehicle classifications, and/or weight information.

In the context of this study, agencies generally purchase data collection equipment to conduct vehicle counts, vehicle classification, or vehicle weighing. Most of the current equipment used for this purpose involves sensing elements mounted either on top of or within the upper pavement layer. This requires significant traffic disruption for installation and maintenance activities. Examples of these sensing elements are inductive loop detectors, magnetometers, and piezoelectric cables. Another category of detectors is being developed to achieve a lower threshold of interference, some of which have the capability of either counting or classifying (or both) vehicles passing a point on the roadway. These are thought of as "non-intrusive" sensors, and a select few of them are applicable to the type of data collection typically done for or by state departments of transportation for purposes of infrastructure preservation.

Intrusive data collection equipment has been used for much longer than non-intrusive equipment, with the lack of maturity being a major source of apprehension for purchase of the latter category. The newer equipment deserves attention because promising technologies and specific products can already be useful to state and local agencies in achieving their data collection goals. Furthermore, researchers anticipate that the accuracy and life span of these new devices will improve over time. A discussion follows which will serve as a synopsis of available information on alternatives to intrusive detection. Its organization follows the three major types of information desired to be collected: vehicle counts, vehicle classifications, and vehicle weights. Non-intrusive detectors only apply to the first two. Many detectors also have the capability of monitoring vehicle speeds, with varying degrees of accuracy.

This chapter shows model names for equipment highlighted in *italics*. This characterization allows readers to easily identify when specific types of equipment and documentation about that equipment are being discussed.

2.3.1 Vehicle Count and Classification Equipment

2.3.1.1 Intrusive Data Collection Equipment

Equipment used to count traffic volumes and classify vehicles is very similar. In many cases, the only differences are the layout of the sensors on the roadway and user-selectable inputs in the data collection electronics unit. Agencies typically use portable traffic volume counters for short-term data collection that require a single-axle sensor. These devices can count all traffic on a roadway or an individual lane, depending on how the installer configures the sensors. The road component may consist of pneumatic tubes or other types of sensors (i.e., piezoelectric film or cable, tape switches, inductive loops, and magnetometers).

Vehicle classification systems currently fit the "intrusive" category, and they can be either permanent or portable. They utilize inductive loops, piezoelectric sensors, or a combination of the two sensor types *(10)*. In any case, a minimum of two sensors sends detections to a data collection and storage unit at the roadside. Most classifier systems generate their most accurate data by using a combination of both piezoelectric and inductive loop detectors. This means either two piezoelectric sensors and one inductive loop (preferred) or two inductive loops and one piezoelectric sensor. The standard FHWA classification scheme requires measurement of axle spacing, requiring an axle sensor (e.g., piezo). Inductive loops provide presence. Automatic vehicle classification (AVC) sites store vehicle classification information for specific lanes (e.g., Strategic Highway Research Program (SHRP) sites) or for each lane of an entire roadway.

Pneumatic Tubes. Pneumatic tubes are hollow rubber tubes stretched across the portion of the roadway for collecting vehicle count and/or speed data. One end of the tube connects to a traffic counter/classifier with the other end plugged to prevent air leakage as a vehicle crosses the tube. As a vehicle passes over the tube, its tires compress the tube, actuating an air pressure transducer on the classifier. This means that pneumatic tubes operate in pulse mode only. Tubes are relatively inexpensive, and installation is quick and easy. These tubes, typically 0.5 inch in diameter, are relatively accurate for light traffic flows, but they damage easily.

Inductive Loop Detectors. The inductive loop consists of one or more turns of insulated loop wire installed in a shallow slot that is sawed in the pavement, a lead-in cable, and a detector electronic unit. A characterization of induction is producing a change in a body without physical contact with the body *(11)*. Electrical induction in a traffic signal system consists of a detector unit that passes a current through the stranded loop wire, thereby creating an electromagnetic field around the wire. Moving a conductive metal object, such as a vehicle, through this field disturbs the electromagnetic field, producing a change in energy level. As the vehicle enters the electromagnetic field of the loop, it causes a decrease in the inductance of the loop and an increase in the oscillation frequency. The inductive loop detector, which was introduced in the 1960s, continues today as the most commonly used form of detector, even though its weaknesses are widely recognized.

Proper installation of the loop in the road surface is important to improve the reliability of the system. Some pavement surfaces, such as bridge decks, preclude the saw cutting necessary to install permanent inductive loop detectors. A primary disadvantage of inductive loop detectors is the expense of relocating or repairing loops after installation. This procedure requires extensive traffic control and results in congestion and motorist delay *(12)*. Detector "cross-talk" and increased pavement stress are two additional disadvantages of inductive loop detector systems. There are also several adverse conditions that affect the operation of inductive loops, including high voltage power lines under the pavement, a pavement subsurface with a high iron content, and unstable pavement conditions. Underground wires, conduit, and pull boxes are susceptible to being damaged by other utility work. Modern detection electronics can overcome the first two conditions, but changing or unstable pavement conditions result in increased inductive loop maintenance costs *(13)*. One advantage of inductive loop systems over some of the non-intrusive alternatives is their ability to operate in all weather and lighting conditions *(12)*.

There are differing opinions on the reliability of inductive loop systems. Some agencies believe that inductive loop technology is the best available, while others have experienced high failure rates *(13)*. Studies on inductive loops revealed that several installation processes needed revision to improve the inductive loop detector's reliability. Improper saw cutting techniques, loop wire splicing, and inadequate loop sealant bonding resulted in loop wire breakage *(14)*.

Given the widespread use of inductive loops throughout the U.S., it is only natural to fully utilize their capabilities and even to further enhance these capabilities. Inductive loops detect "presence" of vehicles. In its typical use, the inductive loop is basically an on-off device, or a switch closure, indicating that a vehicle is either present or not. In conjunction with its companion electronics, a single loop can provide vehicle counts and occupancies, whereas dual loops (often referred to as "traps") can provide speeds and vehicle classification (by length). However, other useful information is available from inductive loops by adding the appropriate hardware and software. These new concepts need to be considered because they add a new dimension to a state or local agency's capabilities in traffic monitoring.

Peek ADR-6000. One of the breakthroughs, which enhance vehicle detector output (formerly called *Idris),* is now available through Peek Traffic. The software enhancement techniques involve several algorithms designed for use in roadside vehicle detection equipment and which may apply to vehicle classification, toll applications, and incident detection. The hardware consists of outstations (consisting of detectors and communications processor), a network manager, and an *Idris* processor linked to a computer. The maximum number of outstations per network manager is 20.

TTI has not tested this system extensively so the following information relies on product brochures. Some promising results occurred from testing with two standard inductive loops per lane. Vehicle count error was only 0.01 percent in free-flowing traffic and only 0.2 percent in congested flow conditions. Available information did not specifically quantify speed and length accuracy, but the vendor claims that both measurements were accurate and consistent for all speeds, regardless of the vehicle's position relative to the sensor. The *Idris* system is sensitive enough to differentiate between tailgating vehicles and towed vehicles, and between two similar vehicles in adjacent lanes versus one vehicle straddling two lanes. When used for incident detection, the vendor claims that the *Idris* can detect a single stopped vehicle anywhere in the roadway, slow-moving traffic, queuing traffic, wrong-way movements, and a slow-moving vehicle in fast-moving traffic. For vehicle classification purposes, the *Idris* can use inductive loops to detect axles instead of using piezoelectric sensors. A recent cost quote for a four-lane system for TxDOT was $24,000 *(15)*.

IVS-2000. The *IVS-2000*, which is available through the U.S. Traffic Corporation, is more than a typical loop amplifier. It operates on the principal that a vehicle passing over an inductive loop generates a complete "loop signature" that contains more information than just an "on" or "off." The shape and magnitude of the signal provides insight into the vehicle type and its speed. According to product brochures, the *IVS-2000* can provide reasonably accurate vehicle classifications without the use of piezoelectric (axle) sensors. Each *IVS-2000* can perform speeds or classifications with either one or two loops. These can be 5-ft square, 6-ft square, or 6-ft diameter round. The classification accuracy is reported to be approximately the same with either one or two loops, at 85 percent to 90 percent. Speed accuracy is reported to be plus-or-minus 10 mph with one loop and plus-or-minus 5 mph with two loops. The *IVS-2000* has a fail-safe mechanism that, when operating on two loops, detects when one loop fails and automatically switches to a one-loop configuration and continues operation.

The *IVS-2000* classifies the traffic stream into 23 categories; the first 13 are the standard FHWA classes. The other 10 classes are vehicles with unique characteristics such as vehicles towing trailers, auto carriers, bobtail tractors, gooseneck trailers, and small buses. These 23 categories can be retained, or they can be customized *(15)*.

Piezoelectric Sensors. Piezoelectric sensors are a film fabricated using a crystalline form of long hydrogen, carbon, and fluoride polymer molecular chains. The crystalline chain produces an electrical charge when a mechanical strain occurs as a result of a vehicle passing over the film *(16)*. In straightforward terms, it is the material's ability to transform mechanical energy into electrical energy; or the sensors' ability to become transducers that make them useful as vehicle detectors. Piezoelectric sensors have been effectively used in vehicle detection, both as axle sensors for vehicle classification and for WIM applications for truck weight data collection and weight enforcement screening (see more detailed discussion below) *(12, 17)*.

Modern vehicle classifiers typically use a combination of piezoelectric sensors and inductive loop detectors to count and classify vehicles in a user-definable classification scheme. Undesirable features of piezoelectric sensors include: weakening of the pavement due to required saw cutting, less than desirable and unpredictable sensor durability, reduction in sensor life due to pavement resurfacing, and sensitivity to moisture penetration if damaged. In recent years, piezoelectric sensors have become more extensively used in the United States.

Magnetometers. A magnetometer typically consists of an intrusive sensor about the size and shape of a small can, a lead-in cable, and an amplifier. The cylinder portion of the magnetometer contains sensor coils that operate in a manner similar to inductive loops. These coils are installed in a small circular hole in the center of each lane and communicate with the roadside by wires or radio link. Magnetometers function by detecting increased density of vertical flux lines of the earth's magnetic field caused by the passage of a mass of ferrous metals, such as a motorized vehicle. They operate in either presence or pulse modes and are embedded in the pavement. Magnetometers require less cutting of the pavement than inductive loop sensors, are easier to install, and can be installed underneath bridge decks without damage to the deck. The disadvantages of magnetometers are similar to those of inductive loop detector systems, in that they sometimes double count trucks and are less likely to detect motorcycles due to the vehicle's small detection zone *(14)*.

2.3.1.2 Non-Intrusive Data Collection Equipment

A number of non-intrusive technologies can also be used for counting traffic volumes and for classifying vehicles. This category of vehicle detectors includes active and passive infrared sensing systems, passive acoustic detectors, ultrasonic detectors, microwave and radar detection systems, automatic vehicle identification systems, and video detection systems *(18)*. The following paragraphs contain a short description of each of these systems and a discussion of advantages and disadvantages of system equipment.

Active Infrared Detection Systems. Active infrared sensors operate by focusing a narrow beam of energy and either measuring the reflected energy or measuring the direct energy disruption by an infrared-sensitive cell. In the first case, one device both sends and receives energy, and interprets the reflected pattern. In the second, energy disruption represents vehicle presence such that detections occur when vehicles pass through the beam and interrupt the signal. The infrared beam can be transmitted from overhead or from one side of the road to the other. Infrared systems can provide information on vehicle height, width, and length, in addition to simple passage of vehicles.

Preliminary testing of active infrared detectors by public agencies indicates very promising results for monitoring vehicle speeds and classifications. TTI tested the *Autosense II* by Schwartz Electro-Optics (SEO) and found it to operate during day/night transitions and other lighting conditions without significant problems. However, its cost of $10,000 per lane may be a deterrent to its use. A second disadvantage of this sensor as compared to most other non-intrusive sensors is the requirement to be placed directly over each lane. This requires lane closure to install and remove the sensor element. Advantages include its ease of setup and generation of data protocols for interpreting its output. Also, it was more accurate in its classification accuracy (based on vehicle dimensions) than another non-intrusive sensor tested *(19)*. Based on information from others, weather conditions that appear to be problematic for this device are heavy fog, heavy dust, and heavy rain. TTI did not encounter any of these conditions during its test period. England uses infrared detectors extensively for both pedestrian crosswalks and signal control. The San Francisco-Oakland Bay Bridge uses infrared detection systems to detect presence of vehicles across all five lanes of the upper deck of the bridge *(20)*.

In contrast to the *SEO ASII*, which monitors and measures vehicle dimensions, the *Autosense IIA* counts axles. Installation of the *IIA* is above and to the side of each lane being monitored so that its field of scan includes a side view of the vehicle and its axles. TTI has not tested this version of the *Autosense* line of detectors, so the following accuracy information relies solely on product brochures. Early testing in November 1998 and during the first quarter of 1999 indicates axle counting accuracy of 95 percent. The manufacturer anticipates further refinement of system algorithms based on "real world" data and improvement of classification accuracy to the design goal of 99.5 percent. The design used by SEO for this detector allows its firmware to execute the axle counting algorithm without a dedicated computer to perform post-processing. Vehicle classification and axle count are reported within 25 milliseconds of vehicle passage. The release date for the *Autosense IIA* to be available to the general public was scheduled for April 1999. The *Autosense IIA* is the only non-intrusive detector known to the authors that can classify according to the standard FHWA classification scheme using number of axles and axle spacings.

Passive Acoustic Detection Systems. Passive acoustic detection systems are generally composed of an array of microphones that are aimed at traffic to "listen" for passing vehicles. Two vendors currently market passive acoustic detectors; one mounts a detector over each lane, and the other monitors up to five lanes using a single sidefire device. The *SmartSonic TSS-1* is the only one of the two passive detectors that currently includes vehicle classification as one of its outputs. The major components of the overhead *TSS-1* sensor system include a controller card, from one to four independent acoustic sensors (microphones), and interconnect cables. It provides a detection zone size of 6 ft to 8 ft in the direction of traffic. The *TSS-1* processing in the controller card has the capability of computing traffic flow measurements such as vehicle volume, lane occupancy, and average speed for a selectable time period. No accuracy data were available except for speeds *(19)*.

In limited testing, the speed accuracy for the *SmartSonic* acoustic detection system was plus-or-minus 10 percent when compared to inductive loop detection systems. The system also classifies vehicles, but researchers found that its error rate was too high to promote its use for this purpose. The power requirement for the system is low, at 5 to 6 watts, which will allow the use of solar panels. The cost of the acoustic sensor is $1450 per unit, with one required per lane per detection location. The detection system also requires a controller card at a cost of $800. Each card can accommodate up to four acoustic sensors. Some weather conditions further compromise the system's detection accuracy; these include very dense fog, snow, and heavy rain *(19)*.

Automatic Vehicle Identification Systems. Automatic Vehicle Identification (AVI) technology utilizes a transponder inside the vehicle and a radio frequency signal unit located alongside or above the roadway. The transponder receives a signal from the roadside unit and responds with an encoded signal uniquely identifying information about the driver or vehicle. A transponder card reader, part of the radio frequency unit, then processes this information. AVI systems are capable of uniquely identifying a vehicle passing through the detection area *(17)*. An AVI system can record headway, volumes by lane and by station, the number of tagged vehicles passing in each lane at a reader station, and the number of tagged vehicles that switch lanes between stations. A sophisticated system may also relay vehicle type, driver-input origin and destination information, and travel speed based on the vehicle's speedometer *(21)*. The major disadvantage of using an AVI system as a vehicle detection system stems from the limited number of vehicles equipped with transponders.

Non-Invasive Microloop. The 3M company recently introduced a modified version of its microloop probe, but little is known about the accuracy or expected life of the probe. This microloop is a transducer that converts changes in the vertical component of the earth's magnetic field to changes in inductance. Vehicles passing over the microloop increase the magnetic field, resulting in a detection. The installation process for the microloop utilizes a horizontally bored conduit that is a fixed depth (18 to 24 inches) below the pavement surface. Sensor installation requires inserting the probe from the shoulder end of the conduit via a ground box and sliding it through the conduit until it is underneath the lane to be monitored. According to product brochures, the microloop provides speed, count, occupancy, and vehicle classification by length when connected to a 3M Canoga vehicle detector. A single probe centered under each lane should detect most vehicles, but small motorcycles or bicycles require two or more probes. These detectors are less likely to be affected by pavement weakness or other surface problems when compared to standard inductive loops. A location needing detection where standard loops are not well suited is on structures. Researchers anticipate that microloops can be placed underneath a bridge deck and strategically placed to provide desired detection. The cost of materials plus boring under the roadway for installing detection for a two-lane freeway in College Station was approximately $9900 *(22)*.

Video Image Detection Systems. A video image detection (VID) system consists of one or more cameras providing a clear view of the area, a microprocessor-based system to process the video image, and a module to interpret the processed images *(23)*. Advanced VID systems can collect, analyze, and record traditional traffic data; detect and verify incidents; classify vehicles by length; and monitor intersections *(24)*. VID systems have proven to be accurate for vehicle counts to within 5 percent of actual counts as long as weather and lighting conditions are favorable. However, their ability to classify vehicles is generally limited to daylight hours because their nighttime detection algorithms depend on detection of headlights. The systems cannot distinguish between the various headlights of individual vehicle classes *(25)*. At least one vendor claims to be able to classify at night with adequate street lighting, but no known verification has occurred. It should also be noted that video systems on the market today only classify according to length, typically providing only three to five vehicle length classifications. Therefore, these systems cannot be used to classify by axles as required by the FHWA classification scheme.

2.3.2 Vehicle Weighing Equipment

Historically, weighing trucks has been accomplished using static devices. Static weighing techniques require investment of considerable resources in terms of special site construction, personnel, and equipment *(26)*. Static weighing activities also cause significant delays to motor carriers, resulting in loss of time and revenue. Drivers of illegal vehicles have been known to avoid static enforcement activities by taking bypass routes or by waiting upstream of the enforcement site until enforcement officers leave the site.

WIM offers significant advantages over static weighing. Trucks incur no delay as they pass over WIM weight transducers: there are no safety problems created by WIM operations, and WIM systems can be operated continuously. Some WIM systems are portable and can be moved easily from site to site, although the placement and removal of the WIM transducer array may require the use of workzone traffic control procedures *(27)*. There are several classes of WIM sensor types that have been developed for use and are currently available in the U.S. A list of WIM systems and a short discussion in the context of WIM sensor types follows.

2.3.2.1 Piezoelectric Cable

Piezoelectric cables have been used as a means of collecting highway data since the early 1970s. The system consists of a cable placed in the pavement surface that is composed of a copper central conductor and an outer copper sheath (0.12 in. in diameter) with a piezoelectric powder acting as the dielectric. Applying a changing force or pressure to the cable causes electrical charges of opposite polarity to be attracted to the copper conductor. The encapsulation channel is usually aluminum, and this channel contains material to protect piezoelectric cable and maintain its position. The typical system consists of at least one piezoelectric sensor and one inductive loop placed in the travel lane perpendicular to the direction of travel. The more common configuration is two inductive loops and two piezoelectric sensors per travel lane.

2.3.2.2 Capacitive Weigh Mats

The weight sensor for a capacitive weigh mat consists of three sheets of steel maintained in approximately parallel position by a rubber dielectric. The instrumentation of the systems treats the weigh mat as a variable three-plate capacitor within a tuned circuit. When a vehicle crosses the sensor and compresses the capacitor, it causes a change in the oscillating frequency of the tuned circuit. This frequency shift correlates to the magnitude of the load. One advantage of the capacitive mat is the low cost of the system.

2.3.2.3 Capacitive Strips

A WIM system using capacitive strips is similar to the capacitive weigh mat and works on the principle of capacitors within a tuned circuit. However, the capacitive strips are much narrower and normally deployed in an array of three or more strips.

2.3.2.4 Strain Gauges Attached to Bridge Beams

WIM systems utilizing strain gauges attached to bridge beams consist of a strain transducer that clamps or permanently attaches to the longitudinal support beams of a highway bridge. The system still needs temporary or permanent sensors to be placed on the road surface approach to the bridge to assist in classification of the vehicle and in acquisition of speed data. This particular weighing system may not be appropriate where the bridge is on a horizontal curve because of reduced accuracy. An advantage of the system is that the equipment typically used is reliable and requires little maintenance.

2.3.2.5 Strain Gauge Load Cells

Strain gauge load cell WIM systems use bearing plates resting on load cells. The load cell locates in the pavement of the travel lane, perpendicular to the direction of vehicle travel. A bearing plate rests on the load cell and transfers force to it. When a vehicle passes over the load cell, the system records the weights measured by the cell.

2.3.2.6 Bending Plates with Strain Gauges

Bending plate WIM systems utilize strain gauges that are bonded to the underside of steel plates. The sensors used in a bending plate WIM system consist of one or two scales that are placed in the travel lane perpendicular to vehicle direction of travel. As a vehicle passes over the system, the measured strain is proportional to the dynamic load. Bending plate WIM systems can be either permanent or portable. There are several advantages to bending plate WIM systems; one is their low mass, which avoids the problem of low natural frequency. The sensors do not have moving parts, and the sensors can be sealed against environmental effects.

2.3.2.7 Hydraulic Load Cells

Hydraulic load cell WIM systems use a weight transducer consisting of a single oil-filled piston that acts as a load cell. This type of system is large and heavy, which requires complex installation. Other disadvantages include possible diminished accuracy at higher speeds. This diminished accuracy may be attributed to the relatively low natural frequency due to the high mass of the weight transducer.

2.3.3 Recent WIM Equipment and Sensor Developments

There has been a steady increase in research and development in WIM systems, sensor technologies, and scales over the last few years. Areas of concern cited by WIM users are: system accuracy, temperature dependency, speed dependency, signal degradation, and cost effectiveness. These concerns have provided the impetus for new system and technology development. The following systems reflect some of the new developments in WIM and sensor technology.

2.3.3.1 Quartz-Piezoelectric Sensor

Some European countries currently use a Swiss-developed quartz-piezoelectric sensor. This sensor utilizes the same piezoelectric principle for signal generation but is innovative in material use and design. The sensor uses a quartz-sensing element placed in an aluminum housing and then encased with an elastic material. Installers attach a load pad of epoxy-silica sand compound to the top of the aluminum housing and wraps the sides of the load pad with closed cell foam padding. The sensors come in 3.3 ft lengths, with 20 evenly distributed quartz-sensing elements *(28)*.

The WIM system configuration utilizing the quartz-piezo sensor consists of two inductive loops and two full lane-width strips of the sensors. Installers place this layout in the travel lane perpendicular to vehicle travel direction and assemble the sensors into the lane-width strips using metal plates screwed to the base ends of the sensors. The Connecticut Department of Transportation is testing this system.

2.3.3.2 Fiber-Optic Sensor

A fiber-optic sensor has been developed which consists of either a laser diode (LD) or a light-emitting diode (LED), optical fibers, and a data acquisition module. The LD or LED emits light that travels through the optical fiber cable. When a force from a load causes microbends in the fibers, the light traveling through the fiber cable “leaks” out, causing a loss in light intensity. An appropriate signal processor can measure this loss of intensity and correlate this change to the force *(29, 30)*.

Successful test and deployment of a fiber-optic sensor has occurred in Melbourne, Florida. Initial data show accurate axle counts and vehicle classifications when compared to data from piezoelectric loop classifier data. The analog signal from the fiber-optic sensor correlated well to axle weight. Some advantages to the system are ruggedness, reliability, low cost, immunity to electromagnetic interference, and lack of metallic conductive path to the electrical interface *(29)*.

The Virginia Tech Fiber and Electro-Optics Research Center (FEORC) is also developing fiber-optic sensors. This sensor is a modal domain fiber-optic sensor, which works on the same principle of measuring intensity fluctuations. The Virginia Tech sensor will be tested on the "smart road," which is being developed near Blacksburg, Virginia. An additional advantage of the fiber-optic sensor noted by FEORC is that the single groove geometry of the sensor eliminates the high strain concentrations that are typical of inductive loop sensors. This offers a potential for the sensor to be used for bridges *(30)*.

The Federal Highway Administration through the Turner-Fairbank Highway Research Center is currently conducting a program concerning fiber-optic sensors. One application that is being evaluated through an agreement with the Naval Research Laboratory (NRL) pertains to Bragg grating-type fiber-optic sensors. The Bragg grating sensors operate by sensing the wavelength of light reflected from the grating. NRL designed a prototype system of Bragg grating fiber-optic sensors that work effectively together. As many as 100 gauges can be placed on the same fiber and then calibrated as a system. This provides a fiber-optic strain gauge that is more reliable and repeatable than gauges that use other measurement methods *(31)*.

New Mexico State University's Vehicle Detection Clearinghouse in cooperation with the New Mexico Department of Transportation conducted field tests of the Bragg grating-type sensor system. The project research team installed a system of 67 NRL-designed, calibrated fiber-optic sensors on an existing bridge on Interstate 10 in Las Cruces, New Mexico. The project goals included demonstrating that fiber-optic sensors could replace conventional strain gauge sensors in the field environment; that the sensors could perform both as a data collector and a data transmitter; and that the fiber-optic sensors were capable of long-term performance in a field environment *(31)*.

The Swiss Federal Institute of Technology is also testing Bragg grating sensors in a field environment. The Institute research team installed 32 of the NRL-designed sensors on the Viaduct de Vaux near Lausanne, Switzerland, to monitor the strains on the steel girders during construction. The Viaduct de Vaux is a box-girder steel and concrete bridge. The construction process extends the girder from one pier to another for a distance of over 330 ft. Once the girders are in place, the contractor pours the concrete bridge deck with a system of

32 encased sensors embedded in the deck. These deck sensors also provide long-term bridge monitoring *(32).*

2.3.3.4 Seismic WIM Sensors

Lawrence Livermore National Laboratory tested the use of seismic sensor arrays as a WIM sensor system in 1999. The laboratory located a 40-ft array of sensors on the shoulder of a roadway parallel to the direction of travel. The sensors recorded the ground displacement caused by a moving vehicle. Findings in these tests showed that seismic sensors used for this application were noninvasive, inexpensive, and portable. Researchers also found that, because the seismic sensor array is non-intrusive, it had the potential to be used on bridges and other structures. Although Lawrence Livermore developed equipment for testing, it did not build a prototype system nor is it currently pursuing further application of the technology *(33).*

VorTek LLC of Huntsville, Alabama, developed a seismic device to detect tornadoes through their vibrations. This seismic device, nicknamed "Snail," is a portable package that is designed to detect the components of a short-period seismic signal. The Snail has a geophone component that is attached by a cable to an electronics package. In December 1999, VorTek signed a contract with the Florida Department of Transportation to demonstrate the feasibility of using the Snail as a seismic weigh-in-motion sensor *(34).*

2.3.3.5 Box Culvert WIM System

Australia developed a WIM system utilizing box culverts. The system is based on the principle that the bending strains deck caused by a vehicle passing over a culvert on the culvert deck is related to the axle weight of the vehicle. The bending strains are measured using a series of electrical resistance gauges placed transversely across the culvert at mid-span. The strain signal then requires amplification. Australia, which has been using culvert WIM or "Culway" systems for over 12 years and has over 100 systems in operation, typically uses existing culverts. The definition of the ideal culvert which would minimize weighing errors is a single span reinforced concrete box culvert, precast, uncracked, and less than 8.9 ft in span *(35).*

2.3.3.6 Weigh-in-Motion of Axles and Vehicles for Europe (WAVE)

Continued research and development of new sensors and systems will provide improvement in WIM costs, portability, and accuracy. Currently, one must still account for vehicle and study site characteristics (i.e., vehicle suspension system, tire pressure, roadway profile, vehicle speed, pavement roughness, and wind velocity) in the dynamic collection of the truck weights *(36, 37).* One ongoing research project in WIM technology is WAVE (Weigh-in-motion of Axles and Vehicles for Europe). WAVE is a pan-European project that has specific objectives of improving accuracy and performance of WIM systems. This initiative is investigating multiple sensor systems and bridge systems as a means of improving accuracy. Additionally, it is conducting research into improved durability in colder climates and improving calibration and test procedures to improve performance *(38)*.

In May 1999, a symposium presented the results of WAVE (1996-1999) in Paris. There were 11 partners representing 10 countries that took part in the WAVE project. There were four main areas that WAVE focused on in its research effort:

- accurate estimation of static weights using WIM systems; this area specifically investigated multiple-sensor WIM and bridge WIM;
- quality, management and exchange of WIM data;
- consistency of accuracy and durability; this area focuses on environmental factors such as cold weather operations and calibration procedures; and
- optical WIM systems *(39)*.

WAVE researchers reported two new theories that were successfully developed to optimize the estimation of static weights. These experimental studies utilized multiple sensor arrays utilizing 11 to 15 sensors that proved to be very accurate (± 2 percent of static weight) *(32)*. Findings also reported progress in the area of bridge WIM. Both of these areas developed new algorithms to improve accuracy. However, these algorithms have yet to be implemented into marketable WIM systems *(39)*.

WAVE researchers also reported strides in the development of fiber-optic technology. These include development of prototype systems and beginning of initial testing. The fiber-optic sensor developed in a partnership with the Laboratoire Central des Ponts et Chaussées uses light birefringence in optical fibers, which undergoes a mechanical strain. The sensor design uses a fiber placed between two metal ribbons and embedded in an elastomer material. Initial testing resulted in waveform problems due to high loading and development of a second prototype. The new design, which tested satisfactorily in the laboratory environment and in initial tests, is ready for field testing *(39)*.

2.3.4 Traffic Data Collection Experience

2.3.4.1 Inductive Loops

Some agencies believe that inductive loop technology is the best available, while others claim that inductive loop detectors malfunction so frequently that they are simply not worth repairing *(9)*. One study that interviewed several California Department of Transportation personnel indicated that only one half of the inductive loop systems installed are currently in operation. In this same study, Illinois Department of Transportation personnel stated only 5 percent of the inductive loop systems in their jurisdiction are inoperable at any given time. Illinois officials attribute this success to an active maintenance program that monitors each loop *(14).* Such programs are costly, but maintaining a low failure rate requires them.

Bikowitz et al. *(40)* analyzed 15,000 inductive loop detectors in New York State and found that loop failures resulted primarily from either improper installation, inadequate loop sealants, or wire failure. The study revealed several installation processes needed revision to improve the inductive loop detector's reliability. Improper saw cutting techniques, loop wire splicing, and inadequate loop sealant bonding resulted in loop wire breakage.

A study by Chen et al. *(41)* conducted in Los Angeles revealed that up to 15 percent of the 115 detectors analyzed were unavailable, and between 2 and 11 percent showed error flags during the experiment. The causes of the detector failures included: moisture, loop sealant deterioration, pavement cracking, broken wires, deteriorated insulation, corroded splices, and detuned amplifiers.

2.3.4.2 Vehicle Classifiers

The Georgia Tech Research Institute and Georgia DOT performed a series of field tests on several vehicle classification devices that are currently used in order to determine accuracy and adequacy of the equipment. The field test location was on IH-20 in the metropolitan Atlanta area, and the test included two 48-hour tests for detailed vehicle-by-vehicle analysis and one seven-day test for longer term accuracy statistics *(42).* Test equipment included:

- *TrafiCOMP III* (Peek Traffic, Inc.),
- *GK-6000* (Peek Traffic, Inc.),
- *TEL-2CM* (Mikros Systems),
- *AVC-100* (PAT Equipment Corp., Inc.),
- *TT-2001* (Diamond Traffic Products),
- *TC/C 530-4D/4P/4L* (International Road Dynamics),
- *MSC-3000 DCP* (Mitron Systems Corp.),
- *Marksman 660* (Golden River Traffic, Ltd.), and
- *HESTIA*, (Electronic Control Measure), and *Delta II* (TimeMark, Inc.).

Published results were in a format that provided anonymity to participating companies and to specific equipment to avoid the appearance of competitiveness *(42).*

Documentation of results compared actual vehicle classification to system classification and the overall classification accuracy. The analysis of results found that the most common classification errors involved the differentiation of class 2 and class 3 vehicles by test equipment. The results also found that the most accurately classified vehicles were large trucks, which comprise classes 8 through 12. The test team also found that there is a strong correlation between the accuracy of a classifier and the reliability of the axle sensor used to collect the data, and that axle sensor error accounts for a large number of the overall classification error. As stated earlier, the team also found that trucks are classified more accurately than smaller vehicles. This increased accuracy regarding trucks is attributed to the distinct separation in the number and spacing of truck axles *(42).*

The testing conducted by the Georgia Tech research team included a seven-day test for longer term accuracy in addition to two 48-hour tests. Results for the second 48-hour test were better than the first test due to rehabilitation of the piezoelectric axle sensors. Results from the seven-day test indicated that generally, time is not a factor in accuracy. Tests of the effects of pavement overlay revealed that axle sensors could no longer accurately classify vehicles due to reduced sensitivity of sensors that had been overlaid *(42).*

2.3.5 Traffic Load Forecasting

The ability to accurately forecast traffic loading is an essential part of pavement design. Pavement structures are designed to last a certain number of years (generally 20 years). When the structure fails prematurely, transportation officials must divert money to rehabilitate or reconstruct the pavement, which may have been planned for other projects *(7).* Accurate traffic load forecasts could result in better designed and built pavements, fewer premature pavement failures, and longer pavement service life.

Traffic loading is the load applied to the pavement by axles of different weights and/or configurations that is equated to the load applied by a chosen reference axle *(43).* This load equivalence factor or ESAL is defined by the American Association of State Highway and Transportation Officials as: "A unit of measurement equating the amount of pavement consumption caused by an axle or group of axles, based on the loaded weight of the axle group, to the consumption caused by a single axle weighing 18,000 lb." *(10).*

Vlatas and Dresser *(7)* found that the percentage of trucks in the traffic stream, the directional distribution of the traffic loading, and the average ESAL factor per truck were the three primary contributors for forecasting variability. Through a thorough literature review Vlatas and Dresser discovered that:

- truck load equivalency factors/axle weight distributions vary significantly by site,
- truck load characteristics may vary from season to season at the same site, and
- truck load and pavement distress may vary significantly from one direction of travel to the other at the same site.

Because these factors are specific to a specific site, accuracy could be improved by more than 85 percent through week-long WIM sessions at a specific site *(7).*

2.3.5.2 Effects of Traffic Loading

Heavy axle loads create strains and stresses in pavements that cause fatigue failures. ADT, peak hour volumes, and similar measures of traffic flow have very little effect on pavement deterioration; however, the number of heavy loads supported by the pavement over its design life affects deterioration. Because a single 18,000 lb single axle load will cause more damage to a road than 2000 large passenger cars, the number, type, and magnitude of wheel loads predicted to use the road are needed to determine pavement life *(43)*.

It is expected that NAFTA will not only result in dramatically increased truck traffic in areas near the U.S./Mexico border and in corridors leading to and from the borders, the traffic will not necessarily follow the simple traffic increase factor practices used in past pavement modeling *(44)*. Trucks traveling from Mexico are heavier than those generally allowed in the United States. Therefore, a fully loaded truck based on limits used in Mexico will cause more damage than a fully loaded truck, based on limits used in the United States *(45)*. Dual and triple axles loaded at allowable loads in Mexico would cause nearly twice the damage caused by axles loaded to the allowable limits in Texas. Single axles loaded at the allowable limits in Mexico would cause nearly one and one-half times the damage caused by legal axles in Texas *(44)*. Many of the highways in Texas most affected by the projected increase by NAFTA traffic from Mexico are rural highways. Since few (if any) rural highways are designed and built to the standards of Interstate highways, the effects of these heavy vehicles could be even greater.

2.3.5.3 Accuracy of Traffic Load Forecasting

Vlatas and Dresser conducted a study examining the effect of traffic loading with regard to pavement design *(7)*. They found that the traffic load forecast components most responsible for forecast variability at the time were "site-specific" characteristics of the traffic stream. As a result of that finding, they investigated improvements in forecast accuracy that could be realized by sampling the traffic stream at specific pavement project locations. The research found that traffic load forecast accuracy could be improved by more than 30 percent from then-current levels by conducting 24-hour manual vehicle classification sessions at specific pavement project sites. Furthermore, traffic load forecast accuracy could be improved by more than 85 percent by conducting weeklong WIM sessions at specific project sites. Improving traffic load forecast accuracy by the amounts shown above would result in better pavements, resulting in less premature pavement structure failures and longer service lives than under current forecasting procedures *(7)*.

Vlatas and Dresser recommended that TxDOT conduct a site-specific 24-hour manual vehicle classification for any pavement project worth more than $248,000, and site-specific 24-hour manual vehicle classification session or, preferably, a site-specific weeklong WIM session for any pavement project worth more than $543,000. It is important to note that almost all pavement reconstruction projects and most major pavement rehabilitation projects exceed the $543,000 threshold. For projects in which TxDOT elects not to conduct site-specific traffic data, TxDOT should use a modified percent truck prediction model with current forecasting techniques *(7)*.

CHAPTER 3.0 CUSTOMER NEEDS ASSESSMENT

3.1 INTRODUCTION

The Customer Needs Assessment of Traffic Data Used for Pavement and Bridge Design was an attempt to ascertain the needs, desires, and opinions of chosen representatives from four TxDOT functional areas in each district about the performance of the TPP Division's Traffic Section in meeting data needs. The assessment also included representatives from other units within TxDOT and the Department of Public Safety (DPS).

3.2 METHODOLOGY

TTI surveyed one engineer from the following functional areas in each district: Area Engineer, District Design, Traffic Operations, and Transportation Planning and Development (TPD). The District Engineer in each district selected each engineer as the individual most likely to provide good responses to the questions.

The needs assessment took the form of a nine-page written survey mailed to the representative in each of the functional areas, with a follow-up office interview to clarify and enhance the submitted answers. The survey had five sections: design issues, data-specific information, data processing, trend information, and data access. TTI sent the survey, along with a cover letter explaining the intent of the project, directly to the four engineers in each district.

3.2.1 TxDOT Districts

TTI conducted the survey in two phases. Phase one surveyed nine districts for a total of 36 responses, with personal follow-up interviews at district or area offices. The phase two surveys went to engineers in the remaining 16 districts, followed by phone calls to each individual after TTI received written responses from them. The response rate was 100 percent in phase one and 84 percent in phase two. The drop in the return rate in phase two may have been due to reliance on telephone interviews; personal contact assured a high response rate. Overall, 90 out of the 100 TxDOT engineers chosen submitted responses to the survey, for an overall return rate of 90 percent. The survey represents all 25 districts by at least one respondent per district (only one district provided a single response). All other districts returned at least two surveys.

3.2.2 TxDOT Divisions and External Agencies

TTI also conducted personal interviews with representatives of several other TxDOT sections as well as with the DPS. The TxDOT units contacted were the Pavements Section of the Design Division, the Bridge Division, and the Motor Carrier Division. The representative from DPS was from the Traffic Law Enforcement Division. All of these sections have an interest in the design of pavements and bridges and their differing perspectives were anticipated to be helpful.

TTI conducted the interviews in October and November of 1999 in Austin. Prior to the interview dates, researchers faxed a copy of the Study Problem Statement, the Executive Summary of the Customer Needs Assessment Survey, and the minutes of the previous project meeting to the interviewees. The interview did not follow the Needs Assessment Survey exactly, but the survey form provided a framework in which to discuss the topic.

3.3 FINDINGS

The general findings below show responses and comments from the written survey listed in the same order as found in the survey. Included in the applicable section are responses and comments received from the supplemental interviews with DPS and other TxDOT personnel.

3.3.1 Design Issues

The need or desire to design by direction or by lane is very conditional for engineers at the district level. Design and traffic operations engineers expressed interest in both design by lane and design by direction, but expressed greater need for design by lane. Area and TPD engineers were more interested in design by direction. A large majority of respondents supplemented TPP traffic data with engineering judgment when designing by direction or by lane.

The Motor Carrier Division (MCD) issues oversize/overweight permits, mostly for non-divisible loads moving throughout the state. Quantifying route-specific permit activity could provide useful information in designing and/or maintaining pavements and bridges. However, MCD personnel stated that projections in the number and types of overweight permit requests by specific route would be inaccurate.

DPS expressed a critical need for additional enforcement areas that are large enough for parking several trucks at any given time. Troopers often use roadway shoulders, but many of the shoulders are not wide enough for this purpose, have sight distance limitations, or they do not have the structural integrity to accommodate large numbers of heavy vehicles.

3.3.2 Data Specific Information

Results categorized information as essential, useful, or desirable. Five traffic database elements are essential to respondents: Average Annual Daily Traffic (AADT), Average Annual Daily Truck Traffic (AADTT), future AADT projections, future AADTT projections, and future ESAL projections. Two elements not desired or needed were axle set weights–tridems and axle set weights–quads.

In addition to the essential data, respondents from the Pavements Section desire more corridor data, trend information, WIM data, and access to the raw data used by TPP. Information that would be useful to the Bridge Section includes ADT, future ADT, and percent trucks. Several respondents stated that their needs for TPP traffic data are being only partly met. AADT, future AADT projections, and future ESAL projections were the only data elements being met sufficiently.

The Department of Public Safety needs updated traffic flow maps from TPP, since their most recent version is 1997. Currently, DPS must request traffic flow maps and traffic projections, whereas they would like to receive them automatically. DPS could also benefit from information on overweight vehicles based on TxDOT's weigh-in-motion program.

Data accuracy was an important category to districts. The districts expect TPP to provide data with 90 percent reliability.

The survey recorded varied comments concerning the timeliness of TPP data. Some respondents considered the timeliness acceptable, while others considered TPP's response time too slow. The threshold beyond which the response time was considered excessive ranged from one month up to 12 to 18 months. Within the Data Specific Information section of the survey, all four functional areas rated timeliness of TPP data as a low priority.

The Pavements Section did not rate timeliness of data as a major problem. Its needs generally come on a predictable annual cycle, as opposed to an as-needed basis. The exception pertains to HPMS pavement roughness data. Districts collect the data in the spring with reports submitted to the federal government by the summer. Some districts lag behind, leaving only one to two weeks to process data, and that is insufficient time for proper analysis by TPP. Some districts considered TPP to be the problem, but the districts must allow more lead time for TPP response. Some districts also noted that TPP response time was excessive for project-specific data needs, primarily rehabilitation projects, which require faster turnaround of data.

The Bridge Division's main problem related to TPP data timeliness is the traffic data used for their annual submission to the National Bridge Inspection database for FHWA. According to federal rules, traffic data for bridges cannot be more than four years old. However, TPP collects off-system data on a five-year cycle. This discrepancy creates quite a few "error messages" when assembling the database for submission to FHWA.

3.3.3 Data Processing

Respondents expressed strong interest in knowing the reliability of TPP traffic data, as reflected in a tabulated score of 3.8 out of a possible 5.0. They showed slightly less interest in their ability to specify the reliability of TPP traffic data (3.6 on a scale to 5.0). Respondents indicated medium interest in procedures and processes used by TPP to develop traffic data. A minor exception was traffic operations engineers, who showed the most interest of the four functional areas. The Pavements Section expressed no reason to doubt the accuracy of the data received from TPP.

3.3.4 Trend Information

Of the four district groups, the only one that indicated more than a medium interest in traffic load trend information was Area Engineers. The Pavements Section indicated a strong need for this same trend information. All four functional areas expressed interest in knowing where "big changes" in traffic volume and weights occur, but the definition of a "big change" is unclear. The Pavements Section needs to be informed when "big changes" occur, which it defines as a 10 percent change. The Bridge Division did not define "big changes," but information on truck movements or percent trucks would be useful in determining need for closer scrutiny. Respondents showed the greatest interest in (highest to lowest) ADT, ADTT, and percent trucks; and the least interest (also in order) in Axle Factor, Axle Sets and Respective Loads, and Percent Single Axles.

3.3.5 Data Access

All four district functional areas expressed interest in having accessible TPP traffic data, with traffic operations engineers having the most interest. The highest rated methods of data access across all four functional areas were Windows database, GIS, and e-mail. The mainframe and verbal methods were the least popular methods. The vast majority of respondents did not know the type, number, and location of TPP traffic data collection sites in their district, while all except District Design had appreciable interest in knowing where they are located.

3.4 CONCLUSION

There were several issues regarding customer needs for pavement and design purposes derived from the survey and interviews. The first is an adequate definition of timeliness. Different districts and sections have different perceptions of timeliness. The threshold for districts for considering traffic data to be late ranged from one to 12 to 18 months. Overall, the districts rated the importance of TPP data timeliness as low, but the large range of responses to the issue suggest differences in expectations of TPP and its output. Further study should be considered in order to determine an acceptable level of "timeliness" between TPP and its customers.

The difficulty in defining timeliness leads to the second issue raised by the study. That is the knowledge at the district and section level of TPP activities. Although districts and sections receive output from TPP, very few of them have a good working knowledge of the TPP activities required to complete the requested analysis. This lack of knowledge may contribute to the varied expectations over timeliness. It may also lead to different expectations between the districts and TPP regarding district requests for analysis.

The third issue is the lack of a clear definition of what constitutes a "big change" in traffic analysis. A large change in traffic volume or type in a district requires greater analysis for future road design in the particular area of the change. However, no consensus emerged from the responses as to the size of change required. The Pavements Section offered the most specific response at a 10 percent increase, but the vast majority of responses were along the line of "knowing it when they see it." Further study may be required to arrive at a consensus definition of a "big change."

All districts and sections interviewed expressed an interest in better communication with TPP regardless of the depth of the formal relationship between the unit or district and TPP. All the districts and sections expressed a willingness to help TPP improve the process. For example, the Bridge Division and the Motor Carrier Division have very little interaction with TPP but felt that increased communication and awareness could help both units. Improving communication between DPS and TPP could include informing TPP where the department is weighing vehicles at any given time. DPS could also inform TPP of any perceptions of traffic increases on a particular road. They could also provide citation information regarding overweight vehicles, including carriers. This would require a little work on the part of DPS to correlate to TxDOT district levels, but it could be done. The consensus within the districts and sections was that good two-way communication between TPP and the sections would be constructive and enhance the quality of data received.

As an example of building improved communication, the DPS would be interested in a short course or workshop on transportation engineering provided by TxDOT. It would discuss terms, data, and processes that TxDOT and TPP utilize when doing their job. Troopers understand the legal requirement to weigh vehicles but not why they need to be weighed in relation to road design. A better knowledge of TxDOT's approach and understanding of the roads on which both organizations work may allow the DPS to help TxDOT, and vice versa. The main opportunity for this short course would come every two years when DPS troopers are required to attend an in-service school to update their skills and job knowledge.

The need for better communication between TPP and the districts and sections in TxDOT has become imperative in light of the upcoming revisions to the AASHTO pavement design guidelines and the Federal Highway Administration *Traffic Monitoring Guide* (TMG 2000). Both documents require a greatly increased amount of traffic data to fulfill their specifications. A greater understanding between district and TPP of their respective needs and activities will lead to a more effective and efficient state traffic analysis program and better pavement and bridge design. One respondent stated, "TPP needs to know what Pavement Design does." Just as important, districts and sections need to know what TPP does. One of the outcomes of the identified need to improve communications between districts and TPP was the development of a document called *Traffic Data Request Guide for Highway Pavement and Geometric Design.*

CHAPTER 4.0 TEXAS TRAFFIC LOAD FORECASTING PROCESS

4.1 INTRODUCTION

The traffic load forecasting process provides valuable information to designers regarding the damaging effects of trucks on the pavement. The process begins in the field with data collection and progresses to the office for analysis and computer forecasting. Both weigh-in-motion and vehicle classification data are critical to the application of the load forecasting process.

Truck weight data provide valuable information for highway design and pavement management. The cost of inaccurate traffic data or erred forecasts is found in both the over-design and under-design of pavements. Over-design increases the project's cost because of the additional materials required. Under-design increases the public's investment in the project because an additional pavement project must be developed and constructed to make the original design adequate.

4.2 METHODOLOGY

The methodology involved conducting intensive personal interviews with various staff of the TPP Traffic Section regarding procedures used for collection and analysis of weigh-in-motion and vehicle classification data. Researchers conducted additional staff interviews concerning procedures used in generating design data for projects. Project staff obtained documentation, both source code and documents in personal files, during the review of the RDTEST68 program. Assimilating this information then required compiling and organizing the information for presentation herein.

4.3 FINDINGS

This section presents findings in the following categories: data collection (WIM, AVC, and manual count), data analysis, data archival, and pavement load forecasting.

4.3.1 Data Collection

4.3.1.1 Weigh-in-Motion (WIM)

WIM equipment has the ability to weigh vehicles with varying axle numbers and configurations at low (10 mph) and high (70 mph) speeds and to determine their appropriate vehicle classification. The two types of permanent WIM devices discussed here are piezoelectric (piezo) and bending plate (PAT). Traffic data are retrieved from out in the field using two different methods that depend on the type of equipment used at the site. Data retrieval is done both manually and with telemetry.

TxDOT performs manual data retrieval by physically visiting the site to download the data from the equipment or retrieving the equipment and transporting it to a centralized location where the data can be downloaded. It performs data collection with telemetry by electronically transmitting the data to a receiver at a centralized location where it is reviewed and used. Appendix A includes the procedure for equipment setup and data retrieval. Piezoelectric WIM equipment is portable but requires manual data retrieval. TxDOT collects a 48-hour data set from the bending plate WIM sites on a quarterly basis with the aid of telemetry.

WIM systems use transducers installed in the roadbed to determine the axle weight of vehicles. Installing the equipment in a roadway with the smoothest surface possible ensures the best performance. Piezoelectric sensors use a special material inside a protective jacket. The material acts as a transducer, generating an electrical voltage that is proportional to the force being applied by vehicle tires. The system also uses inductive loops for presence detection to determine total length and to filter out extraneous signals that may be generated.

Bending plate systems determine the axle weight of a vehicle as it comes in contact with the sensor. The system consists mainly of wheel detectors and electronic equipment, which records the presence of a vehicle and the corresponding weight data. TxDOT installs one inductive loop in each lane for presence detection and vehicle length measurement. It installs plates with one immediately before and another immediately after the loop in each lane as shown in Figure 1. The WIM processor receives and interprets signals from the induction loops and bending plates based on proprietary software.

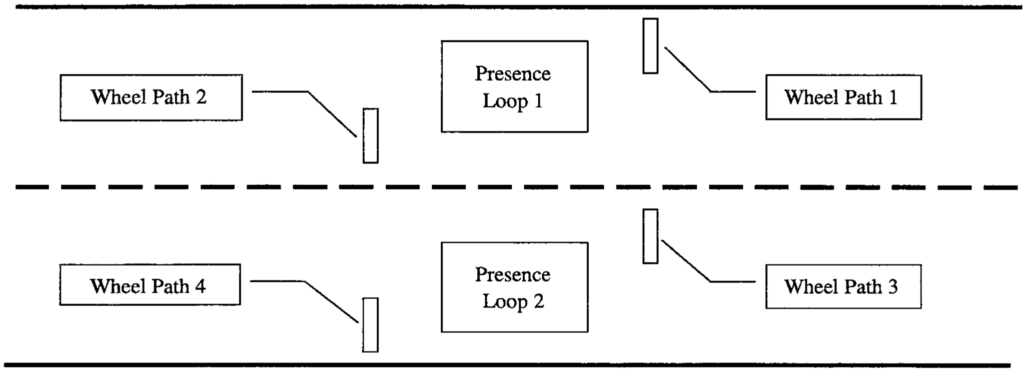


Figure 1. Bending Plate Configuration.

The TMG 3rd Ed. recommends using at least 90 WIM sites for statewide traffic monitoring. The recommendation regarding monitoring cycles is data should be collected at each site every three years. In other words, at least one-third, or 30 sites, should have data available each year. Currently, TxDOT has 15 WIM sites in operation in the state, with the majority of sites collecting data on Interstate facilities. Conforming to current TMG standards would require providing additional sites throughout the state for on-system and off-system facilities distributed by area type (rural or urban) and by functional classification according to HPMS categories.

The Traffic Analysis Section of the TPP Division has a skilled staff with primary responsibilities directed in the area of technical services. Within this section the Technical Services group collects raw data from the field and subjects it to both preliminary validation procedures and reformatting using specific computer programs. The staff has developed validation criteria based on extensive previous experience and also rely on professional judgment for identifying possible problems or areas of needed improvement in which to obtain the most accurate traffic data possible.

The PAT software (bending plate systems) generates a status to identify and track both weight violations and invalid measurements by lane for vehicle classes 4 through 15. Appendix B provides an example of the report. Technical Services reference the status report to determine if the percentage of unclassified vehicles exceeds 10 percent of the volume. It reviews class 9 (3S2) weight data to determine if the recorded weights exceed the expected weight of 80,000 lb by 8 percent or more. Data below these threshold values are acceptable and of suitable quality for submission to the Traffic Monitoring Systems Unit of the Traffic Analysis Section.

When data exceed the threshold values noted above, it is not necessarily an indication of false or inaccurate data. Rather, it represents a flag that the field equipment may need to be inspected for possible malfunctions or setup changes. At such time, one or more technicians proceed to the data collection site to check the equipment for needed repairs or calibration. The data collected usually reflect equipment malfunction based on values for loads per axle and axle spacing. In the event the equipment needs servicing or calibration, technicians collect a new set of data. Technical Services determines whether or not to accept the new data. It sends acceptable data via the TxDOT local-area network (LAN) to TPP's Data Management Section for further processing.

Acceptable data are contingent upon the degree of calibration to which the equipment was subjected. Dynamic calibration of the WIM systems is performed with a two, three, and five-axle truck. PAT equipment (bending plate systems) requires calibration four times per year using a reference truck of known weight. The reference truck makes multiple passes over the weight pad equipment at both high and low speeds.

Comparison of truck (3S2) vehicle static weight to dynamic weight data determines whether the equipment is calibrated properly. Using the measured weight results at different speeds, and calculating the percentage of deviation from expected results yields correction factors. Appendix C provides the procedure for equipment setup and calibration, as well as required computations. Calibration is acceptable when the difference between expected axle weight and actual axle weight is plus-or-minus 6 percent.

Calibration of piezoelectric equipment first requires entering information for weight factors of the truck. As the calibration truck makes multiple passes over the equipment, the electronic system self-calibrates. The bending plate and piezoelectric WIM systems collect data under FHWA's Scheme F classification system. Most piezoelectric WIM equipment uses the FHWA Scheme F set as the default. The FHWA Scheme F consists of 13 vehicle classes to describe the typical vehicle types present on roadways. Figures 2 and 3 show a graphic representation the FHWA scheme and that used by bending plate systems. Figures 4 and 5 show the threshold values defining how the automated equipment references number of axles and axle spacing for use in vehicle classification.

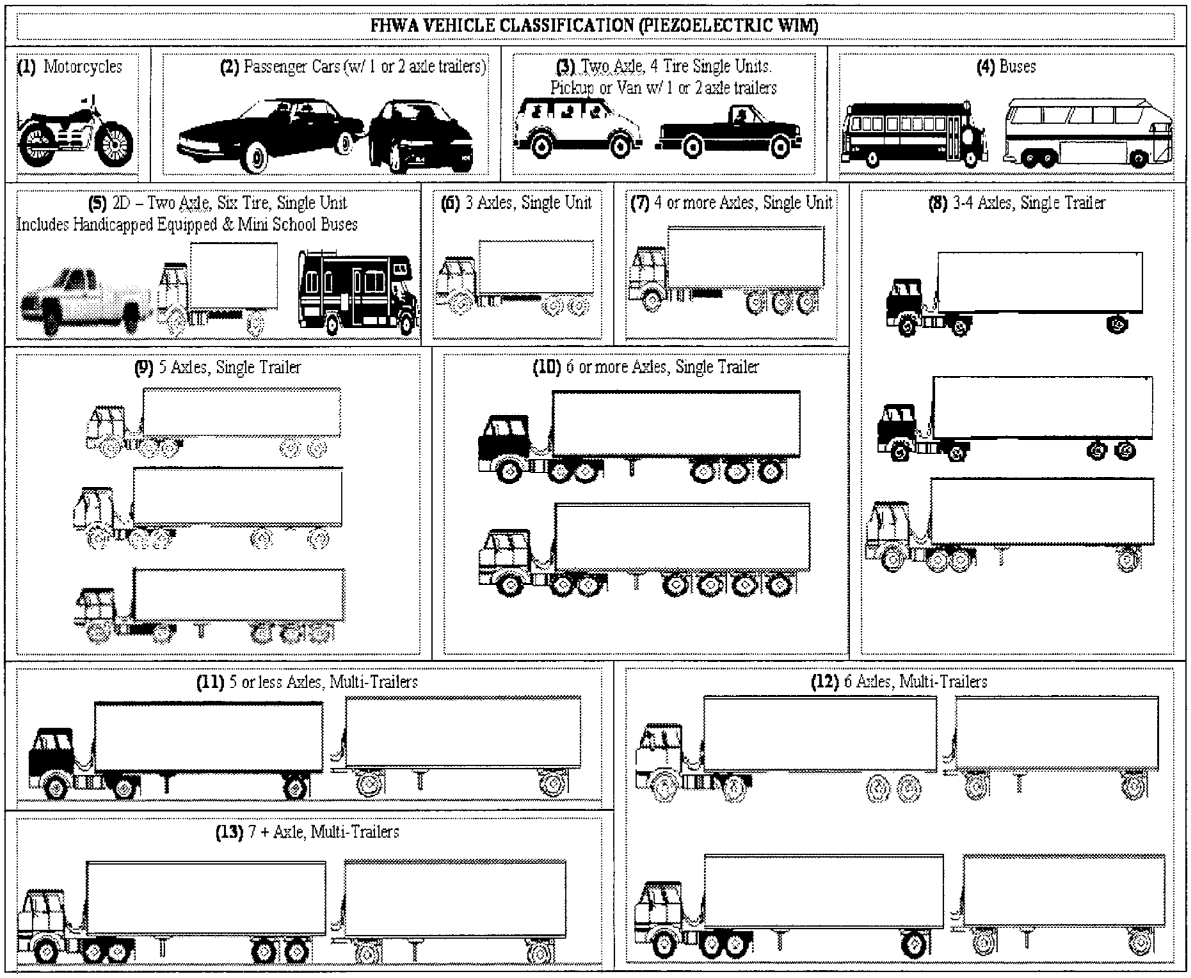


Figure 2. FHWA Vehicle Classification Scheme.

4.3.1.2 Automatic Vehicle Classification (AVC)

AVC systems use sensors embedded in the pavement or temporary devices placed on the surface of the pavement to record vehicle data. The system's processing unit aggregates data from each sensor device and interprets it as a particular type of vehicle passing the site. AVC data are manually retrieved from the field once per year by connecting the field equipment to a computer module on which the data are stored. Appendix D provides the procedure for equipment setup and data retrieval. The computer module goes to Technical Services, where the saved data are then copied to an AVC machine similar to the machines used in the field. By linking the AVC machine with a desktop computer, the data are converted from a binary file format to an ASCII file format. The data are sent via the

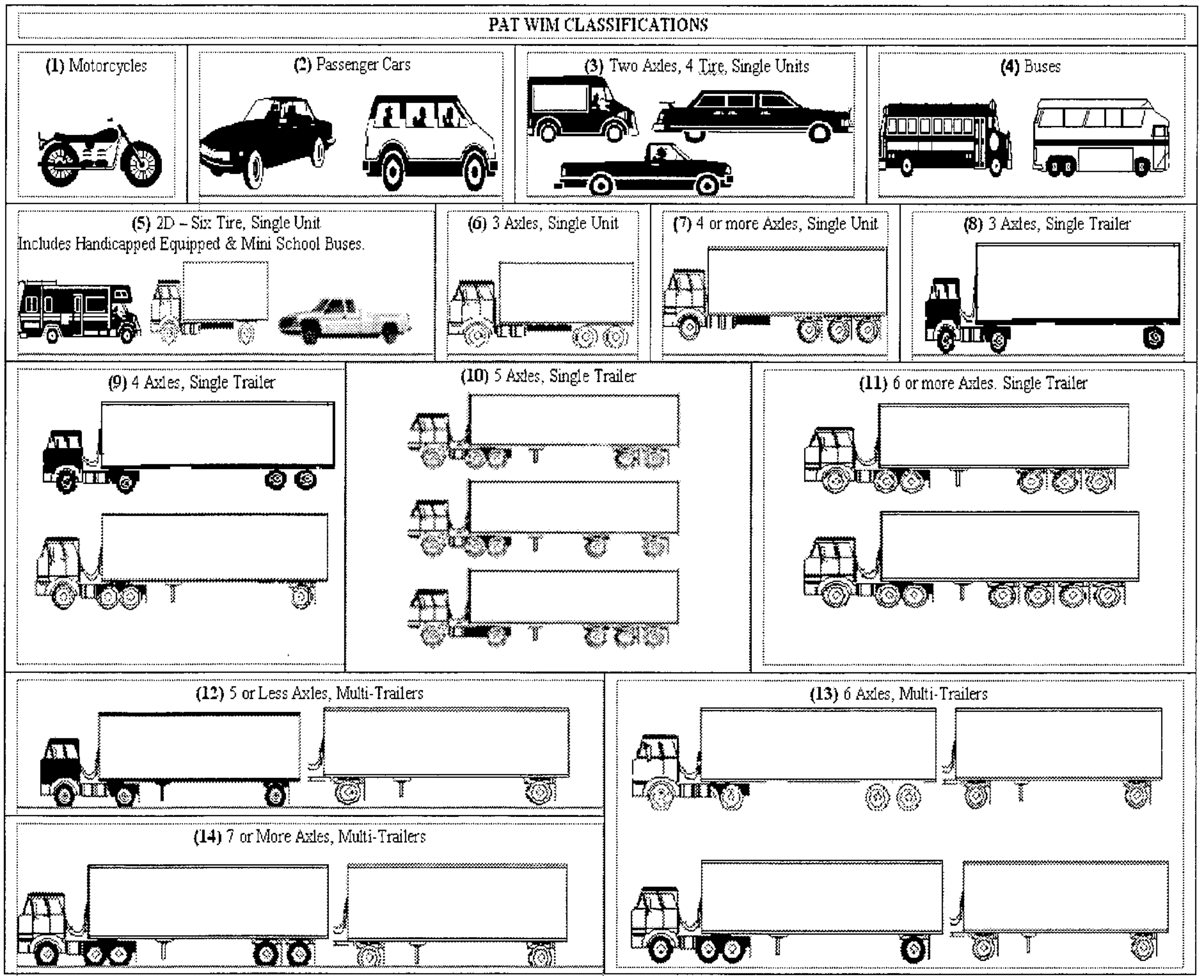


Figure 3. Classification Scheme Used by Bending Plate Systems.

TxDOT LAN to the Data Management Section. There, the data are consolidated into the same format used for analysis of manual count data and subjected to a preliminary review by experienced staff in the Traffic Monitoring Unit of the Traffic Analysis Section.

The calibration procedure for AVC includes visually checking the vehicle types recorded at the site during the initial equipment setup. Data analysts use vehicles of known axle spacing to test the equipment's accuracy. TxDOT Technical Services annually bench-tests and services the equipment for accuracy.

Figure 6 shows the graphic representation of the various vehicles as recorded by AVC systems. Figure 7 displays the various vehicle classification threshold values for the TEXAS6 vehicle classification scheme used by AVC systems.

FHWA VEHICLE CLASSIFICATIONS (PIEZOELECTRIC WIM)															
Vehicle Class	TEXAS-6 CAT	SUB CAT	STAT CAT	Number of Axles	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	MEAS	WEIG
A	1	1	1	0	CAR								0-7.0		
B	1	2	1	0	CAR								7.0-16.0		
C	14	3	4	0	U/C								0-99.99		
D	1	4	1	1	CAR								3.0-7.0		
E	1	5	1	1	CAR								7.0-16.0		
F	14	6	14	1	U/C								0-99.99		
G	1	7	1	2	0.1-6.6	MC									
H	1	8	2	2	6.6-10.2	CAR									
I	2	9	2	2	10.3-13.9	P/U									1.0-80
J	3	10	3	2	21.5-40.0	BUS									
K	4	1	4	2		2D									80-100
L	4	12	4	2	15.0-21.4	2D									
M	14	13		2	0-99.99	U/C									
N	1	14	1	3	3.0-6.6	2.0-8.0	MC&TRL								
O	1			3	6.6-10.2		CAR& 1A-TR								
P	2	16	2	3	10.3-13.09	6.0-23.00	P/U& 1A-TR								1-100
Q	3	17	3	3			BUS 3AX								
R	4	18	4	3	13.1-21.4	6.1-20.1	2D& 1A-TR								80-600
S	5	19	5	3											
T	7	20	7	3	10.3-20.0	14.0-40.0	2S1								
U				3	0-99.99	0-99.99	U/C								
V	1	22	1	4	6.6-10.2			CAR&2A-TR							
W	1	23	1	4	6.6-10.2	8.0-12.9	6.6-10.0	CAR&2A-TR							
X	2	24	2	1	10.3-13.09	6.0-40.0	0.1-3.3	P/U&2A-TR							
Y	2	25	2	4	10.3-13.09	8.0-20.0	6.6-12.9	P/U&2A-TR							
Z	4	26	4	4		6.6-40.0		2D&2A-TR							150-600
AA	4	27	4	4	15.0-21.40	8.0-22.0	6.0-15.0	2D&2A-TR							100-600
AB	6	28	6	4				4 AX S/U							
AC	6	29	6	4	6.1-20.90	3.6-4.8	3.6-4.8	4 AX S/U							
AD	8	30		4	6.6-22.0										
AE	8	31	8	4	6.6-22.0	14.0-42.0	3.3-8.0	2S2							
AF	14	32	4	4	0-99.99	0-99.99	0-99.99	U/C							
AG	2	33	2	5	10.3-13.09	0-99.99	1.5-3.3	1.5-3.3	P/U&3A-TR						3.0-150
AH	4	34	4	5					2D&3A-TR						
AI	4	35	4	5	15.0-21.4	0-99.99	1.5-3.3	1.5-3.3	2D&3A-TR						
AJ	6	36	6	5											
AK	9	37	9	5	6.6-22.0	3.3-8.0	6.6-40.0	3.3-8.0	3S2						
AL	9	38	9	5											
AM	9	39	9	5	6.6-22.0	6.1-40.0	3.3-8.0	3.3-8.0	2S3						
AN	11	40		5											
AO	14	41	14	5	0-99.99	0-99.99	0-99.99	0-99.99	U/C						
AP															
AQ	12	43	12	6	6.6-16.7	3.3-8.0	13.3-270	10.0-27.0	3S1-2	6 AX M-TR					
AR															
AS	14	45	14	6	0-99.99	0-99.99	0-99.99	0-99.99	0-99.99	U/C					
AT															
AU	13	47	13	7	6.6-22.0	3.3-8.0	6.6-40.0	3.3-8.0	6.7-13.3	10.0-27.0	3S2-2	7 AX M-TR			
AV															
AW	10	49	10	8	6.6-22.0	3.3-8.0	3.3-8.0	6.6-40.0	3.3-11.0	3.3-11.0	3.3-11.0	8 AX S-TRL			
AX															
AY	14	51	14	8	0-99.99	0-99.99	0-99.99	0-99.99	0-99.99	0-99.99	0-99.99	U/C			

Figure 4. Threshold Values Used by Piezoelectric Equipment for Classification.

4.3.1.3 Visual Manual Vehicle Classification (MC)

Private contractors who collect visual classification data manually in the field provide MC data to TxDOT. These contractors initially record data on hand-written forms, then they manually input the data to an electronic computer file for easier data analysis. The data then go to Technical Services staff for a random spot-check to determine acceptability. Upon determining that the data are acceptable, Technical Services forwards it via the TxDOT LAN to the Traffic Monitoring Unit staff for further analysis.

One of the weaknesses in this type of data collection is the differences between one visual observer and another that often occur during manual data collection, especially in high traffic volumes and high speeds. In classification schemes with 13 classes, 10 classes include different variations of trucks, both single units and combinations. The human classifier must perceive, process, classify, and record several vehicles in a very brief time interval. Errors can occur when processing and recording data this quickly, especially in high traffic volume

PAT WIM VEHICLE CLASSIFICATIONS

Axle Number	Type	Dist. Axle low	Dist. Axle high	Dist. Axle low	Dist. Axle high	Dist. Axle low	Dist. Axle high	Dist. Axle low	Dist. Axle high	Dist. Axle low	Dist. Axle high	Dist. Axle low	Dist. Axle high	Dist. Axle low	Dist. Axle high	Total weight low	Total weight high	Lim Total weight
2	2	10	600													10	0	8000
2	2	601	1029													100	799	8000
2	3	1030	1330													100	799	8000
2	4	2100	4000													1650	2500	8000
2	5	1331	2360													500	0	8000
2	5	610	2000													800	0	8000
2	2	1029	2010													10	800	8000
3	2	610	1029	600	2010											100	1199	8000
3	3	1030	1330	600	2040											100	0	8000
3	4	2100	4000	340	600											1200	0	8000
3	5	610	2360	10	2800											500	1299	8000
3	6	610	2500	340	600											1300	0	8000
3	8	610	2000	1110	6000											1300	0	8000
4	2	610	1029	600	2010	10	360									100	1999	8000
4	3	1030	1330	600	2500	10	360									100	1999	8000
4	5	610	2360	10	4000	10	2300									800	1999	8000
4	7	1310	2300	340	600	340	600									2000	0	8000
4	9	610	2000	340	600	610	4600									2000	0	8000
4	9	610	2000	1110	4600	3000	600									2000	0	8000
5	10	610	2500	340	600	601	4600	3400	1200							2100	0	8000
5	12	610	2600	1110	2600	610	2000	1110	2600							2000	0	8000
5	3	610	1330	600	3200	10	360	10	360							100	0	8000
5	5	610	2360	600	4000	10	360	10	360							100	0	8000
5	6	610	2500	100	600	10	1800	10	2500							0	2099	8000
6	11	610	2600	340	600	1040	4600	3400	600	340	600					2000	0	8000
6	13	610	1700	1110	2600	340	600	601	2400	1110	2600					2000	0	8000
6	13	610	2600	340	600	601	4000	601	2600	1110	2600					2000	0	8000
7	14	610	2700	340	600	601	4000	340	600	601	2700	1110	2700			2000	0	8000
7	11	610	2500	340	600	1040	4200	340	600	340	600	340	600			2000	0	8000
8	11	100	4500	100	4500	100	4500	100	4500	100	4500	100	4500	100	4500	2000	0	8000
8	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 5. Threshold Values Used by Bending Plate Equipment for Classification.

areas. One solution is to use multiple persons at high traffic volume locations to make visual classification more accurate.

Even in low to moderate traffic volumes, some variability will exist between different human counters when deciding how a vehicle not exactly fitting a particular category should ultimately be classified. This variability is a result of personal judgment and can be significant when comparing results of visual classification from different individuals collecting data at high traffic volume locations.

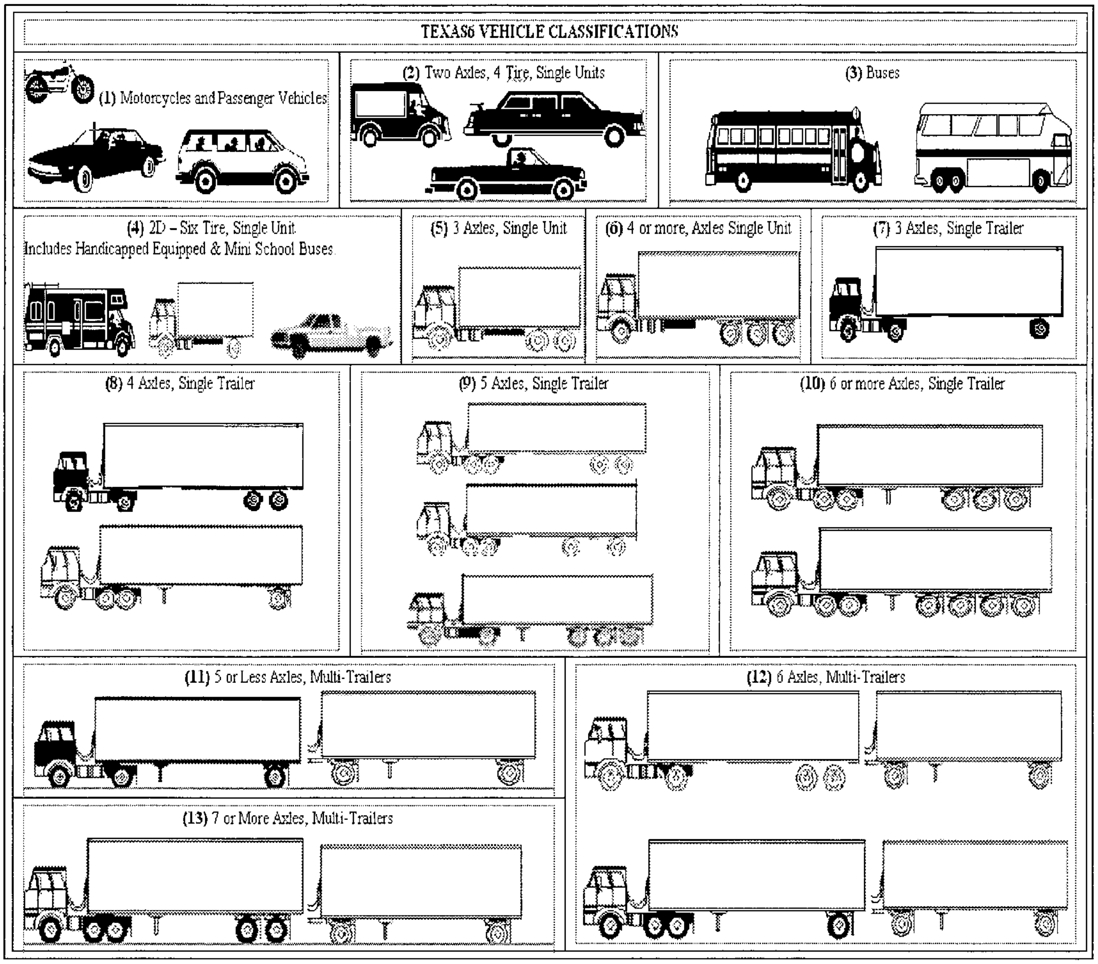


Figure 6. Classification Scheme Used by Automated Vehicle Classifiers (AVC).

4.3.2 Data Analysis

4.3.2.1 Weigh-In-Motion

Technical Services staff performs the preliminary validation procedure outlined in the data collection section. When the data are deemed acceptable, they go in electronic format to the Data Management Section for processing. The Traffic Monitoring System Unit conducts a trend analysis between the current data and historical data at the same WIM site.

Professional judgment determines whether the data are acceptable. Accepted data are used to develop various factors for use in the Road Inventory (RI) file and other analysis purposes, including ESAL forecasts for pavement design. The analysis performed here is the least rigorous of the data collected.

4.3.2.2 Automatic Vehicle Classification and Visual Manual Classification

The department collects AVC data and MC data separately. After some preliminary formatting, the system support specialist in the Data Management Section forwards the data to the Traffic Monitoring System Unit staff where the data are combined and analyzed. Further processing results in tables that show data totals and the percentage difference between the current data and previous years' data in an easily understandable format for validation purposes.

TEXAS6 VEHICLE CLASSIFICATIONS

BIN	Axles	Class	Axle Spacing (ft.)					
			1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7
1	2	1	0.1-10.2					
2	2	2	10.3-13.0					
3	2	3	21.0-40.0					
4	2	4	13.1-20.9					
5	3	1	6.1-10.2	6.0-21.0				
6	3	2	10.3-13.0	6.0-20.1				
7	3	3	21.0-40.0	3.4-6.0				
8	3	4	13.1-20.9	6.1-20.1				
9	3	5	6.1-20.9	3.4-4.7				
10	3	7	6.1-20.0	20.0-60.0				
11	4	1	6.1-10-.2	6.0-20.1	0.1-3.3			
12	4	2	10.3-13.0	6.0-20.1	0.1-3.3			
13	4	4	13.1-20.9	6.0-20.1	0.1-3.3			
14	4	6	13.1-20.9	3.4-4.7	3.4-4.7			
15	4	6	0.1-6.0	13.1-29.0	3.4-6.0			
16	4	8	6.1-20.0	16.5-40.0	3.4-6.0			
17	4	8	6.1-20.0	3.4-6.0	6.1-40.0			
18	5	9	6.1-25.0	3.4-6.0	6.1-40.0	3.4-12.0		
19	5	11	6.1-17.0	11.1-23.0	6.1-18.0	11.1-23.0		
20	6	10	6.1-22.0	3.4-6.0	10.4-40.0	3.4-6.0		
21	6	12	6.1-17.0	11.1-23.0	3.4-6.0	6.1-18.0		
22	6	12	6.1-25.0	3.4-6.0	6.1-40.0	6.1-18.0		
23	7	10	6.1-25.0	3.4-6.0	10.4-40.0	3.4-6	3.4-6.0	3.4-6.0
24	0	1						

Figure 7. Threshold Values used by AVC Equipment to Classify Traffic.

These processing steps develop various factors for use in analysis. Vehicle classification data validation uses 20 criteria; each of the criteria applies to AVC, MC or both. These criteria along with a brief description follow.

1. Search for the "Typical Day"
    - Applicable to AVC and MC.
    - Days for vehicle classification data are Mondays, Tuesdays, Wednesdays, or Thursdays. Data totals from each vehicle class and totals from the sum of all vehicle classes are combined and reviewed. The "Typical Day" is simply the day where the data collected are representative of the data that can be expected at a particular site on any day.

2. Non-holiday traffic on major routes
    - Applicable to AVC and MC.
    - Major routes in this case include U.S. Highways and Interstates. It is important that vehicle classification does not occur during or around a holiday (e.g., Thanksgiving, Christmas, or Labor Day Weekend) since atypical traffic patterns can be expected on these days. This activity must also consider seasonal elements that may affect traffic.

3. Spatial: local, area-wide, or regional economic activity
    - Applicable to AVC and MC.
    - Economic activity (e.g., factory or rock quarry) within an area and vehicle characteristics associated within a particular industry will impact vehicle classification data subsequently reviewed by Traffic Monitoring System Unit staff. Examples of atypical vehicles that are expected to affect vehicle classification data for particular areas include gravel haulers or cotton trailers. AVC equipment provides optimal vehicle classification at locations with typical roadway speeds of 45 mph or faster. Gravel haulers may have operating speeds of less than 45 mph.

4. Temporal: Same season or different season comparison
    - Applicable to AVC and MC.
    - Each time states collect vehicle classification data at a particular site, the FHWA requests that the state schedule the data collection during a season of the year other than the season when the previous data collection occurred.

5. Proximity to traffic generators in rural areas
    - Applicable to AVC and MC.
    - The validation process considers traffic generators in the vicinity of a vehicle classification site such as nearby cities/towns with a population range of 10,000-20,000.

6. Proximity to traffic generators in urban areas
    - Applicable to AVC and MC.
    - The methodologies used to validate data in these areas include using the general highway maps and manually drawing in the stations on photocopies. It is also

necessary to use Automatic Count Recorder (ACR) ramp maps, which in urban areas determine the base volume to compare with data from AVC and MC. Old urban maps sometimes suffice for comparison since these maps provide some idea of what data should be expected. If the data recorded are deemed unreliable, TxDOT must rely on the following year's data. It is necessary to apply a great deal of leniency when determining the level of acceptability of urban area data.

7. Compare total volume to ACR vehicles (for on-system)
    - Applicable to AVC and MC.
    - Make comparisons to ACR ramp map books and district maps.

8. Compare total volume to ACR vehicles (for off-system)
    - Only for MC.
    - Use most recent data available for city streets and county routes.

9. Percent of unclassified vehicles in AVC data
    - Only for AVC.
    - Unclassified vehicles representing 10 percent or more of the total vehicles recorded at a site represents a flag to closely review the data. Data are ultimately deemed acceptable or unacceptable based on professional judgement and not strict criteria.

10. Distribution of vehicle types within each count compared to historical data
    - More oriented toward AVC.
    - Criteria include several items. First, TPP reviews individual vehicle classes (column totals) for consistency with previous years. Then, it considers any shifts in volume percentages. For a Farm-to-Market road, it considers a change of plus-or-minus 9 percent from the previous year's data to be substantial. That much change on a high volume facility would be less critical. Comparisons typically use statewide averages for all facility types.

11. Turning movement validity at leg stations for each vehicle type
    - Applicable to AVC and MC.
    - Logically, the same number of vehicles going into an intersection should be about the same or more as the number of vehicles leaving an intersection. In a previous analysis year, TPP rejected over 38 percent of the vehicle classification data collected. In 1998, TPP adopted a more lenient approach for accepting data.

12. Evaluate the Ebb-Flow (primary and return trip) characteristics at each directional site compared to historical data
    - More oriented toward AVC.
    - TPP reviews the Ebb-Flow characteristics of vehicle classification much the same way as the Ebb-Flow characteristics of ATR data. It compares the vehicle classification volumes in one-direction for the morning peak periods against the classification volumes experienced in the other direction in the evening peak period.

For AVC, the Ebb-Flow characteristics are critical since the data are collected using automatic machines. The review of Ebb-Flow characteristics from MC is important since human counters collect the data. Typical problem areas that are seen when conducting MC include: the human counter falling asleep, hourly volumes recorded in the wrong column, or data transcribed incorrectly to the database. The vehicle classification analyst in the Traffic Monitoring System unit can correct incorrect data transcription.

13. Hour-by-hour analysis and proofing of manual count input
    - Applicable to MC.
    - Same as item 12.

14. Car-pickup-truck ratios compared to historical data
    - More oriented toward AVC.
    - The sum of cars and pickup trucks is typically around 70 percent of the total vehicle volume. Abnormal data require explanation. This 70 percent statistic is a threshold but not a reason in itself to reject the data.

15. Percent trucks
    - Applicable to AVC and MC.
    - It is critical to make comparisons to the previous years' data. TPP typically uses three years of previous data.

16. Number of trucks
    - Applicable to AVC and MC.
    - It is critical to make comparisons to the previous years' data. TPP typically uses three years of previous data.

17. Axle factors/ACR
    - Applicable to AVC and MC.
    - It is critical to make comparisons to the previous years' data. TPP typically uses three years of previous data.

18. Comparison of present data to three years of history
    - Applicable to AVC and MC.
    - TPP typically uses three years of previous data. TPP must consider other factors, such as roadway improvements or construction of a major traffic generator when it uses four or more years of historical traffic data.

19. Objectivity versus subjectivity
    - Applicable to AVC and MC.
    - In considering the sum of the analysis criteria used, the analyst must ask the question "Have I been objective?" and repeat some of the other steps if deemed necessary or move forward with the analysis.

20. Total volume comparison to ATR data from the same site
    - Applicable to AVC and MC.
    - It is critical that the totals are similar between vehicle classification and ATR at the same location. FHWA expects similar totals. If there is a difference of plus-or-minus 10 percent, the process automatically rejects the vehicle classification data.

4.3.3 Weight Data Forecasting

The corridor analysis process supplies data for roadway design purposes based on requests from TxDOT districts. Both traffic and environmental data are made available. Traffic data include roadway and vehicle characteristics information and estimates of the number of ESALs expected on a particular facility. Environmental data include information for use in air and noise analyses.

Data collected from permanent ATR or other historical traffic data provide the input to develop a facility's K-factor, directional distribution, and peak hour factor for use in design. For project locations without access to ATR data or historical data, TxDOT usually develops the K-factor, directional distribution and peak hour factor from data taken from ATR machines at another roadway facility with similar site and traffic characteristics.

4.3.3.1 The Traffic Data Request from a District

Transportation Analysis Branch in the Traffic Analysis Section supplies traffic data for use in roadway geometric design, pavement design, and environmental analyses to districts across the state and other divisions. Districts must supply the Traffic Analysis staff with information related to the project location and special circumstances that might affect traffic characteristics. The following items are typical preliminary information provided by the districts on the Traffic Data Request Form (Appendix E) at the time of traffic data request:

- TxDOT district;
- county;
- Control Section Job (CSJ) number;
- highway name/limits;
- district priority;
- estimated letting date;
- existing number of traffic lanes;
- proposed number of traffic lanes;
- contact person at the district;
- telephone number of the contact person;
- 8 ½ inch by 11 inch site location map;
- information on known or proposed development that will be a traffic generator from area engineer or district headquarter staff;
- for complete Corridor Analysis, a traffic schematic diagram should be provided; and
- line diagrams should be included for all line diagram analyses.

4.3.3.2 Traffic Data Available to District, If Requested

The districts have the option to request a complete or partial corridor analysis. A "Traffic Data Request Form," along with project location information provided by the district, indicates the type of information needed. The Traffic Analysis Branch staff also use the completed form for record keeping purposes.

The data provided by the Transportation Analysis Branch depend on both the type of project and the information requested by the project engineer. The majority of the traffic information comes from the Traffic Analysis Section's Traffic Log (Tlog). Other sources of traffic data include counts from previously completed projects in the same corridor or an adjacent corridor, traffic maps or freeway ramp maps, or previous studies or counts of the facility performed by the local district office or another local agency. The section considers traffic data older than five years out-of-date and does not use the data in the analysis.

When sufficient counts or acceptable data are not available, members of the Transportation Analysis Branch conduct 24-hour counts for the specific project. They use automatic count equipment to count through-movements. Visual observation of pertinent intersections yields the required data for turning movements.

The traffic data and related information that is produced by the Traffic Analysis Branch and made available to the districts upon requested are the following items:

1. Basic highway traffic data for pavement design
   a) Base year or beginning year ADT
   b) Forecasted 20 year ADT (flexible pavement design or signal design)
   c) Forecasted 30 year ADT (rigid pavement design)
   d) Directional distribution (percentage)
   e) K-Factor
   f) Percent truck ADT/ Design Hourly Volume (DHV)
   g) Average Ten Heaviest Wheel Loads (ATHWLD)
   h) Percent tandem axles in the ATHWLD
   i) One direction cumulative 18 kip (ESAL) at the end of 20 years or 30 years for flexible pavement and rigid pavement, respectively
   j) Slab thickness (8 inches unless otherwise specified)
   k) Structural Number (3 unless otherwise specified)

2. Vehicle classification for environmental studies (data for air and noise analyses)
   a) Percentage of ADT for the base year (light duty, medium duty, and heavy duty)
   b) Percentage of DHV for the base year (light duty, medium duty, and heavy duty)
   c) Average daily and peak hour facility speed

3. Line diagram analysis for straight line turning movement volumes for each interchange. The district is responsible for providing the line diagram to the Transportation Analysis Branch.

4. Complete corridor analysis which provides highway traffic data including turning movements for pavement design and environmental studies. The critical elements of corridor analysis are:

   - Roadway geometrics/turning movements/AADT
   - ESALs
   - Data for air quality (vehicle classification)

   The district is responsible for providing a detailed traffic schematic on which the expected turning movements are indicated by Transportation Analysis Branch staff. Figure 8 provides this request and response process.

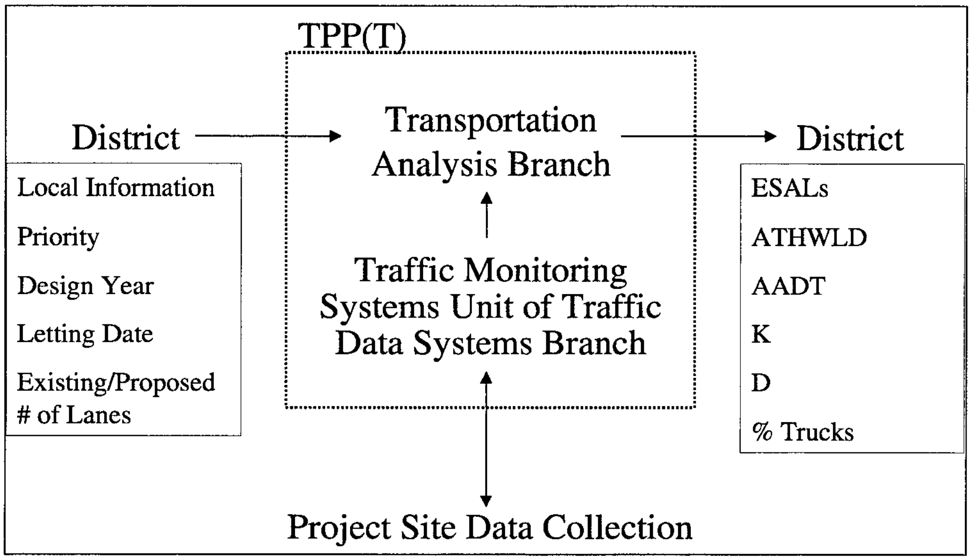


Figure 8. Generalized Project Design Data Process.

4.3.3.3 Generating Pavement Design Data Using TxDOT's RDTEST68 Program

The Transportation Analysis Branch uses RDTEST68, consisting of a main program and several subroutines, to forecast ESALs as part of the project design process. Appendices F and G provide detailed flowcharts and a variable listing of RDTEST68. Figure 9 displays how data flow from the field to ESAL estimates. Discussion of its components, assumptions, and mathematical calculations occur below.

Components for ESAL Generation with RDTEST68

Pavement design requires the calculation of the expected total number of 18,000 lbs (18 kip) ESALs throughout the facility's design life. The RDTEST68 program calculates 18 kip ESAL applications for both rigid and flexible pavement design over a specified time period. The program also calculates the ATHWLD and the percent of tandem axles within the average of the 10 heaviest wheel loads daily. The RDTEST68 program bases its forecast on the following:

- ADT growth rate,
- base year ADT,
- design period,
- percent trucks,
- percent single axles,
- axle factor,
- axle weight distribution table,
- directional distribution factor, and
- lane distribution factor.

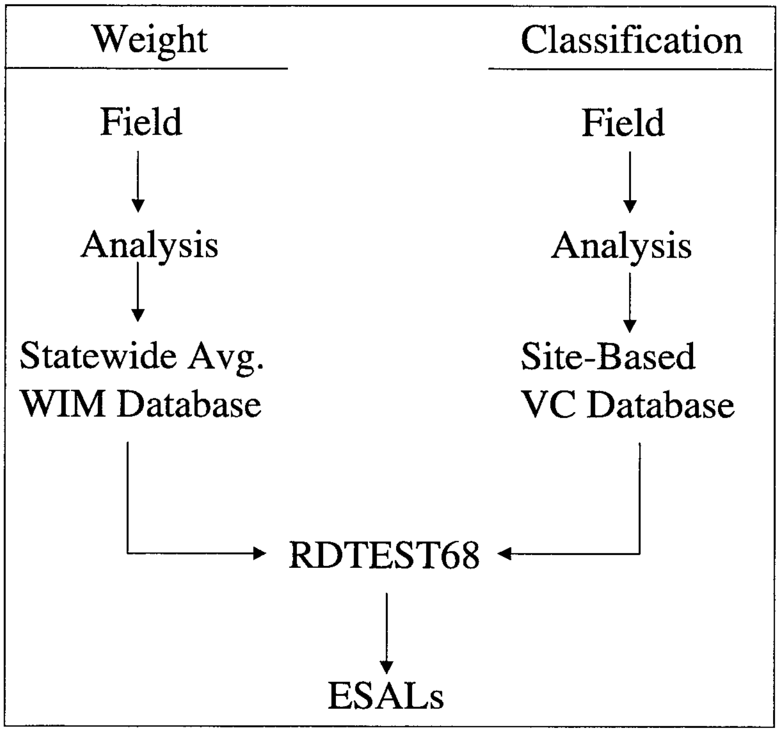


Figure 9. Representation of Data Flow from Field to RDTEST68.

Vlatas and Dresser *(7)* identified the accuracy of inputs and the resulting traffic variance. Their work showed that the three primary contributors to traffic load forecast variance are percent trucks, directional distribution and the average load equivalency factor per truck (calculated from the axle weight distribution table, percent single axles, and axle factor). Table 1 shows the coefficient of variance for each of the ESAL inputs. Table 2 shows five inputs' contribution to the variability in a typical forecast.

Assumptions in RDTEST68

The RDTEST68 load forecasting process uses many assumptions. There is information provided below on these assumptions, including their potential impact on forecasts.

Percent Trucks. Percent trucks indicates the fraction of the traffic stream that is heavy trucks, including 2-axle, 6-tire trucks and buses (class 5 – 13). The forecasting process assumes that the percent trucks remain constant through the design period (i.e., total traffic and truck traffic grow at the same rate) *(7)*. TTI *(46)* documented that as a planning parameter in forecasts, percentage of trucks can range between 2 and 10 percent with a variation from the mean of +/- 67 percent. As reported, this may have a negligible effect (+/- 4 percent of facility size in number of lanes) on the design of number of lanes. Pavement design is more sensitive to this variable.

Table 1. ESAL Input Coefficients of Variance.

Component	Coefficient of Variance (%)
Base Year ADT	2.1 - 10.9
ADT Growth Rate	29.3
Percent Trucks	13.4 - 47.5
Percent Single Axles	≤ 19.7
Truck Axle Factor	≤ 10.8
Average Load Equivalency Factor per Truck	0 - 23.1
Directional Distribution	34.4
Lane Distribution Factor	7.7

Table 2. Selected Input Contributions to Variance of Typical Forecasts.

Component	Contribution to Variance (%)
Percent Trucks	38
Directional Distribution	38
Average Load Equivalency Factor per Truck	17
Base Year ADT	< 4
Lane Distribution Factor	< 2

Vehicle classification data collected at or near the project location, or from sites on roadways with similar characteristics, is the basis of input to the model. When project-specific data are not available, forecasters use a "1/2-growth model" to estimate the percent trucks at the project site based on data from another location (i.e., it assumes that truck volume between the sites grows at half the rate total volume grows between the sites). Research *(7)* has shown that this model over-predicts trucks.

Changes in percent trucks over a facility's design life can contribute to either lengthened (decreases in percent trucks) or shortened (increases in percent trucks) pavement life. A change in percent trucks might be tied to economic activity (expansive or recessionary periods) or effects from trade treaties such as NAFTA.

Axle Factor. Axle factors represent the average number of axles per truck passing a particular point. Tandem axles are one axle set. One assumption is that axle factors remain constant through the design period, implying that the truck traffic stream characteristics remain constant over time *(7).* Research performed by Middleton et al. *(47)* found that axle factors and percent single axles were unrelated to ADT, highway system, or geographic area. Cervenka and Walton *(48)* noted that changes to the axle factor caused a directly proportional change in the forecasted ESALs.

Axle factors can change with the adoption of new truck configurations and can be used extensively within the freight transport industry. For instance, a common 3-axle tractor, 2-axle semitrailer (class 9) would be characterized by an axle factor of 0.33 (one steering axle, a tandem drive axle, and a tandem trailer axle or 1 vehicle/3 axles). However, the axle factor for a split or spread tandem axle set on the trailer would be 0.25 (1 vehicle/4 axles). The latter configuration is growing in popularity with flat-bed truck haulers. A significant increase of these configurations in a pavement's design life can cause premature failure of that pavement.

Percent Single Axles. Percent single axles represent the amount of single axles on all truck axles that pass a particular point. Tandem axles are one axle set on a truck. For example, a 3S2 truck with one single steering axle and two tandem axles (one set on the tractor and the other on the trailer) equates to a 33 percent single axle value. A 3S2 'spread' configuration has three single axles and one tandem axle set that equates to a 75 percent single axle value. Figure 10 shows the difference in single-axle values between these two configurations. Estimates of single axles come from the truck portion (class 5 through 13) of the vehicle classification data. There are no adjustments made for the difference in ADT between the vehicle classification and project sites. The process assumes that percent single axles remain constant through the design period, implying that the makeup of the truck traffic stream does not change with time *(7)*. Because the average load equivalency factor per tandem axle is generally greater than the average load equivalency factor per single axle, a higher proportion of single axles will lead to a lower average ESAL per axle. The opposite condition is also true. Cervenka and Walton *(48)* found that ESAL forecasts dropped 5 percent for flexible pavements and 8 percent for rigid pavements for every 10 percent increase in the percent single-axle variable.

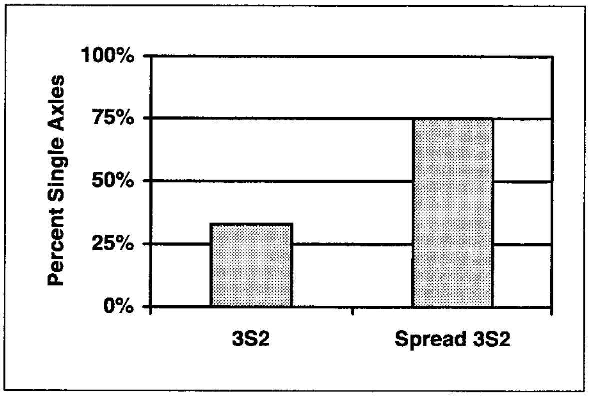


Figure 10. Differences in Percent Single-Axle Values for Standard 3S2 and Spread 3S2.

Axle Weight Distribution Tables. The RDTEST68 program creates axle weight distribution tables for each permanent WIM station and a combined statewide average. TxDOT uses the most recent distribution table of a particular WIM station if it is located on the same roadway as the project, and it uses the statewide distribution if there are no WIM stations on the project roadway. The process assumes that the values in the tables remain constant through the design period *(7)*. Cervenka and Walton *(48)* discovered that the ESAL forecasts varied by more than 40 percent for flexible and rigid pavements depending on the weigh station selected to represent the weight distribution table. Because of this relationship they noted that the selection of a representative axle weight distribution table to represent the traffic load pattern at a particular highway segment was a key assumption. TTI later recommended that project-specific vehicle weight data be continuously collected for seven days at the project site to improve traffic load forecast accuracy by more than 85 percent if the project cost was greater than $543,000 *(7, 46)*. In reference to the effects of spread 3S2 configurations, work by Qu *(49)* on U.S. 59 in TxDOT's Lufkin District showed that ESALs for spread tandems were 2.4 times higher than for the standard 3S2 configuration. Qu's work confirmed earlier work by Pangburn who found–using the same data set–that the ESALs of the spread 3S2 configurations accounted for 12 percent of the daily ESALs. Qu also stated that not separating the spread 3S2 from all other class 9 trucks results in missing about 7 percent of the daily ESALs.

Bass and Dresser *(50)* noted that the assumption that truck classification and truck weights are similar for like roadways and areas, currently used in the traffic load forecasting process, can introduce errors into ESAL estimates on the order of three or four times. They strongly recommended that project-specific data be collected. At a minimum, they suggested that a vehicle classification study be conducted at each project site and if possible to also collect truck weights. A summary of the assumptions described above are: (1) that percent trucks remains constant over the design period; (2) that the truck traffic stream makeup (axle factors and percent single axles) remains constant over the design period; and (3) that the average load equivalency factor per truck remains constant over the design period.

RDTEST68 Mathematical Calculations for Design Lane ESALS

The determination of total ESALs through the use of RDTEST68 requires mathematical calculations using several traffic parameters or components that have already been noted. The RDTEST68 computer program performs these calculations internally thereby easing the task of ESAL forecasting. The program follows the following order in its calculations:

1. The program calculates *Total Vehicles, Total Trucks, and Total Other Vehicles* by using the *Base Year ADT, ADT Growth Rate*, and *Percent Trucks.*

2. The program calculates *Total ESALs for Other Vehicles* by multiplying the *Average Load Equivalency Factor per Other Vehicle* (programmed as 0.000626) by *Total Other Vehicles.*

3. The program calculates *Average Load Equivalency Factor per Truck Axle* by summing all of the EASLs of the single and tandem axle weight groups in the axle weight distribution table.

4. The program calculates *Average Load Equivalency Factor per Truck* by multiplying the *Average Load Equivalency Factor per Truck Axle* by the *Axle Factor.*

5. The program calculates *Total ESALs for Trucks* by multiplying the *Average Load Equivalency Factor per Truck* by the *Total Trucks.*

6. The program calculates *Total ESALs* at the location by summing the *Total ESALs from Trucks* and the *Total ESALs for Other Vehicles.*
7. The program calculates *One-Directional Total ESALs* by multiplying the *Total ESALs* by the *Directional Distribution Factor.*
8. The program calculates the value for *Design Lane ESALs* by multiplying the *One-Directional Total ESALs* by the *Lane Distribution Factor.*

4.3.4 Archival and Reporting

4.3.4.1 Archival

Data archival is important for retaining and using accurate records to support decisions, re-create analyses, and provide information to researchers and analysts on past occurrences. The *AASHTO Traffic Data Guidelines (51)* suggest that data should be retained for a minimum of 10 years. Currently, TxDOT permanently retains all final traffic data; however, varying standards apply to raw traffic data.

4.3.4.2 Reporting

The final step in the traffic load cycle is that of reporting the information to the federal government (Federal Highway Administration), TxDOT pavement designers, and others. Not providing or formatting the data in the correct manner to the user diminishes its value and utility.

Traffic loads are reported to the FHWA through a number of weight tables (W-Tables) generated by the Vehicle Travel Information System (VTRIS) program. The W-Tables are a series of engineering summaries from vehicle weighing and classification programs at truck weigh sites. These tables include station characteristics, comparison of weighed to counted, average empty, loaded and cargo weights, equivalency factors, gross vehicle weights, overweight vehicles, and distribution of overweight vehicles.

Pavement design commonly uses the W-4 Table (Equivalency Factors). Otherwise, department staff report and access traffic load data through the Roadway Information System, which is tied to the Traffic Log.

Though the FHWA Card 7 format described in the TMG is very useful, the format does make it difficult to perform detailed analyses. This is because not all vendor-provided data are transmitted to FHWA and are lost at the state or local user level. Appendix H provides the Card 7 formats. The vendor information contains equipment validity results, perceived axle configurations, speed, lane number, and other data. These data items may be of interest to various users performing specific query functions to determine trends or relationships. For example, equipment performance over time may be of great interest to those who schedule and perform maintenance on this equipment.

A variety of tabular and graphical reports could be generated from continuously collected WIM data. The two primary groups of users of this data are pavement designers and transportation planners. Each group has unique reporting needs.

Pavement designers do not differentiate their designs by season, month, or year. They simply require estimates of truck axle weights expected to be applied to the pavement. As such, their reporting requirements are somewhat simplistic. Conversations held with pavement designers in TxDOT's Design Division Pavement Section indicated that they request weight distribution tables for some period, preferably a year, for each axle group (single, tandem, tridem, and quad). Table 3 shows weight intervals used in an example in the 1993 *AASHTO Pavement Design Guide (52, page D-21)*, which was referenced during these same conversations. The *AASHTO Pavement Design Guide* did not indicate intervals for quad axle groups, so designers use the intervals for tridem axle groups applied to the quad axle group. The AASHTO Guide for Design of Pavement Structures provides LEF in 2 kip intervals. The areas highlighted below can present problems because the standard deviation of the legal axle limit may influence the two intervals.

Table 3. Axle Load Grouping (000s lbs.) by Axle Set.

Single	Tandem	Tridem	Quad
below 6	below 10	below 14	below 14
6 - 12	10 - 16	14-20	14-20
12 - 16	16-20	20-24	20-24
16-18	20-24	24-28	24-28
18-20	24-28	28-32	28-32
20-22	28-32	32-36	32-36
22-24	32-34	36-40	36-40
24-26	34-36	40-44	40-44
	36-38	44-48	44-48
	38-40	48-52	48-52
	40-42	52-56	52-56
	42-44	56-60	56-60
	44-46	60-64	60-64

More discrete intervals are available for more finite analysis. The collapsible nature of a more discrete interval system is an advantage for data reporting. Less discrete information cannot provide more finite analysis and would require a re-query of the data. The user might be presented a selection of interval choices to allow for either broad or discrete analysis of the weight data.

For transportation planning purposes, reports on a seasonal, monthly, or directional basis may offer advantages to a better understanding of freight and commodity movements. This increased understanding could result in better review of forecasted ESALs and more appropriate collection of data (vehicle classification and weight) through scheduling and locating improvements.

CHAPTER 5.0 CONSIDERATIONS FOR CHANGES TO FORECASTING PROCESSES

5.1 INTRODUCTION

Changes to the current TxDOT pavement load forecasting process are imminent. The considerations to these changes include changes in truck configurations, permit loads, seasonal loading, accurately accounting for the effects of steer axles, accounting for directional loading when appropriate, and the proposed mechanistic pavement design process.

5.2 METHODOLOGY

Data collected by TxDOT at the S.H. 48 continuous WIM site provided the basis of analyses in this chapter, unless otherwise noted. TTI received the data from TxDOT and placed them in a relational database. From this database, researchers developed queries to extract the data of interest. Once extracted, researchers analyzed data with conventional spreadsheet software, developing tables and graphs to identify trends and relationships and develop possible explanations. Even when partial data existed, TTI used methods (e.g., average truck per observed day or average ESAL per truck) to standardize the data for comparison.

5.3 FINDINGS

5.3.1 Case Study of S.H. 48 near the Port of Brownsville

A substantial part of this chapter relies on weigh-in-motion data collected by the Texas Department of Transportation on S.H. 48 (0.5 mi SW of the FM 511 intersection) between the City of Brownsville, Texas, and the Port of Brownsville. S.H. 48 at this location is a four-lane, divided roadway section.

Brownsville is located on the Texas-Mexico border and is a major U.S.-Mexico border crossing point for the lower Rio Grande Valley. The Gulf of Mexico is located in near proximity to the east of the city. The proximity of the port and the city being a gateway to Mexico both facilitate a very good trade flow through the City of Brownsville either to Mexico or to the Port of Brownsville. Figure 11 shows the geographic relationship between the WIM site, the port, and the city.

Data collected between May 1998 and December 1999 provide the basis of the analysis; however, some of the monthly data are incomplete. Table 4 shows the months in which partial data were available. Figure 12 characterizes the truck distribution at this site.

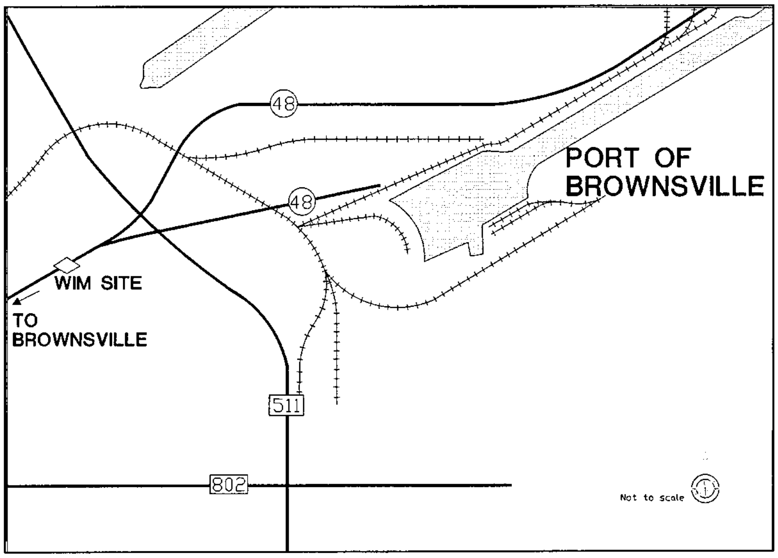


Figure 11. Geographic Representation of S.H. 48 WIM Site.

Table 4. Partial Monthly Data Collected at S.H. 48 WIM Station.

1998	1999
May	January
October	February
November	March
December	April*
	May*
	October
	December

* Note: No data collected for these months

5.3.2 Impacts of Changing Truck Configurations

This report previously introduced vehicle classification schemes. It should be noted that in some cases, vehicles within a specific class may differ in configuration. The most prominent example of this is within class 9 (5+ axle tractor-semitrailer). Class 9 trucks can be one of three body styles: 2S3 (2-axle tractor and 3-axle semitrailer), 3S2 (3-axle tractor and 2-axle semitrailer), and spread 3S2 (3-axle tractor and spread 2-axle semitrailer). The most common body style within this class is the 3S2.

The spread tandem axle configuration utilizes a separation between the two axles on the semitrailer of up to 10 ft. The spread tandem configuration is most prominent in flatbed heavy haul operations. Because the axles are allowed to be loaded like single axles

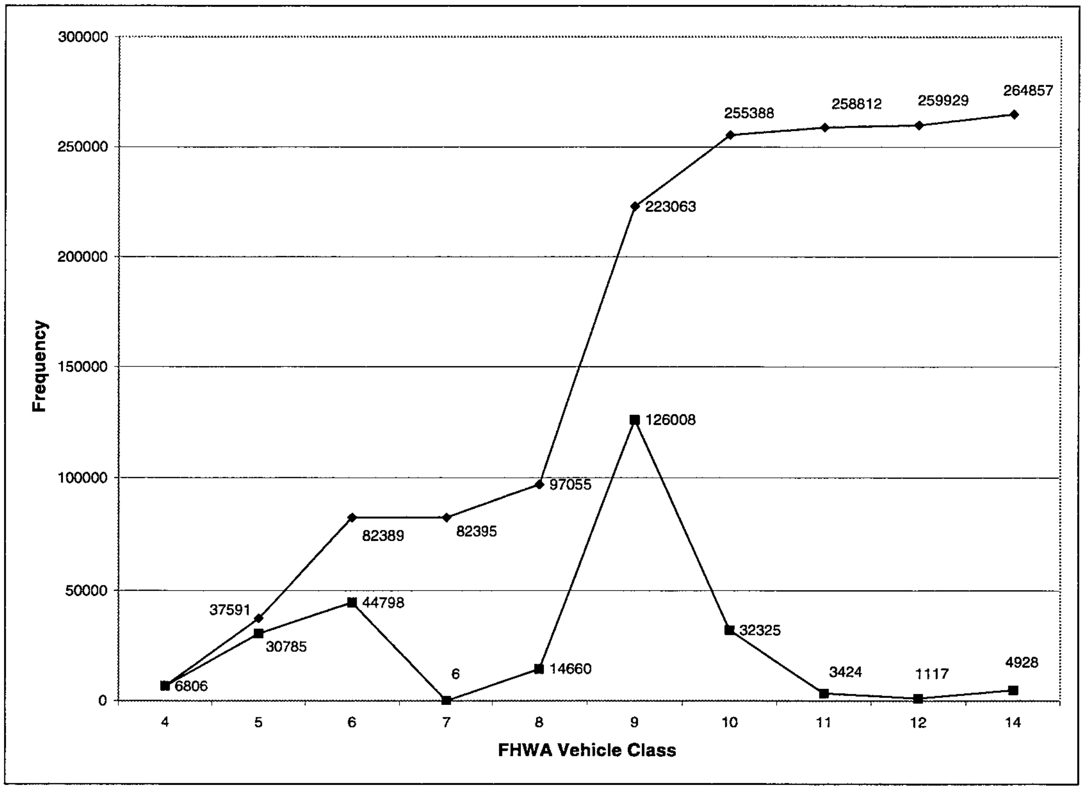


Figure 12. S.H. 48 Truck Class Distribution (May-December 1998).

(20,000 lb limit each v. 34,000 lb tandem limit), two distinct benefits accrue through their use on five-axle tractor-semitrailers: (1) full achievement of the 80,000 gross vehicle weight (GVW) legal limit and (2) better load distribution *(53)*. However, Table 5 shows that the configuration causes more pavement damage than their class counterpart, the 3S2. Relative pavement damage increases 81 percent on flexible pavements and 30 percent on rigid pavements.

Table 5. ESAL Differences for 3S2 and Spread 3S2 Truck Configurations.

Class 9 Type	GVW	ESALs Flexible Pavement (pt = 3.0, SN = 6)	ESALs Rigid Pavement (pt = 3.0, D=11)
3S2	80 kips	2.367	4.074
Spread 3S2	86 kips*	4.297	5.284

*Maximum legal axle weights were used in the calculation

The impacts of these varying configurations are that axle factors increase, as well as percent single axles, both of which can affect ESAL design forecasts. ESALs per truck also increase. Previous research by Lee and Pangburn *(54)* found that the spread tandem configuration of class 9 trucks caused a disproportionate amount of pavement damage given their numbers in the truck fleet. As such, the growth in these vehicle types is of increased interest to researchers and transportation officials.

Continuous WIM data from the S.H. 48 site provided the basis to investigate the proportion of spread-3S2 trucks in the traffic stream. From these data, researchers extracted all class 9 trucks over the analysis period (May 1998 – December 1999). Figures 13 to 19 show relationships observed between a standard 3S2 and spread 3S2.

Figure 13 shows the class 9 vehicle type distribution by month observed on S.H. 48. Months with partial data were: May 1998, October 1998 through March 1999, October 1999, and December 1999. Because only partial monthly data were available, the number of trucks observed passing a point might not show trends in the data. To minimize the effect of partial data, research staff standardized the number of trucks by the number of days of data collected each month to yield the average number of trucks per observed day. This minimizes the effect of partial data. Figure 14 displays the average daily observed trends.

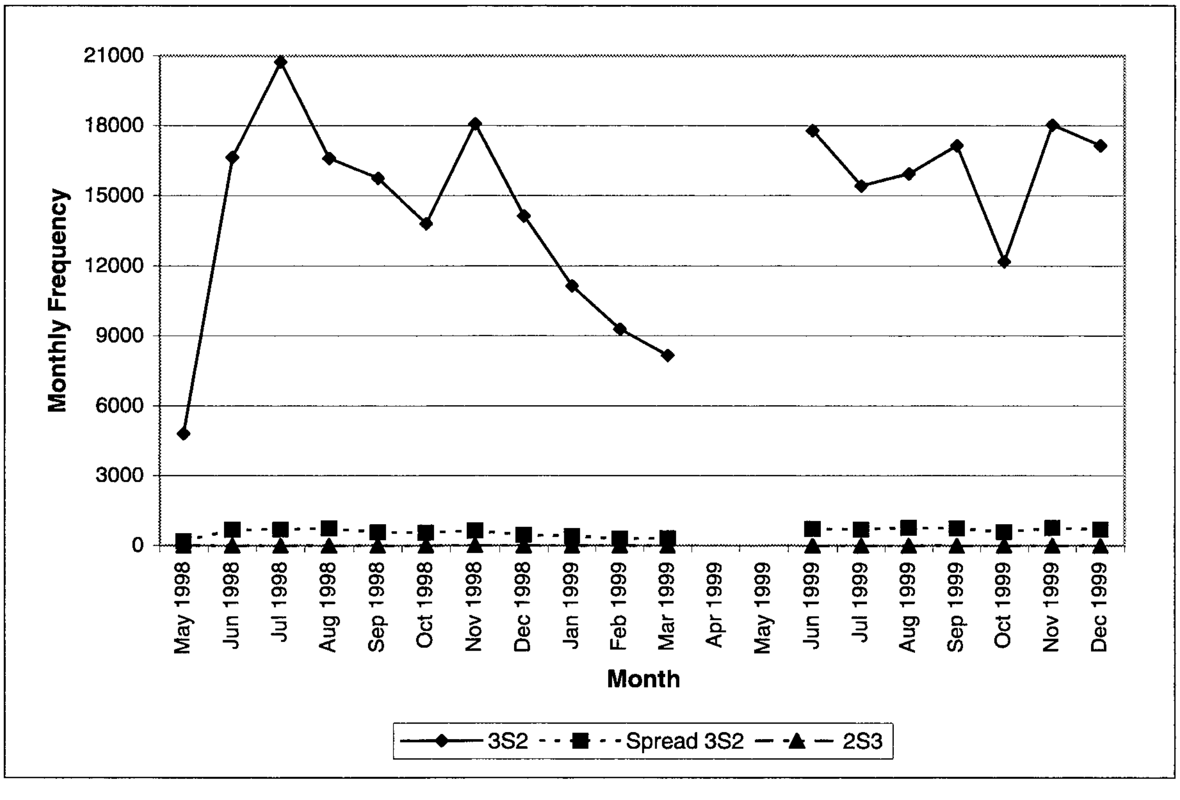


Figure 13. Class 9 Vehicle Type Distribution by Month.

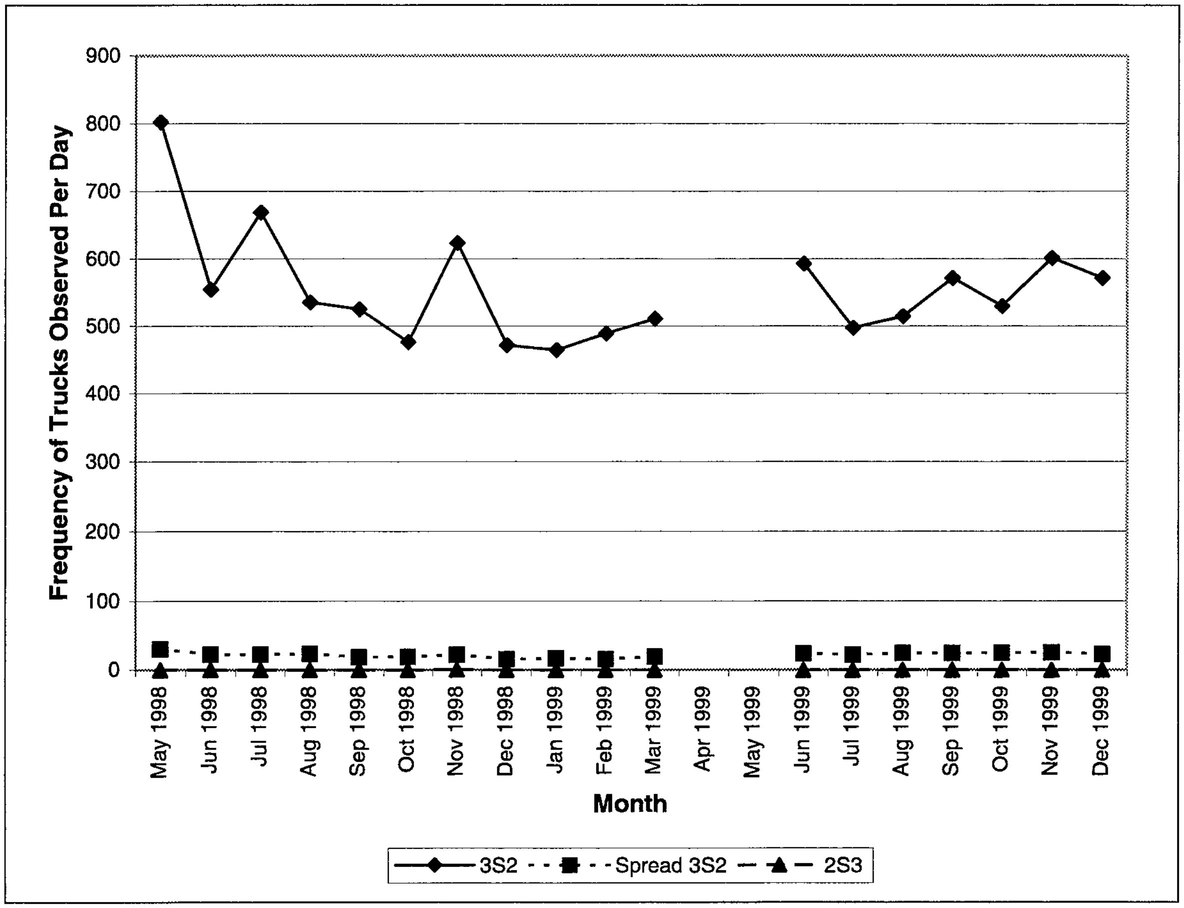


Figure 14. Class 9 Vehicle Type Distribution by Month Normalized by Days Observed.

The only complete months for which a comparison between actual month to actual month can be made with these data are June through September. Figure 15 displays the growth in each vehicle class from the same month the previous year. It is interesting to note that the 3S2 spread tandem configurations change ranged from zero to greater than 20 percent. Qu *(49)* found that the annual growth rate for spread 3S2 trucks was 7 percent. Averaging the monthly increases for S.H. 48, the spread 3S2 was growing at 9 percent while the 3S2 was decreasing 3 percent.

Figure 16 shows the continuous trend for 3S2 spread tandem trucks at the study site. The average proportion of spread tandem trucks at this location each month ranges from 3.5 to 4.5 percent. The proportion decreases during the winter season and increases during the summer season. Figures 17 and 18 show that the average number of spread tandem 3S2 trucks was higher in 1999 than in 1998 for the period from June through December. A decrease in December is consistent between each year, but the magnitude of the decrease is not. The standard 3S2 truck remains a significant portion of the class 9 truck fleet as shown

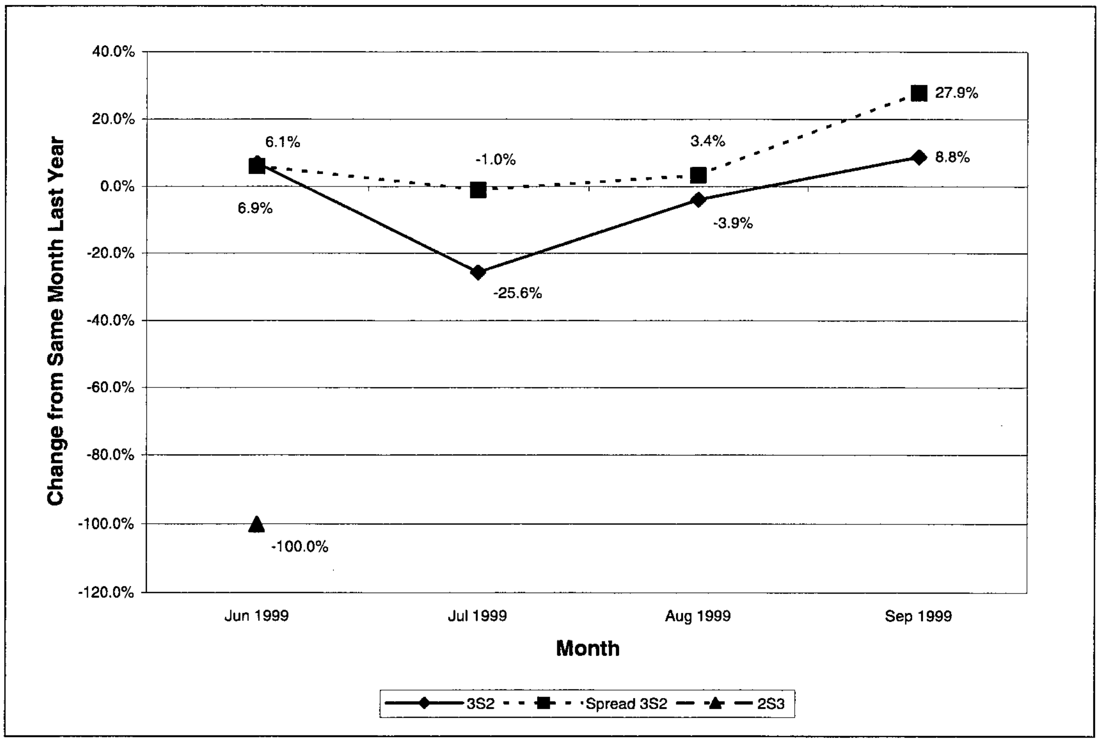


Figure 15. Relative Yearly Class 9 Vehicle Types at Port of Brownsville Site.

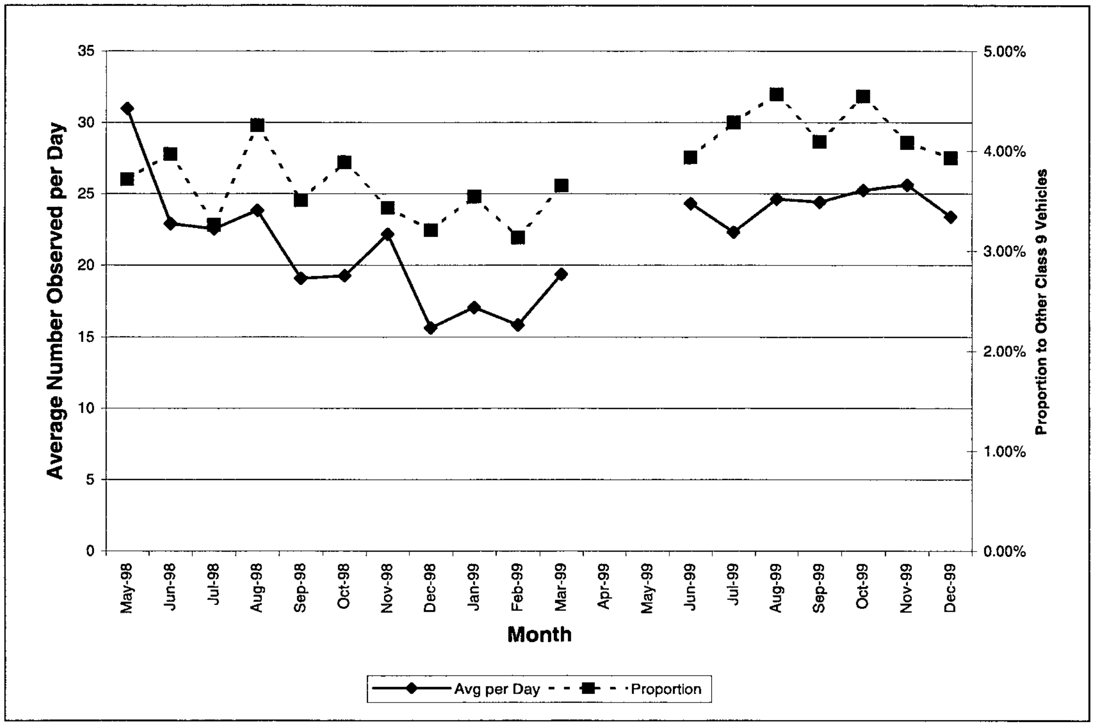


Figure 16. Historical Trend for 3S2 Spread Tandem Trucks.

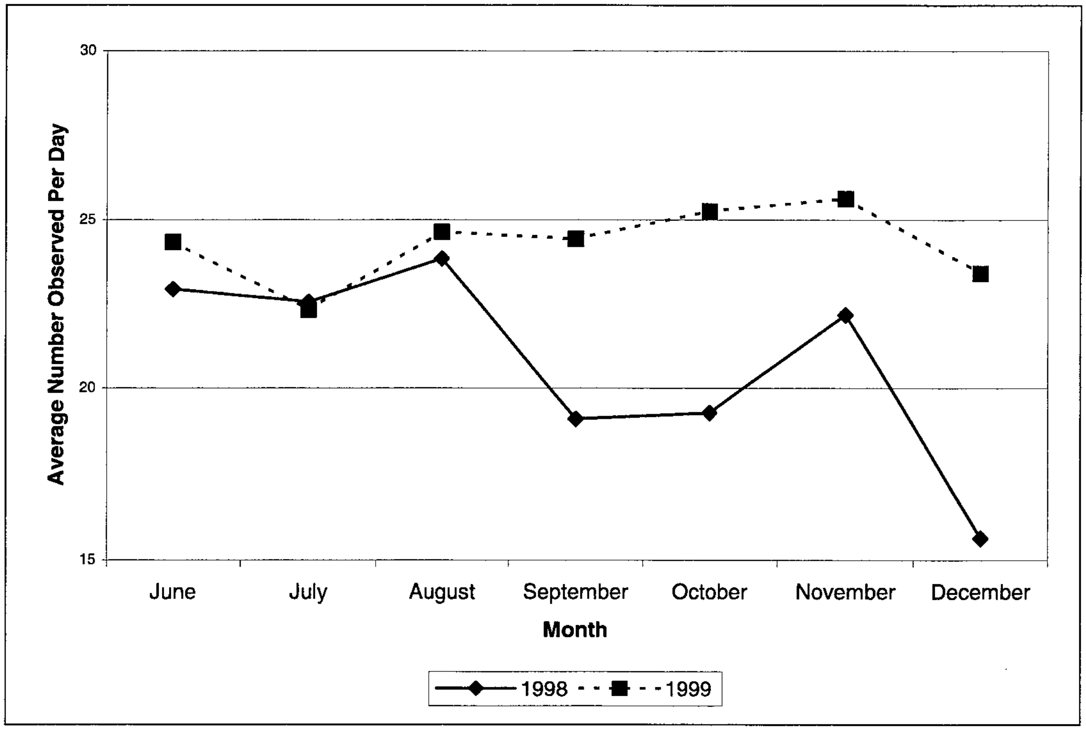


Figure 17. 1998 v. 1999 Average Number of Spread Tandems Observed per Day.

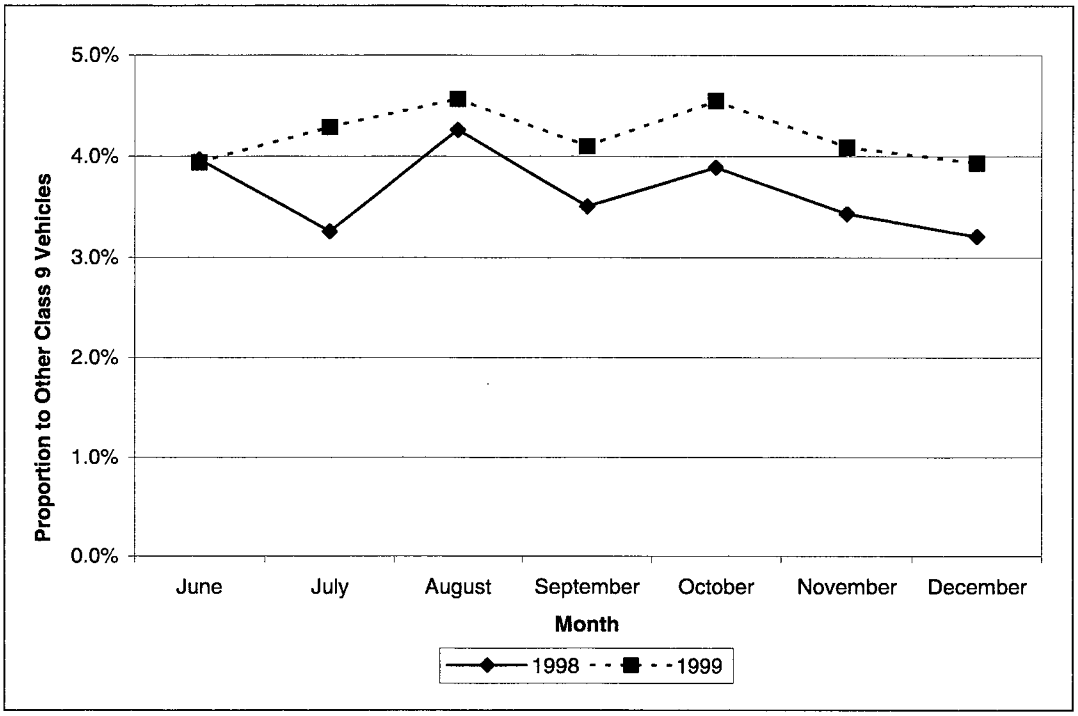


Figure 18. 1998 v. 1999 Spread Tandems as a Percent of Class 9 Vehicles.

in Figure 19. As shown in other figures, the trends from 1998 to 1999 are similar with the exception of the month of July. The number of 3S2 spread tandems appears to be growing at this site. However, calculating a growth rate for this vehicle type is not appropriate due to a lack of annual historical data.

5.3.3 Impacts from Differences in AADT and Truck Growth Rates

Truck growth rates in urban areas can be higher than the AADT growth rates on the same roadways, violating a RDTEST68 assumption of fixed percent trucks. Increasing numbers of 2-axle, 6-tire trucks used for personal and business uses may account for a significant amount of the change. As noted previously, the percent truck component of the load forecasting process is one of two factors contributing to the highest variance in predictions. The FHWA has previously suggested that separate growth rates be developed for trucks and even further suggesting that individual growth rates be developed for each truck class. Figure 20 reflects a hypothetical scenario in which the AADT growth rate is 5 percent, and the truck growth rate is 8 percent. At the end of 30 years, trucks as a percent of the traffic stream far exceed an assumed constant percent trucks, in this case 5 percent. As the graphic shows, the proportion of trucks approaches 12 percent by the end of the 30-year period.

5.3.4 Observations on Overweight Trucks

In NCHRP 241, gross weight is considered the primary factor of pavement rutting *(55)*. However, findings of FHWA's Truck Size and Weight Study identified axle weights as the primary factor in rutting. Legal limits of truck weights are defined through individual axle weights, gross vehicle weight, and use of the Bridge Formula (function of axle spacing and weight). These weight limits protect the design life of both bridges and pavements. The effects of axle weights are more significant to pavements and short span bridges, whereas GVW is more significant to long span bridges *(53)*. Pavement damage increases by a power of four with respect to axle weights.

This portion of the study defines overweight trucks as any vehicle with a GVW greater than 80,000 lbs. This is the maximum statutory legal limit in Texas, but there are also permitted loads such as non-divisible load permits or 2060 permits (issued by TxDOT's Motor Carrier Division). Figure 21 is a plot of weigh-in-motion data (May 1998 – December 1999) from near the Port of Brownsville. Months with partial data are: May 1998, October 1998 through March 1999, October 1999, and December 1999. Classes 9 and 10 significantly represent the overweight trucks, and summer months indicate higher incidence rates than during other seasons. Figure 22 shows the weight data normalized by number of trucks passing the site, indicating a generally decreasing trend in the rate of overweight trucks among all truck classes at this site. Table 6 is a tabular summary of these same data.

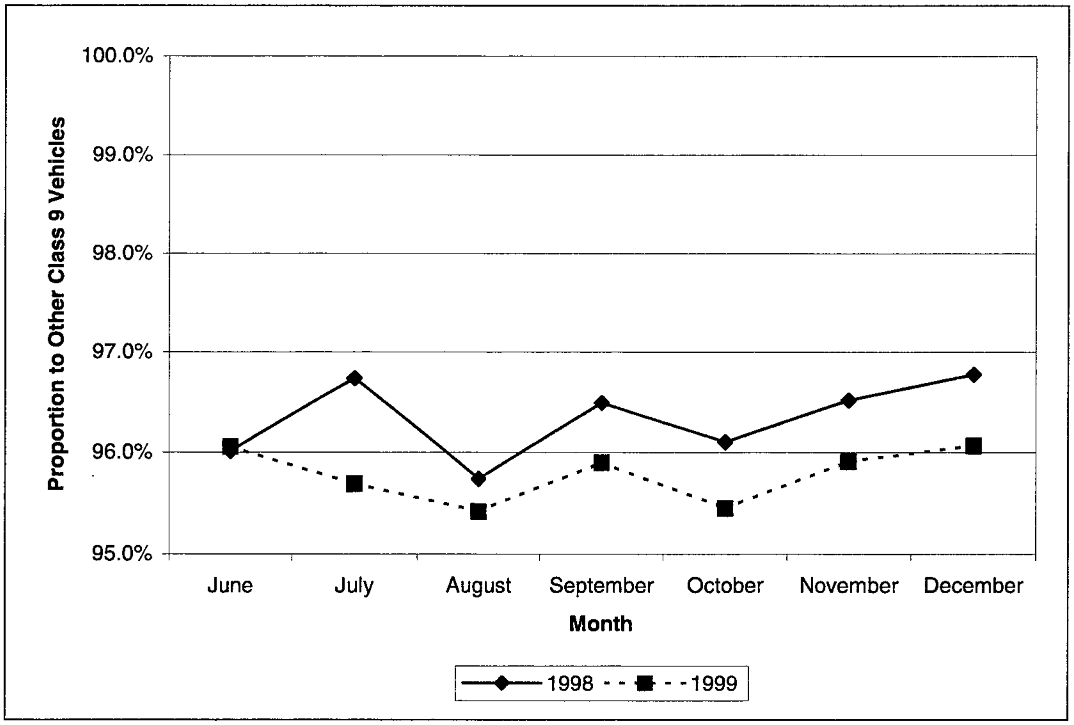


Figure 19. 1998 v. 1999 Trend of 3S2 Proportions, June – December.

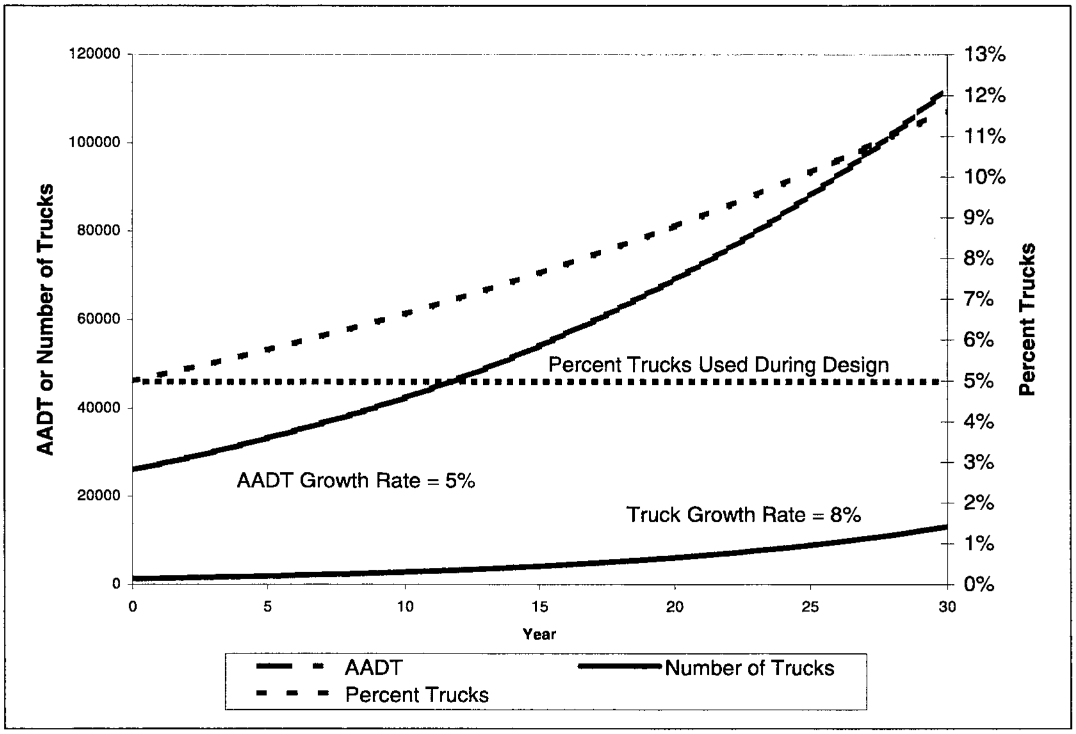


Figure 20. Impacts from Differences in AADT and Truck Growth Rates

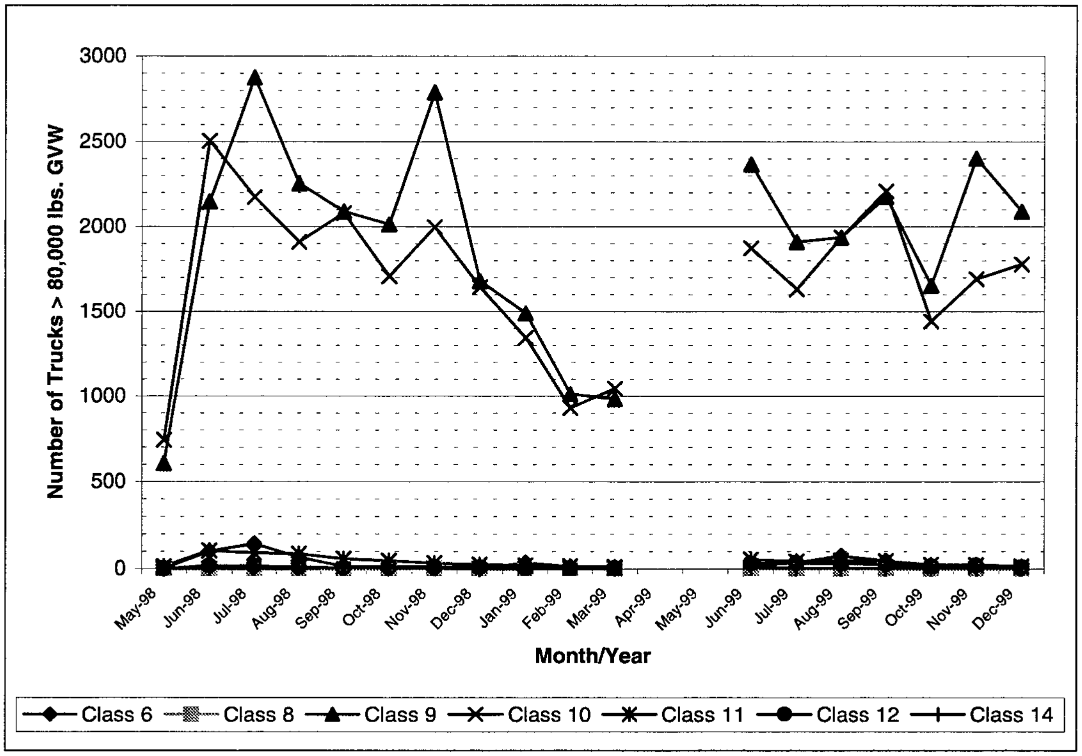


Figure 21. Historical Number of Trucks Greater than 80,000 lb GVW by Class.

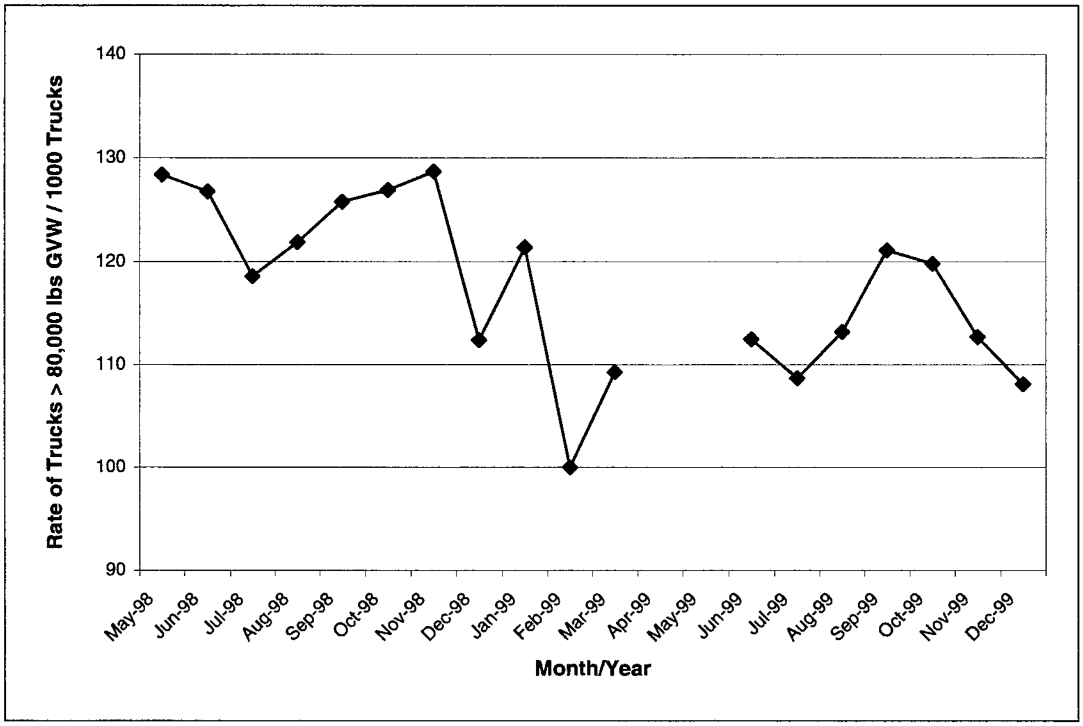


Figure 22. Incidence Rate of Trucks Exceeding 80,000 lb GVW per 1,000 Trucks.

Table 6. Number of Overweight Trucks Observed (over 80,000 lb).

Dates	Class 4	Class 5	Class 6	Class7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 14	Total	OW Trucks/1000
May-98	0	0	2	0	0	608	744	15	2	1	1372	128.4
Jun-98	0	0	101	0	1	2149	2505	105	18	4	4883	126.8
Jul-98	0	0	146	0	0	2878	2176	92	17	3	5312	118.6
Aug-98	0	0	67	0	0	2254	1911	86	11	3	4332	121.9
Sep-98	0	0	16	0	0	2091	2082	59	6	7	4261	125.8
Oct-98	0	0	13	0	0	2016	1710	47	9	5	3800	126.9
Nov-98	0	0	15	0	3	2791	1999	34	11	3	4856	128.7
Dec-98	0	0	0	0	0	1681	1646	24	10	0	3361	112.4
Jan-99	0	0	35	0	0	1491	1346	20	3	2	2897	121.4
Feb-99	0	0	14	0	1	1013	930	16	4	2	1980	99.98
Mar-99	0	0	3	0	0	983	1045	11	3	0	2045	109.3
Apr-99												
May-99												
Jun-99	0	0	18	0	3	2368	1874	54	30	12	4359	112.5
Jul-99	0	0	36	0	0	1912	1633	44	34	5	3664	108.7
Aug-99	0	0	76	0	3	1937	1938	49	30	5	4038	113.2
Sep-99	0	0	47	0	0	2178	2209	45	26	3	4508	121.1
Oct-99	0	0	19	0	0	1654	1444	25	15	5	3162	119.8
Nov-99	0	0	24	0	0	2404	1692	23	20	8	4171	112.7
Dec-99	0	0	6	0	0	2090	1779	15	10	5	3905	108.1
Total	0	0	638	0	11	34498	30663	764	259	73	66906	
OW Trucks/1000	0	0	14.2	0	0.75	273.8	948.6	223	232	14.8	294.4	

5.3.5 Effects of Seasons on Pavement Loading

Truck loads can vary weekly, monthly, or annually, not unlike traffic patterns. The use of continuous WIM affords analysts data from which these trends or patterns may be identified and predicted. However, this analysis requires large amounts of data.

Researchers examined four months (June – September 1998) of continuous WIM data from the Port of Brownsville site. Figure 23 suggests that the number of trucks in July 1998 were significantly higher than for the other three months simply because the number (frequency) of axles is greater throughout the spectrum of weight intervals investigated. Figure 24 normalizes the months by the numbers of trucks, indicating closer agreement in the four months of data.

Review of the monthly changes in the tandem axle distributions shown in these figures highlights the importance of collecting vehicle weight data at the appropriate time. Seasonal effects may impact both the number of trucks and hence truck axles and the average ESAL per truck. Work by Southgate *(56)* led him to make the following statements after review of WIM and AVC data from multiple sites, multiple states, and multiple calendar years:

- seasonal effects are highly site-specific; and
- even a week's WIM data may yield results not representative of the calendar year.

The pavement designer or transportation planner forecasting loads must decide if data collected at the project site should include seasonal events such as a harvest. These annual events can result in higher truck activity and higher truck weights as commodities move to towns and cities for sale and distribution. Designers should give attention to these seasonal events and should include them in the initial or overlay design for roadways where these trends occur.

5.3.6 Effects of Steering Axles on Pavement Loading

Batelle *(57)* stated that the AASHTO factors underestimate the steering axle impacts on pavement wear because "the AASHTO load equivalency factors strictly apply only to axles supported at each end by dual tires." They further summarized from work performed by Gillespie et al. *(58)* that the "single tires on a steering axle carrying 12,000 pounds can be more damaging in fatigue and rutting to flexible pavement than a 20,000-pound axle with dual tires."

Researchers reviewed both the steering and single axles of class 9 trucks from the S.H. 48 site. Figure 25 shows how significant the steering axles are in the single axle distribution. Figure 26 disaggregates components of Figure 25 to show how each contributes to this relationship. Almost 90 percent of the steering axle loads at this site were under the legal 12,000 lb limit. The slightly more than 10 percent of these 'illegal' steering axles may be attributable to the accuracy of the WIM equipment and the fact that the axle weight bins used change at the legal limit. Only the spread 3S2 single axles significantly contribute to the

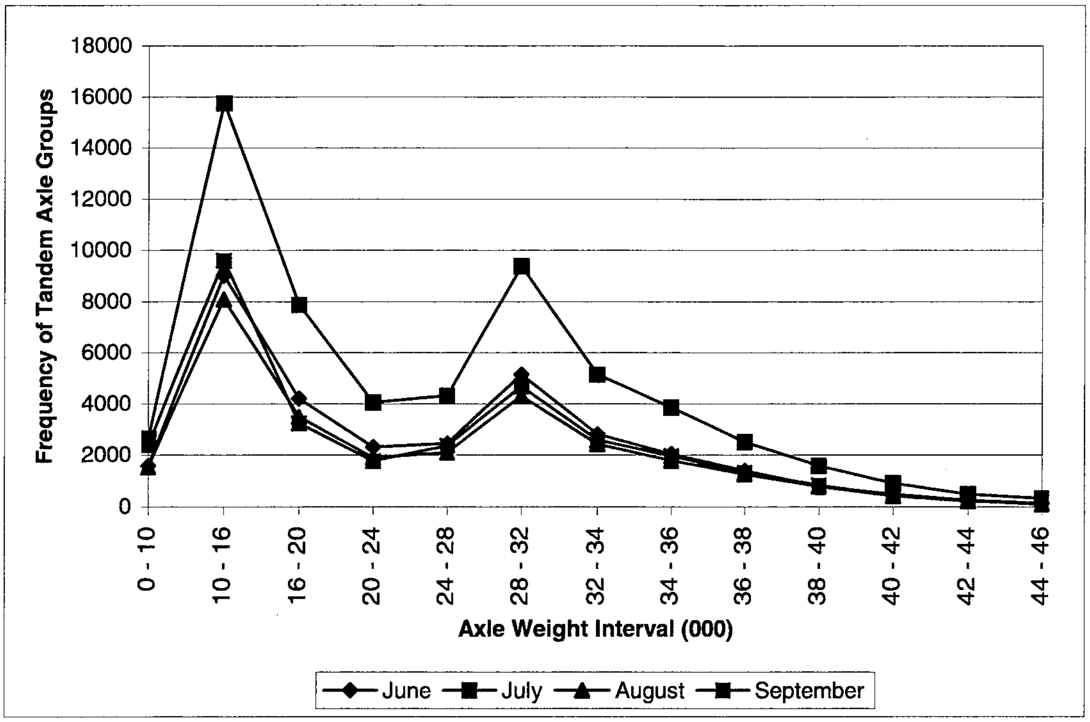


Figure 23. Frequency of Tandem Axle Groups by
Weight Interval for Class 9 Trucks, June - September 1998.

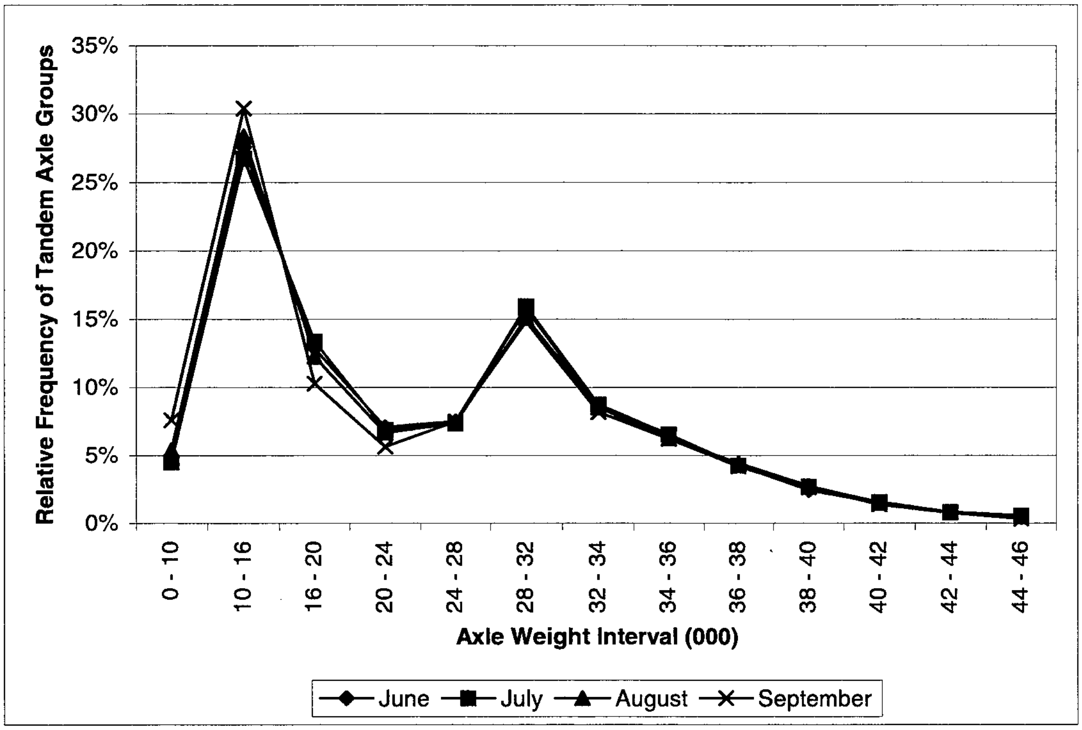


Figure 24. Normalized Frequency of Tandem Axle Groups by
Weight Interval for Class 9 Trucks, June - September 1998.

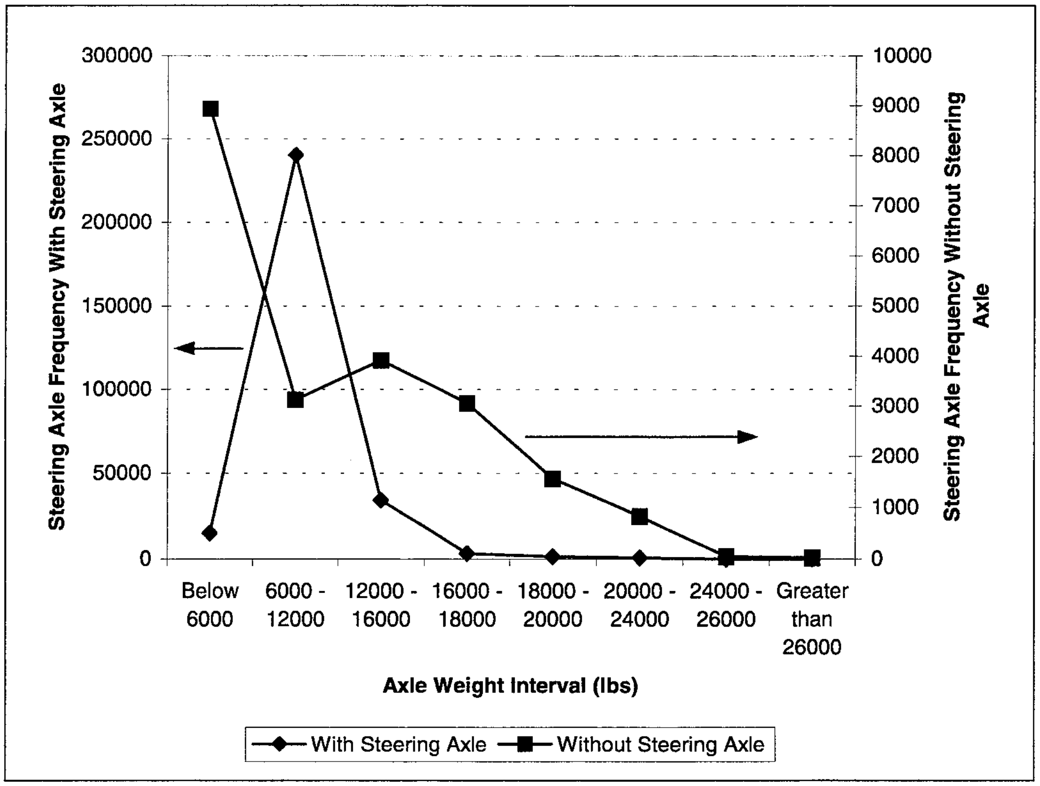


Figure 25. Steering Axle Frequencies for Class 9 Trucks.

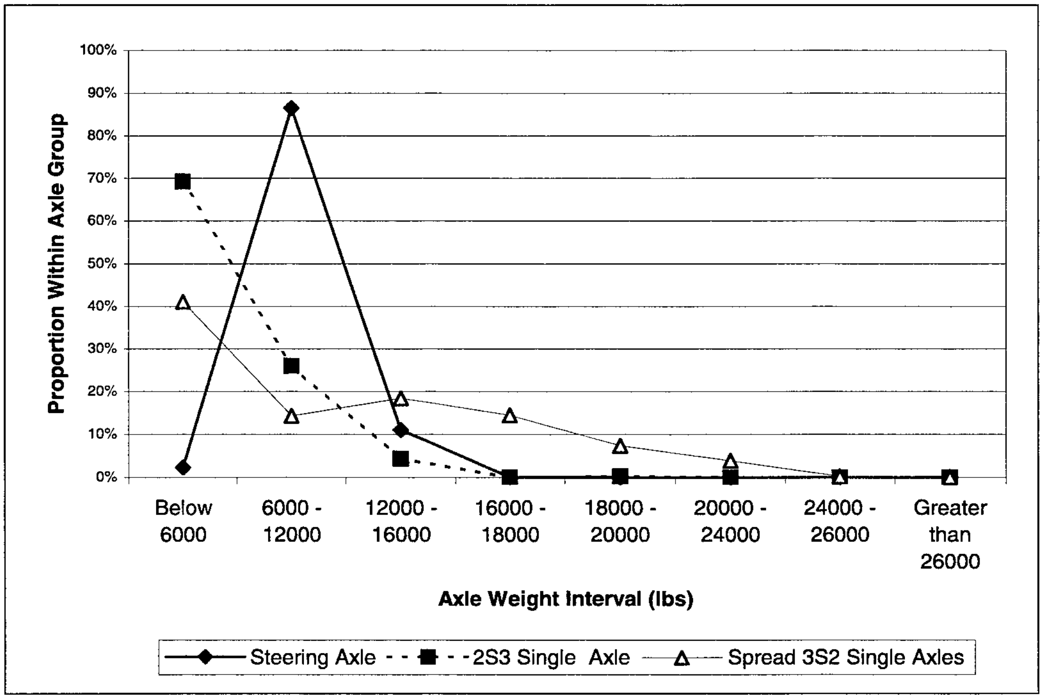


Figure 26. Contributions of Single Axles.

distribution beyond the 6000-12,000 lb interval, with a peak in the 12,000-16,000 lb interval. The spread 3S2 single axles also have a small proportion (approximately 5 percent) that exceed the legal limit for a single axle. Again, this may be due to factors already noted.

5.3.7 Need for Directional Analysis

Increased pavement costs per added ESAL-mile can vary significantly depending on pavement thickness, quality of construction, and season of the year *(57)*. It is important to collect relevant and site-specific data if there are concerns about locally heavy loads in one or both directions. Significant cost savings–through rehabilitation costs or sooner-than-expected replacement costs–can be realized if pavements are designed by direction under special circumstances.

5.3.7.1 Conditions Requiring Directional Analysis

Experience gained in the local area is the best indicator for suspect locations where directional analysis of weight data should be conducted. This experience draws from local trucking operations, development or expansion of special generators (e.g., gravel pits, lumber mills), and the rate of pavement rutting. These components will guide the engineer in identifying candidate locations.

5.3.7.2 Examples of Need for Directional Analysis

Only a small number of recorded cases exist where engineering studies were conducted using WIM technology to determine if a directional pavement design was needed. An example of this study type was US 380 near Decatur, Texas, outside of Fort Worth. TxDOT analysis of the collected truck weight data revealed that the average ESAL per truck was seven times greater in one direction than another (2.26 v. 0.32 calculated for flexible pavement with SN=3 and P=2.5). As a result of their analysis, they were able to significantly alter the pavement design of this project to accommodate loaded and unloaded truck flows, saving hundreds of thousands of dollars in initial material and construction costs or rehabilitation costs for premature pavement failure.

Examining data from the S.H. 48 site, there does not appear to be a significant difference between directions of travel. Figures 27 and 28 display the directional characteristics of class 9 trucks at this site. Directional distribution of class 9 trucks is for practical purposes the same for both directions of travel. Analysis of lane distribution of class 9 trucks shows that, on this four-lane section, trucks favored the right lane both inbound and outbound from the port by a margin of 8:1 to almost 11:0. Figure 29 shows the ESAL analysis of class 9 trucks from June through August 1998. It shows that the average ESAL per truck traveling to the port is 0.49 and traveling to the city is 0.79, despite a 7300 difference in class 9 trucks traveling to the port (140,692 v. 133,337). This site certainly does not exhibit as significant a difference between directions as the US 380 location; however, additional analysis with all truck classes may reveal higher differences in the directional ESAL estimates.

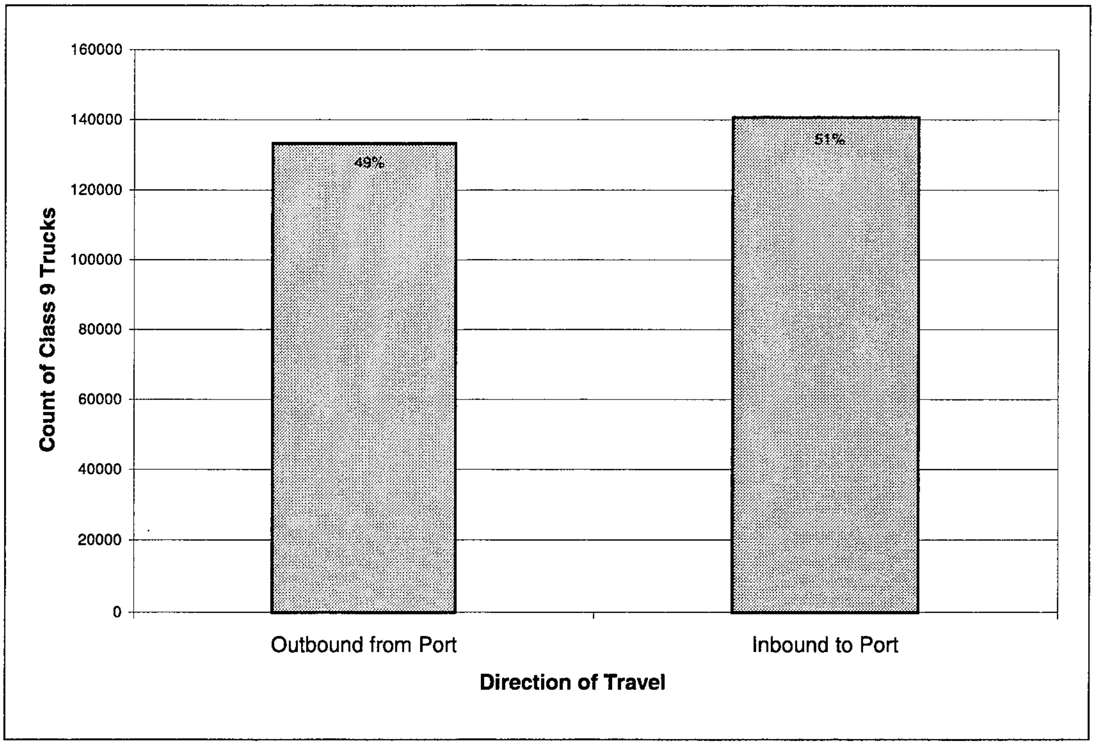


Figure 27. Travel Distribution for Class 9 Trucks.

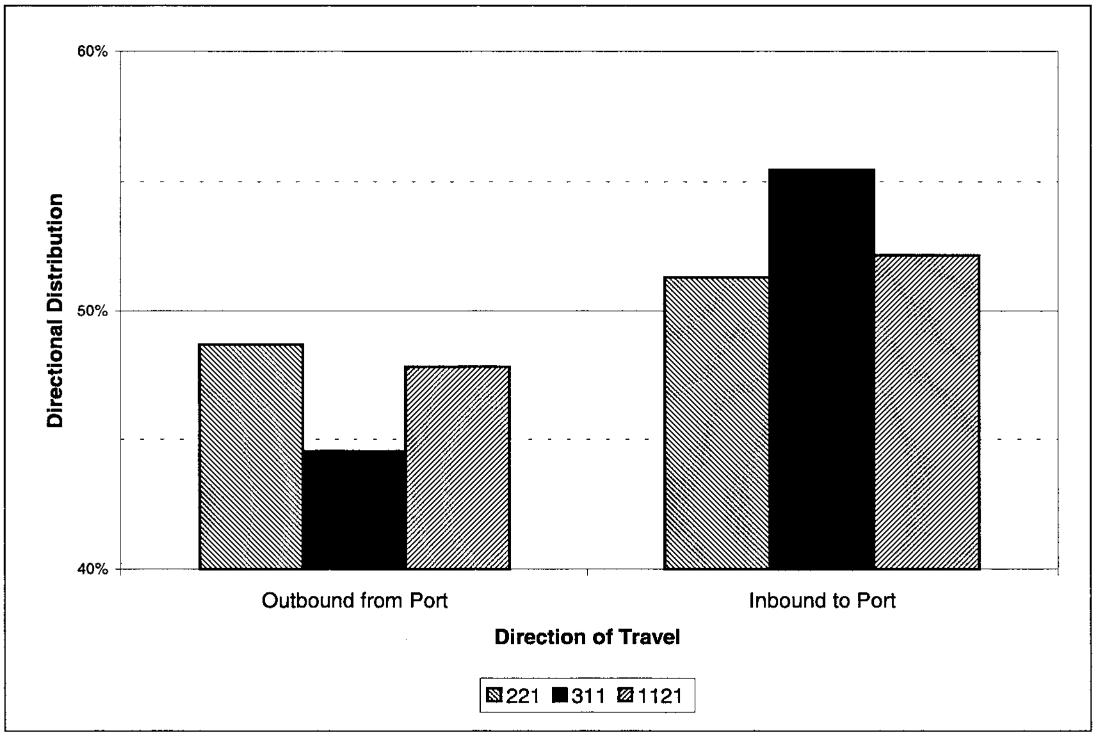


Figure 28. Directional Distribution for Class 9 Trucks.

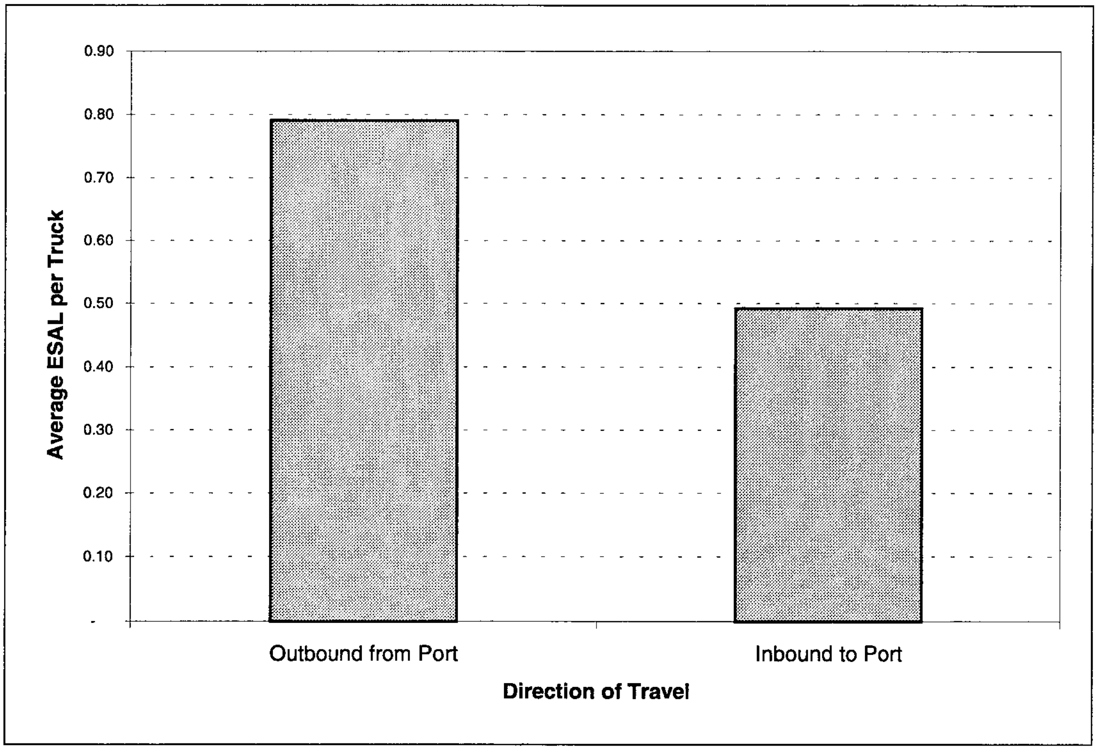


Figure 29. Directional Distribution of Average ESAL per Class 9 Truck, June - August 1998.

5.3.8 Impacts of Mechanistic Design Process

Procedures under development propose a drastically different approach from that currently in use (use of ESALs), a mechanistic design process, which will soon replace existing methods for designing pavements. As stated in the procedures *(59),* ESAL data are not warranted when using mechanistic based pavement performance models. The procedure suggests a hierarchical approach for design/analysis levels based on the availability of certain data types.

The new design guidelines will require the development of a full axle-load spectrum for single, tandem, and tridem axles. The five traffic inputs identified in this process are:

- normalized axle load distributions or spectrum,
- normalized vehicle class distribution or spectrum,
- vehicle counts,
- loading details of the axle load and axle configuration (e.g., tire type and pressure, axle and tire spacing), and
- traffic factors (e.g., directional distribution, lane distribution, traffic growth factor).

The procedures encourage that the importance and level of effort in sampling the traffic population over time be increased. For a 90-10 statistical plan, this new procedure requires a minimum of :

- one day of WIM data to estimate the normalized axle load distribution,
- two days of AVC data to estimate the normalized vehicle class distribution, and
- twenty-seven days of AVC data to estimate the total axles per day by month or year.

Other suggestions for the sampling plan include using a minimum of three years included in the traffic sample (to reduce sample bias), use of appropriate seasonal samples (for consistent computations, month-month or year-year), and developing a stratified random sampling plan to identify differences in the traffic population). TxDOT can meet the data needs for a 90-10 statistical plan to normalize the axle load and vehicle class distributions. However, TxDOT will be required to increase data collection and retrieval activity at AVC sites throughout the state to begin estimating changes in total axles per day by month or year.

The normalized vehicle class spectra also require the number of axles for each axle type over a specified period of time. This is done to determine changes within each classification. Normalizing each axle load spectrum for each axle type within each vehicle class follows. This approach places increased emphasis on the higher load groups with reasonable numbers of axles.

In both of the normalizing processes mentioned, one must examine both annual and seasonal differences in data. Additionally, the analysis should determine if significant differences exist between days of the week or between weekdays and weekends. Changes to current TxDOT data analysis processes will be required to accommodate the procedures outlined in the new process to better evaluate and identify significant differences in vehicle class and axle weight data.

The new procedures suggest the use of all available data for developing traffic growth or decay factors. This will include time series analysis to either forecast or back cast for the number of axles or vehicles per day and the average number of axles per day for each year or season. Although TxDOT creates forecasts today, it does not develop back casts. Development of back casts would be extremely beneficial to TxDOT in assessing the accuracy of forecasts, what assumptions changed and affected forecasts, and how to improve future forecasts.

CHAPTER 6.0 CONSIDERATIONS FOR ACCOMMODATING CONTINOUSLY COLLECTED WEIGHT DATA

6.1 INTRODUCTION

Collecting continuous WIM data poses an information systems challenge. Traditionally, Texas collects WIM data each quarter for 48 hours from each operational site from the state total of 15 sites. The collection and use of continuous WIM data would represent a significant departure from the current system used by TxDOT.

Continuously collected truck weight data requires large amounts of storage space regardless of the file format (flatfile or TXT v. database). Low-cost, conventional office methods for data storage and analysis may not be practical for large amounts of truck weight data. Spreadsheets such as Microsoft Excel have space limitations for rows, columns, and pages. For continuous truck data, the row and page limitations become critical with these types of applications.

Common database programs such as Microsoft Access are the next logical option to handle large amounts of data. Upon importing data into a database, users can develop queries to extract data of interest. These queries also increase the storage requirements. Some applications exhibit their limitations during queries by requiring unusually long periods of time to execute on a PC workstation.

6.2 METHODOLOGY

The methodology used in this chapter began with acquiring data collected by TxDOT at the S.H. 48 continuous WIM site. Research staff used the data primarily for the sampling frequency investigation discussed later in the chapter. TxDOT transmitted the decompressed vendor data files in ASCII-formatted files to TTI. The next step was to pre-process these files to strip out header information then load the data into a Microsoft Access database. Importing these data required splitting each element of the daily data file into one of several tables (rejected, accepted-speed, and accepted-remainder). Then came query development and application, in most cases, to the Accepted-Speed table, extracting data of interest to the research team.

Experience gained while working with the data facilitated estimates and recommendations to be made concerning storage requirements and database environments. Projections of the actual file sizes allowed development of annual and system storage requirements. The other consideration dealing with database environments was strict adherence with TxDOT ISD documentation resulting in only approved platforms being used in this document.

6.3 FINDINGS

6.3.1 Data for Trend Analysis

Trend analysis is very beneficial to engineers and planners in identifying historical patterns and preparing for future conditions. Though extensive historical data appear very desirable in developing trends, changing conditions at the data collection site may prove a challenge in developing meaningful long-term trends.

When does historical traffic data become too old to be useful? The data becomes old when the data no longer serve the purpose for which it was collected. The period of time each dataset is useful depends on the goal. Data from 10 years past can be significantly different from the present for reasons such as changes in roadway geometrics, surrounding land use and demographics, and economic conditions. For purposes of forecasting, current data–for example the most recent two or three years–would be more useful because it contains more representative data collected under similar environments and/or circumstances. Yet 10 years of data can also be used to examine historical patterns that can be related to similar locations where no data were collected.

AASHTO recommends retaining permanent traffic counts for a minimum of 10 years *(51)*. They did not infer that this amount of historical data be used for future trend development or analysis. Rather, this desire reflected the possibility of states developing historical trends to show the evolution of traffic over time.

As mentioned earlier, the customer needs assessment performed for this project found that 1-, 5-, and 20-year historical trends were the most desired from which to make future forecasts. Because annual changes are not found in 1-year trends, the 5- and 20-year timeframes would better identify significant changes in traffic or vehicle weight characteristics. District staff favored 5-year trends, whereas Design Division staff preferred 20-year trends.

Historical trend development should be performed with a minimum of 10 years of data when available. This meets the recommendations of AASHTO, exceeds the expectations of district staff, but does fall short of Design Division desires.

6.3.2 Aggregation

Each record in a vendor's raw WIM file is unique and holds valuable information for the research community, policy makers, and the department. Information such as date and time, equipment error checks, vehicle speed, and the vehicle's physical characteristics are all important data. The authors do not recommend aggregation of data at any level once taken from the field and placed in the primary WIM database.

Certainly WIM data can be used for other purposes. The system is the most comprehensive data collection device of typical traffic statistic information. These systems not only collect weight information, but record vehicle classification and traffic volume. Therefore, aggregation may be performed to meet the hourly or 15-minute needs of continuous vehicle volume and continuous vehicle classification programs from the primary WIM database.

6.3.3 Size of Data Storage Needs

A conservative estimate of annual storage space was prepared using data collected from the continuous WIM site located in Brownsville, Texas. The daily file sizes ranged from 24 kb to 440 kb, with an average file size of 180 kb. At the conclusion of adding calendar year 1999 to a relational database management system (RDBMS) data set, the file size increased by 39 MB. The traffic and truck volume at this site is much less than that observed on Interstate routes between Texas' major urban areas; therefore, the size of these files may be half as that expected from Interstate routes.

Given both the average file size taken from the field and the currently recommended federal WIM program size, a minimum of 12 GB will be required to store data collected from the system for one year. This contingency would allow storage space for data collected at large traffic volume WIM sites, an expanded system, or inclusion of other data deemed of value in future applications. Based on annual storage requirements, the authors recommend a total storage system of not less than 60 GB so that historical trends may be developed from a minimum of 10 years of continuous data. Figure 30 shows the calculation of storage needs. Table 7 shows various storage estimates based on expressed needs for historical data.

(180 kb/day/site) x (365 days/year) x (TMG suggested 90 sites) x (contingency factor of 2) = 12 GB/year

Figure 30. Estimation of Storage Needs.

Table 7. Storage Space Estimates for Continuous WIM System.

Expressed Historical Use	**Storage Space (GB)**
5 years - Choice of District staff	60
10 years - Recommended by AASHTO	**120**
20 years - Choice of Design Division staff	240

6.3.4 Development of Sampling Frequencies to Approximate Continuous WIM Distributions

Continuous WIM sites offer many data advantages over current collection methods; however, the amount of data collected is substantial. The challenges of such a large dataset present a problem of increasing query times with off-the-shelf RDBMS. A solution to this problem is to utilize a sampling plan from the large dataset to reduce the records queried.

Researchers investigated sampling plans of various frequencies and methods in developing axle load spectra for all truck classes and by truck class.

The data are a known population of continuous counts of axles and corresponding weights for different classes of trucks during the time period from June 1, 1998, to August 31, 1998, in Brownsville, Texas. The data examined were records that had an equipment validation code of "0." Results indicated no problems with the equipment in recording the vehicle, greatly reducing the possibility of including anomalous data in the set.

The problem presented was to find a representative sample of the total population of axle weights to approximate the known continuous distribution since processing the total dataset consumes excessive PC workstation CPU time and resources. The total population can be stratified into axle sets for a more detailed examination: single, tandem, tridem, and quad. There may be a need for a sampling procedure for each axle set since the distribution of each axle set is different than the total population distribution. Users should use a goodness of fit (GOF) test to determine if the sample is representative of the known population distribution.

As far as sampling was concerned, the investigation began using days as the sampling unit, with two days per quarter as the minimum. The FHWA established the two days per quarter minimum for federal reporting purposes. This analysis was an investigation into the sample sizes that would be most appropriate, hence analysts considered two days per quarter, three days per quarter, and others. Each weekday has about 1500 trucks recorded, Saturdays had about 500 trucks and Sundays had about 250 trucks recorded.

6.3.4.1 Kolmogorov-Smirnov (K-S) GOF Test

The K-S GOF test usually works well in settings similar to that described above. There are several variations of this test. The test of hypothesis for the K-S test involves comparing distributions for significant differences. An assumption is that, in all cases, the samples are independent identically distributed. Comparing a sample distribution to a known population distribution assumes that the sample is independent of the population. For this analysis, most of the K-S type tests were inappropriate, so analysis with the Chi Square GOF test began. Subsequent review of the K-S GOF led to the discovery of one reference that does suggest a solution. Pettitt and Stephens *(60)* define a K-S type of statistic for discrete or grouped data, with group data being the case examined. Use of this method requires extensive calculations to find critical values. The researchers were unable to apply this statistic.

6.3.4.2 Cluster Sampling and Chi-Square GOF Test

The cluster (the sampling unit) is one randomly selected day, which contains all axles recorded for that day. Investigating sampling schemes across all truck classes and all axle types, "two days per quarter" is not significantly different from the continuous distribution. Yet as more clusters (days) are included–such as four days per quarter, two days per month, three days per month, etc., –these sampling schemes (using the seven-day week and the five-day workweek) return a sample distribution significantly different from the continuous data. Problems occurred since the differences in the expected values for one or two axle weight intervals returned p-values below 0.05 and below 0.01 for many cases for the Chi-Square GOF test. The larger the sample size tested, the smaller the differences in each axle weight interval that are needed to be significantly different.

Table 8 shows *p*-values for different sample frequencies of different sizes for individual truck classes; the last column covers all classes. As tabulated values indicate, many samples are significantly different for both single and tandem axles.

Table 8. Chi-Square *p*-Values for Samples Including Seven-Day Week.

SINGLE AXLES

Frequency	**Class 4**	**Class 5**	**Class 6**	**Class 8**	**Class 9**	**Class 10**	**Class 11**	**Class 12**	**ALL**
Two / Quarter	0.6751	0.8902	0.0012	0.8111	0.0120	0.0067	0.4830	0.1278	0.0360
Three / Quarter	0.3975	0.3429	0.0000	0.0001	0.0234	0.5455	0.0000	0.6120	0.0004
Four / Quarter	0.6120	0.7508	0.0611	0.0002	0.0354	0.8861	0.0190	0.4790	0.4314
Two / Month	0.0538	0.7389	0.4627	0.2153	0.1449	0.1466	0.0923	0.1361	0.0000
Three / Month	0.1630	0.0238	0.0000	0.0003	0.0047	0.0570	0.0291	0.6403	0.0004
Four / Month	0.8156	0.1464	0.1469	0.1008	0.0000	0.0509	0.0580	0.2856	0.0383
Six / Month	0.6044	0.5112	0.0000	0.4588	0.0000	0.4752	0.0000	0.0179	0.0000
One / Week	0.3035	0.6507	0.5301	0.2121	0.0194	0.0021	0.2226	0.4037	0.0286
Two / Week	0.0298	0.2630	0.0000	0.0178	0.0009	0.0000	0.0001	0.4344	0.0000
Three / Week	0.2365	0.0142	0.0060	0.2389	0.0003	0.0000	0.0000	0.0652	0.0000
Five / Week	0.6946	0.9409	0.0669	0.3911	0.0000	0.3295	0.2930	0.9651	0.0000

TANDEM AXLES

Frequency	**Class 4**	**Class 6**	**Class 8**	**Class 9**	**Class 10**	**Class 12**	**ALL**
Two / Quarter	0.9410	0.2930	0.5966	0.4650	0.0000	0.7242	0.0000
Three / Quarter	0.4962	0.0000	0.5361	0.0490	0.6581	0.3121	0.0000
Four / Quarter	0.8185	0.0000	0.0343	0.0000	0.0000	0.6041	0.0000
Two / Month	0.0087	0.0000	0.0217	0.8666	0.0007	0.1787	0.0000
Three / Month	0.4525	0.0000	0.0013	0.0000	0.0001	0.5075	0.0000
Four / Month	0.7350	0.0000	0.1575	0.0008	0.0000	0.4815	0.0000
Six / Month	0.0499	0.0314	0.1671	0.0969	0.0000	0.0000	0.0000
One / Week	0.2066	0.0030	0.9062	0.0001	0.0000	0.3367	0.0000
Two / Week	0.7537	0.0000	0.5481	0.0224	0.0000	0.0000	0.0000
Three / Week	0.7933	0.0000	0.0025	0.0074	0.0000	0.3480	0.0000
Five / Week	0.4043	0.0000	0.7947	0.1706	0.0023	0.8995	0.0000

NOTE: Critical p-value < 0.05

The Chi-Square GOF did not conclusively show a definitive point within the sampling frequencies that moved from significantly different to not significantly different distributions or vice versa. So other sampling schemes needed to be applied to these data.

6.3.4.3 Two-Stage Cluster Sampling

Consider one day being viewed as a cluster. Samples were taken from each cluster (day) randomly selected from the 92 days and then tested (Chi-Square GOF) to see how well it represented the population. Table 9 shows the resulting *p*-values for different samples using two or more clusters for single axles. From Table 9, the best results come from a sampling scheme of two days per quarter of sample size 30 or size 100. Yet these results are not satisfactory since 20 percent or more of the samples fail to be representative. Using two-stage cluster sampling, Table 10 shows similarly unsatisfactory results for tandem axle samples. Note that not all frequency and sample size were tested nor were they tested the same number of times. Cluster sampling is not necessarily a better choice to examine data as much as it is another method to find the desired results.

Table 9. *p*-Values from Cluster Sampling: Single Axles.

Sample Size Per Day	Frequency (Days)			
	Two / Quarter	**Three / Quarter**	**Four / Quarter**	**Two / Month**
30	0.0000	0.0006	0.0000	0.0031
	0.0284	0.0017	0.0000	0.0101
	0.1060	0.0082	0.2284	0.0101
	0.1379	0.0889	0.7751	0.7128
	0.2372	0.2693	0.9633	0.8770
	0.2732	0.3216		
	0.2863	0.4637		
	0.2973	0.6732		
	0.4305	0.6769		
	0.5359	0.8325		
50	0.0024	0.0000	0.0000	NA
	0.0289	0.0283	0.0005	
	0.0317	0.3095	0.1172	
	0.3347	0.6163	0.2856	
	0.9319	0.9983	0.4276	
100	0.0000	NA	0.0227	NA
	0.1911		0.0560	
	0.3842		0.1586	
	0.8214		0.2445	
	0.8494		0.6848	

NOTE: Critical *p*-value < 0.05
NA – Not available

Table 10. *p*-Values from Cluster Sampling: Tandem Axles.

Sample Size Per Day	Frequency (Days)			
	Two / Quarter	**Three / Quarter**	**Four / Quarter**	**Two / Month**
30	0.0000	0.0017	0.0107	0.0010
	0.0006	0.0103	0.1070	0.0129
	0.0520	0.0364	0.1168	0.0479
	0.1661	0.0473	0.4114	0.0793
	0.1738	0.0550	0.6651	0.2724
	0.1877	0.0861		
	0.2557	0.2694		
	0.3909	0.3989		
	0.7655	0.4798		
	0.8638	0.6836		
50	0.0072	0.0000	0.0003	NA
	0.0504	0.0000	0.0026	
	0.0670	0.0001	0.1170	
	0.0871	0.0033	0.2219	
	0.1711	0.5280	0.2700	
100	0.0072	NA	0.0003	NA
	0.0277		0.0004	
	0.0670		0.0005	
	0.1504		0.0330	
	0.2599		0.1322	

NOTE: Critical *p*-value < 0.05
NA – Not available

Simple Random Sample

Another approach required taking a simple random sample from all the trucks recorded. This method took samples of size 30, 50, and 100 and then applied the Chi-Square GOF test. Table 11 shows the results. This method is not necessarily better than the previous methods but is a sampling scheme designed to resolve the problem stated above. The p-values resulting from the Chi-Square tests again show unsatisfactory results since too many samples are significantly different (*p*-value less than 0.05).

6.3.4.4 Multinomial Probability

The multinomial distribution offered another potential solution. This method partitioned the data into separate categories with known population frequencies, then tested them using the multinomial distribution. Using many of the sampling schemes listed above (two per quarter, etc.) resulted in the observed frequencies being significantly different from the expected frequencies, again leading to unsatisfactory results.

Table 11. Simple Random Sampling and Chi-Square GOF *p*-Values.

	Sample Size		
Axle Set	**30**	**50**	**100**
Single	0.0143	0.0073	0.0259
	0.1400	0.1072	0.1041
	0.5055	0.2481	0.1150
	0.5567	0.3340	0.1723
	0.8702	0.3446	0.2949
	0.9089	0.4283	0.4781
	0.9384	0.4671	0.5277
	0.9939	0.9909	0.8289
Tandem	0.0018	0.0000	0.0001
	0.0127	0.0002	0.0002
	0.0578	0.0029	0.0016
	0.1599	0.0992	0.1671
	0.4037	0.3856	0.0150
	0.6058	0.4318	0.1622
	0.6194	0.5797	0.3083
	0.7765	0.5876	0.4486

NOTE: Critical p-value < 0.05

6.3.4.5 Summary

Researchers used many different methods to evaluate the data to develop a representative sampling scheme with which to approximate the continuous WIM distributions. Finding a successful sampling scheme would reduce the demands on CPUs when queries will be directed at the extensive continuous WIM database. This investigation examined many statistical sampling and goodness-of-fit schemes. In each case, the methods returned unsatisfactory results, showing that the sampling frequencies often were significantly different from the continuous data.

6.3.5 Currently Available Technology

For the large datasets expected from the envisioned WIM program, application of the appropriate software technology is important. At issue are the applicability of off-the-shelf, widely used software packages such as spreadsheets and relational databases or use of much higher-powered relational database management systems. To adequately handle the volume of data that would be collected, researchers investigated several types of application technologies in terms of their storage capacity, querying, and reporting functions.

Research staff imported data into two off-the-shelf, widely used software applications: Microsoft (MS) Excel and Microsoft Access. One reason for choosing these applications was because they are suite components of software adopted by the department *(61)*. These applications are also popular programs with a wide cross-section of computer users.

6.3.5.1 Spreadsheets

Spreadsheet applications such as MS-Excel allow users to enter data into a flat database file. Functionally, all spreadsheets are similar, although differences between the spreadsheets exist at the aesthetic and macro function levels. This project evaluated MS-Excel, partly because the Microsoft suite of programs is defined in TxDOT's core technology architecture standards. However, problems surfaced immediately.

Though the import feature ran smoothly, manually defining fields and separating the data fields was quite cumbersome. Upon successfully defining the import attributes, users encountered problems with the number of records that could be imported. MS-Excel is limited to approximately 65,000 rows per worksheet. Because WIM systems record each individual vehicle as a record, each vehicle would occupy one row in this application environment. Therefore, continuous WIM station data would have to be split interday or intraday should volumes exceed 65,000 records, as represented in Figure 31. Importing some data would not be feasible because it would exceed this row limitation.

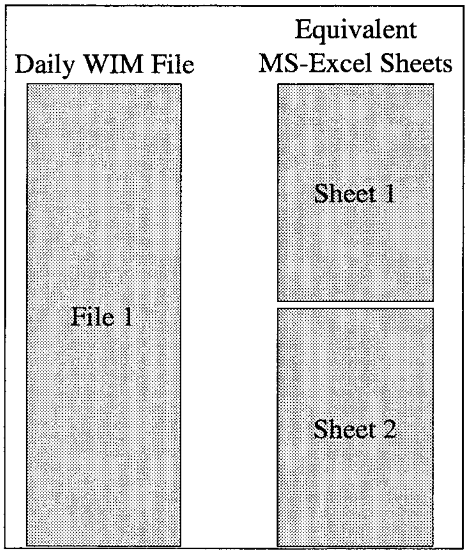


Figure 31. Representation of Multiple MS-Excel Sheets for WIM Files.

Differentiation of day or station day would be difficult. Individual sheets within a workbook may be assigned a specific day, if the number of records that day does not exceed the row limit. An MS-Excel workbook is also limited to 255 worksheets. Even under ideal conditions where each worksheet would represent an observed day, a full calendar year would not be available under one filename. Figure 32 shows this representation.

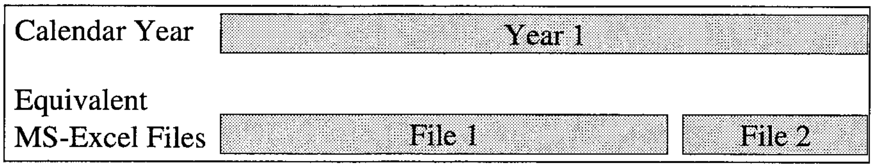


Figure 32. Representation of Multiple MS-Excel Files for Calendar Years.

This spanning effect would be a hindrance to customized or detailed investigations of the data because a great number of sheet and file names must be used to accommodate the large datasets generated by the WIM system. The presence of so many sheet and file names would make an automated analysis virtually useless due to the extensive amount of programming labor required to manually modify the sheet and file names.

MS-Excel does afford a large number of concurrent users (255). This would meet the internal needs of TPP and would also be useful within districts and divisions.

6.3.5.2 Relational Database Management Systems (RDBMS)

PC Workstation

For limited-scale desktop applications, small RDBMS programs such as MS-Access are applicable. These programs provide for a more robust analysis of data because relationships may be formed between different data sets so that comprehensive and complex queries or reports may be generated. Each database can contain a family of tables, queries and reports.

This project evaluated MS-Access. Both novice and experienced database application developers can use the application, and its user interface is consistent with other Microsoft Suite applications making it more familiar. This application showed more promise than use of spreadsheet applications. The most significant benefit of this application is that it is a relational database. Users can import data into one or several tables. Once relationships among many tables are established, users can invoke the power of query language. Users can access the databases with ANSI-SQL, making this a powerful development application. Integration of other data is also possible for user manipulation and reporting through ODBC links.

MS-Access limits the size of a single database file to 1 GB. Each table within the database is also limited to 1 GB in size. This size limitation might be overcome by linking tables in other files; the result of this linking method then would only be limited by the available storage capacity.

MS-Access also affords a large number of concurrent users (255) that would meet the internal needs of TPP(T) and allow external departmental customers access to the data.

TTI continued to find limitations with this application in the query language. To overcome these limitations, researchers used Visual Basic script to extract data from the tables using ODBC, then process it externally and return the results to a temporary table in the database. When analysts ran queries for other analyses as part of this project, they found that some query times became unacceptably long. This is a concern because as more data are amassed from both continuous operation and from additional physical sites, query times will continue to lengthen. These times may lengthen to such an unacceptable level for the user or manager that mining the data may become a low priority task.

Workgroup

Corporate environments utilize large RDBMS for their database functions at enterprise and workgroup levels. Several different products exist; however, at this product level, unit costs become a factor and corporate standardization becomes the rule.

A large-scale RDBMS does not have the limitations of its scaled-down peers like MS-Access. It is scalar and can expand as the data expands. Its processing time is much less than that required by common relational databases.

At the beginning of this evaluation, TxDOT's core technology standards specified the use of the Sybase family of products. However, during the evaluation, TxDOT modified those standards, adopting the Oracle product line. The March 2000 TxDOT Core Technology Architecture Standards *(61)* recommended:

- **Oracle** for enterprise and workgroup applications but with major spatial data components;
- **Sybase Adaptive Server Anywhere** (formally SQL Anywhere) for workgroup applications and PC workstation applications that have the potential of being shared by a workgroup or have the potential of expanding above size and use limits; and
- **Microsoft Access** for individual PC workstation applications with no data sharing.

Table 12 further describes the selection criteria for a database environment.

Adaptive Server Anywhere (ASA) has many advantages. It uses both relational data-integrity and network-based client/server structured query language (SQL) access. It also supports full transaction processing with automatic data recovery. The Open Database Connectivity (ODBC) standard is used as its functional application programming interface (API). Finally, all of the code developed to access ASA can be migrated to access other databases if needed *(61)*.

Oracle is used for many mission-critical data management solutions in the private sector. It is closely integrated with the Windows operating system and has a market share of nearly 50 percent on such platforms *(63)*. This product also offers numerous data access methods including traditional ODBC.

Table 12. Database Selection Criteria.

Database Alternative	When to Use
Oracle	- Enterprise or workgroup application development - Number of users > 40 - Database size is > 2 GB
Sybase Adaptive Server Anywhere (formally SQL Anywhere)	- Workgroup applications - PC workstation applications with potential for being shared among a workgroup - Number of users < 40 - Database size < 2 GB - Applications with the potential of expanding above size and use limits
Microsoft Access	- PC workstation applications for a single user with no data sharing

Source: Modified from (*62*)

6.3.6 Summary of Findings

The authors recommend development of historical trend information from 10 years of data, when available. This recommendation conforms to AASHTO traffic data program guidelines and mediates the desired horizons of district and division staff.

The authors do not recommend data aggregation within the primary WIM database. Each record in the primary WIM database represents a unique vehicle with sub-characteristics that may be of interest to researchers or department staff interested in the physical attributes of the trucks. Aggregation for other processes such as vehicle volume or classification should be made external to the primary WIM database so that the integrity of the data is protected.

Researchers estimated that 120 GB of data storage would be needed for a fully implemented WIM system in Texas. This estimate included data for 10 years of historical data so that historical trend analyses might be developed.

This research found no particular sampling frequency or method to be appropriate when estimating the continuous data distribution. Several methods produced mixed results and did not conclusively show a benefit or point of diminishing returns. Because of the lack of evidence to support a reduced sampling frequency when supplied continuous data, it is best to query all of the available data to generate the appropriate continuous distributions instead of estimating the continuous distribution.

Researchers recommend a large-scale, relational database system such as Oracle for storing and accessing continuous WIM data because of the expected size of annual and combined historical WIM data (60 GB). The many limitations of spreadsheets hinder importing and extensive analysis of the data. Common or off-the-shelf relational databases lack the robustness and database size that the larger RDBMS applications offer. Even

Sybase's ASA is not expected to accommodate the WIM data system once fully implemented. As indicted in the Core Technology Architecture Standards, TxDOT should consider using Oracle for databases greater than 2 GB. ASA could likely handle only one year of continuous data at the current level of sites (15) before exceeding its database size threshold.

Users can easily develop and modify standard queries to accommodate historical trend analysis. Once users mine the data warehouse, they can use summary tables within MS-Excel or with graphical reporting software like Crystal Reports to convey desired trends identified in the customer needs assessment.

Though development of a WIM data system could begin at the MS-Access level and then migrate to more powerful and scalable applications as the system expands, the department will require programming or systems analyst expertise for each of these migrations. This need would likely result in higher total costs to the department than initial development of the database in the Oracle environment.

CHAPTER 7.0 NATIONAL TRAFFIC LOAD FORECASTING STATE-OF-THE-PRACTICE

7.1 INTRODUCTION

The objective of this task was to gather information on data collection equipment and processes used by states to collect and use data. Processes used by other states in their WIM and count/classification data collection processes and traffic load forecasting could be useful to Texas in improving its processes. Another topic that is important to TxDOT that relates to the content of this chapter is the use of geographic information systems (GIS) for traffic load forecasting. Chapter 8 provides that discussion.

7.2 METHODOLOGY

Information gathered on equipment came from discussions with vendors, from the Internet, from product brochures, and from users of the equipment. Information gathered for national traffic load forecasting state-of-the-practice came from the literature review, from a FHWA pooled fund study, and from telephone interviews. The pooled fund study is project DTFH61-95-C-00060, entitled "Traffic Load Monitoring and Projections" *(64)*. Project staff contacted many states to request information, but the response rate was low.

7.3 FINDINGS

This chapter separates findings by states providing information on data collection only and those that provided information on their entire traffic load forecasting process. This information allows comparison with Texas practice in Chapter 4. The states providing information on data collection were: Alabama, California, Colorado, Florida, Idaho, Illinois, Indiana, Iowa, Minnesota, North Carolina, North Dakota, Ohio, Pennsylvania, South Carolina, South Dakota, Washington, and Wisconsin. The only state that provided information on its entire process was Florida. The information below is organized by data collection process first, followed by the full traffic load forecasting process.

7.3.1 Data Collection Equipment

Some of the vehicle monitoring equipment sold by various vendors is capable of classification as well as weighing in motion, depending on how it is configured. The distinction in some cases is merely a card inserted in the machine to change it from one type of device to the other. For this reason and for brevity, the following text presents both types of devices together. Also, some of these systems are portable and can easily be moved, while others are less portable.

7.3.1.1 Aviar

The Truvelo TCL-300 and TDL-500 models incorporate a multilane classifier and WIM system in one basic package. The system uses two inductive loops and one capacitive weight sensor in permanent or temporary configurations. The data collected from a maximum of four lanes includes: timestamp, gap time, lane number, travel direction, vehicle straddling present, trailer present, vehicle chassis height, speed, length, FHWA class, number of axles, axle weight, axle distance, and 18 kip ESAL. Specifically developed vehicle pattern recognition algorithms identify vehicle classes. Data storage is in battery-backed up RAM (512 Kb standard) with space for 34,000 individual vehicle data strings. Data storage can also utilize logical AND/OR combinations of all parameters, (e.g., all class 9 vehicles exceeding a certain speed AND a certain weight AND a certain length). Use of data bins can enhance memory usage. The classifier has a keypad for setup and a liquid crystal display. The detector can be connected to a computer via RS 232 or modem and stores data in an ASCII format.

7.3.1.2 Diamond

Unicorn and Phoenix classifiers by Diamond differ in the number of lanes in which they can detect vehicles, and they accommodate a combination of piezo, road tube, or inductive loop sensors. The Unicorn can classify from one to four lanes, and the Phoenix can classify from one to eight lanes and count up to 16 lanes. Both detectors classify according to the FHWA classification scheme, and they can store raw or bin data in the standard 68K of counter memory. Both classifiers have a keypad for setup and a LCD display. The two classifiers also have an RS 232 serial port to interface with a modem, PC, laptop, or palmtop and use TrafMan software for communications and data recovery. An optional solar panel can be mounted in the lid for power.

7.3.1.3 Electronic Control Measure (ECM)

The Hestia WIM system intended for permanent installations can cover from one to eight lanes, whereas the Hestia-P2 is portable and capable of monitoring one or two lanes. The Hestia-P4 is a portable system that monitors three or four lanes. Typical sensor configurations are two piezoelectric sensors and one loop per lane for WIM and one piezo and two loops per lane for classification. Individual vehicle records include: date/time, vehicle number, axle weight, axle spacing, classification, weight violation, bridge load violation, gap, validation, lane, and speed. Calibration of the Hestia systems is automatic, based on statistical axle weights. It can also be calibrated manually with pre-weighed calibration vehicles. The Hestia can download data directly via an RS-232 port at 9600 bps. In its permanent configuration, the Hestia system can store up to 8 Mbytes and the portable version can store up to 4 Mbytes. Twenty-five thousand individual five-axle vehicles require one Mbyte of storage. The WIM system can operate on 12V DC 110 or 220V AC. Its internal battery can keep it operating continuously for 48 hours. It can operate an additional eight days with an additional external battery. It has a two-month internal back-up power supply for memory.

7.3.1.4 Golden River

There are two models of the Golden River Marksman 660; one is a classifier and the other is a WIM system. Both models can be installed either in a temporary or a permanent mode and use low power complementary metal oxide semiconductor (CMOS) technology. They both also have a keyboard and LCD display and use modular construction. The classifier is compatible with road tube, inductive loop, and piezoelectric sensors and can monitor up to eight lanes. The classifier records combinations of vehicle count, speed, length, class, wheelbase, headway, and gap. On-site data retrieval is available via three options, with PC, data module, or by radio. The classifier has a RS 232 serial port for PC communication.

The 660 WIM has five loop-array configurations, supporting WimStrip or linear quartz WIM sensors. The WIM has a larger standard memory than the classifier and can monitor four lanes. The vehicle data recorded include gross weight, individual axle weight, classification, overall length, wheelbase, axle separation, speed, gap, and headway.

7.3.1.5 International Road Dynamics (IRD)

The IRD TCC 540 can be configured to classify up to eight lanes of traffic or count up to 16 lanes. The TCC 540 can be fitted with four road tube sensors, four to 16 inductive loop sensors, or four or eight piezoelectric sensors. There are three modes of vehicle classification: binning, time-stamped sensor events, and individual raw vehicle records. The standard memory stores enough raw data for approximately 5000 vehicles. The TCC 540 has a keypad for setup and a LCD display for monitoring setup and data collection. It also has an RS 232 for serial interface to a PC, or a modem with optional modem software, which enables two-way communication for setup and access to stored data. When properly equipped, this classifier can also serve as a portable WIM. As such, it generates vehicle counts, speed, length, class, individual axle weight, and gross vehicle weight in a user-selectable format.

The IRD Model 1070 is a portable weigh-in-motion system that can be used for either fixed location piezoelectric WIM data collection or in a portable mode. It interfaces with portable or permanent axle and vehicle presence sensors for up to four lanes of data collection. It offers real-time display of traffic in both graphical and text formats. It can store up to 2 million raw vehicle records and offers auto calibration, which reacts to both site and pavement conditions. Its internal battery can operate the system continuously for over 24 hours; longer operation is also possible using an external connection for charging or by connecting to external AC, DC, or solar power. It has connections for optional modem.

The IRD Model 4020 slow-speed/static scale system consists of a single-axle scale, computer interface display, optional printer, optional remote scoreboard, and computer connection. The system uses a hydraulic load cell to determine axle and vehicle weights. IRD claims accuracy at slow speeds within 0.5 percent of static weights if the pavement meets ASTM E-1318 criteria for smoothness.

7.3.1.6 International Traffic Corporation (ITC)

The TRS model has 24 inputs, and by using any combination of piezo, road tube, and loop or contact sensor, it can classify up to 12 lanes of traffic. The detector stores data in raw or binned modes. The TRS unit can be operated via the integrated keypad and display, by using a serial link with a PC or modem. The unit can be used to make decisions in the field, programmed to call back to a central office, or turn signs and lights on/off when preset levels of congestion or speed are exceeded. An Automatic Vehicle Identification (AVI) interface is also available.

Traffic A.C.E. has four inputs and counts up to four lanes or classifies one to two lanes of traffic. Sensor inputs accepted are piezos, road tubes, inductive loops, and tapeswitches. This classifier has a small LCD display and two-button operation. Collected data can be downloaded via RS 232, or the memory module can be removed to facilitate data transfer. It has optional speed and FHWA classification capabilities and can be configured for detection outputs.

7.3.1.7 Jamar

The Trax I and II use only road tube sensors. The Trax I is only for standard volume counts and simple speed, classification, and gap studies, whereas the Trax II can classify vehicles according to FHWA or custom classifications. The Trax II can also do per-vehicle studies, raw data studies, standard volume studies, and binned (speed, classification and gap) studies. The Trax III can be configured for tubes, piezoelectric sensors, or loop sensors for up to eight lanes and does everything the model II can do. The data from all three models can be downloaded in the field with the Jamar Data Module through a RS 232 serial port.

7.3.1.8 Mitron

The MSC 3000 operates with tubes, piezoelectric sensors, or output signals generated from optional loop detectors. The MSC 3000 can classify up to four lanes. The unit uses a removable memory pack, a translator to recover the data, and a programmer with a keypad and display to set up. The detector uses low-power CMOS technology that enables it to operate one year with four C-size alkaline batteries. The unit can be modified to count vehicles violating red lights.

The MSC 4000 is a 20-channel modular traffic recorder that is rack mounted or portable and supports loop, piezoelectric, and tube sensors. The unit has user-defined standard bin recording, individual vehicle, and event recording. With Mitron's PC software, the user can program, monitor, retrieve data, and run diagnostics on location or via modem.

7.3.1.9 Nu-Metrics

This portable traffic counter classifier uses vehicle magnetic imaging sensor technology to detect vehicles. The installer secures the small device in the middle of the lane on the surface of the pavement. According to the vendor, installation and retrieval time with protective cover is less than 15 seconds. The unit employs a low power 1 milliwatt radio transmitter that transmits an 11 byte data string for each passing vehicle. A pocket size receiver activates an LED and an audible signal to announce each vehicle. A RS 232 port provides connection to a PC for monitoring and recording each vehicle's speed and classification.

7.3.1.10 Piezsch Automatisierungstechnik (PAT)

The PAT DAW 190 is a WIM and classification system that has the following applications: pavement design/planning, volume, weight, and speed statistics, and mainline screening (in combination with automatic vehicle identification). It utilizes either bending plate or piezoelectric sensors to monitor up to six lanes at a time. It can store either raw or bin vehicle data. Its storage capacity is 4 Mbytes standard and can store approximately 60,000 to 100,000 raw vehicles. Other PAT WIM systems included elsewhere in this document are the DAW 50, DAW 100, and DAW 200.

7.3.1.11 Peek Sarasota

The ADR-1000 and ADR-2000 portable units can be configured for tubes, piezos, and loop sensors, and they both classify vehicles consistent with the FHWA scheme. They also have a keypad and LCD display for setup and monitoring. The ADR-2000 and 3000 can both accept tapeswitches and a WIM card for up to eight lanes of WIM operation. These two data recorders also have a per-vehicle WIM-alarm output. The ADR-3000 is a permanent automatic data recorder. It needs an external keypad and display for setup and monitoring, but this function can also be done with a PC. All these units support high-speed RS 232 serial communication for data transfer.

7.3.1.12 Schwartz Electro-Optics (SEO)

The Autosense II by SEO is a single lane, active infrared detector typically mounted directly over each lane. It detects speed, count, occupancy, headway, density, height, width, length, and type of vehicle. The detector is self-calibrating upon power up. Communication is through RS 422 serial port, and RS 232 and fiber-optic communications are optional. The unit sends the serial data stream to a PC running the Schwartz DOS program for communications and data collection. The unit requires 120VAC. A later version of this device, the Autosense IIA will be capable of vehicle classification by number of axles and axle spacing. It has the potential of classifying by the FHWA classification scheme. It will be mounted in a sidefire orientation.

7.3.1.13 TimeMark

The Beta recorder is a simple two-channel interval volume counter that requires only one button to operate. The Gamma is exclusively a raw data classifier, which uses two road tubes and has single button operation. The Delta III is a raw data recorder that is designed to work with standard memory cards to collect raw data. The Delta supports four tubes and is available in LED version or LCD version with keyboard and display. The Lambda series classifier uses tube, piezoelectric, and loop sensors. It also collects raw data via LCD display and keypad. Most of the classifiers and WIM units have the following options: solar panel, data management software, and expandable memory.

Table 13 provides a summary of the information on vehicle classifiers, whereas Table 14 provides a summary of WIM equipment. The tables also give other information besides what has been covered thus far such as quality of the user interface and cost.

7.3.2 Data Collection Process

7.3.2.1 Alabama

Alabama selected WIM sites to satisfy the WIM program outlined in the Traffic Monitoring Guide. It selected classification sites by project location or by HPMS program guidelines. The state follows procedures outlined in the *Traffic Monitoring Guide* and the *AASHTO Guidelines for Traffic Data Programs* in their traffic data collection and projections. The state checks 10-year projections by checking specific projects upon request. The section that is responsible for the collection and analysis of vehicle classification data is the Traffic Monitoring Section of the Transportation Planning Bureau. The state uses 13 vehicle categories at automated counters and 24 at manual sites. Alabama uses truck weight data to develop pavement design tables and to satisfy the requirements of the HPMS, SHRP, and long-term pavement performance (LTPP) programs. For efficiency, the state coordinates the data collection needed for HPMS, LTPP, and projects. Alabama collects traffic data on a project-specific basis. The state updates traffic data between preliminary and final designs on an as-needed basis. Traffic load forecasting is the responsibility of Pavement Design. It uses only one truck class in the projection. The forecasting procedure considers recent growth as well as long-term growth (10 to 15 years) in the area. Alabama does not have a set program to compare actual traffic loadings to predicted traffic loadings, although it does conduct informal periodic checks. The state predicts truck traffic separately from overall vehicle growth for Interstates and other high-volume controlled access facilities. Alabama does not generally use load factors that are region- and time-of-year-specific. The only exception was for a coal-producing area with heavily loaded coal trucks. The last time truck factors were re-evaluated by the Alabama DOT was August 1994. The state determines accumulated traffic loadings for rehabilitation projects by the AASHTO procedure for an eight-year performance period. The state makes provision for updating traffic figures if its design process does not meet the design timetable. This is accomplished by updating traffic annually until the project is let to contract. The pavement engineer does not modify traffic loadings in this state *(64)*.

7.3.2.2 California

Weigh-in-Motion. California Department of Transportation (Caltrans) provided a spreadsheet, which displays their data collection WIM systems and the types of equipment being used as of November 1999. The list shows a total of 90 "systems" using IRD and PAT

Table 13. Classifiers.

Manufacturer	Model	Tube	Piezo	Loop	Number of Lanes	FHWA Classes	Portable	Standard Memory	User Interface	Base Price
Aviar	TCL-300	no	yes	yes	1 to 4	yes	yes	256kb	None Sold	$3,500
Diamond	Unicorn	yes	yes	yes	1 to 4	yes	yes	68kb	Excellent	$1,700
High Leah	Phoenix	yes	yes	yes	1 to 8	yes	yes		Excellent	$1,700
Golden River	Marksman 660	yes	yes	yes	1 to 8	yes	yes	32k	Excellent	--
IRD	TCC 540	yes	yes	yes	1 to 8	yes	yes	68kb	Excellent	$3,100
ITC	ACE	yes	yes	yes	1 to 4	yes	yes	32k	Excellent	$499
	T.R.S.	yes	yes	yes	1 to 4	yes	yes	256k	Excellent	$695
Jamar	Trax I	yes	no	no	1 to 2	no	yes	512kb	Acceptable	$995
	Trax II	yes	no	no	1 to 2	yes	yes	512kb	Acceptable	$995
	Trax III	yes	yes	yes	1 to 8	yes	yes	512kb	Acceptable	$1,200
Mitron	MSC 3000	yes	yes	yes	1 to 4	yes	yes	16k	--	$2,871
	MSC 4000	yes	yes	yes	1 to 4	yes	yes	6M	--	$2,795
Nu-Metrics	High Star NC-97	NA	NA	NA	1 to ? optional	no	yes	64kb	Excellent	$1,000

Note: User Interface = Excellent, Acceptable, or Poor

Table 13. Classifiers (Continued).

Manufacturer	Model	Tube	Piezo	Loop	Number of Lanes	FHWA Classes	Portable	Standard Memory	User Interface	Base Price
PAT	Daw 190	no	yes	yes	--	yes	--	4 meg	--	--
Peek	Traffic	yes	no	no	1 to 4	yes	yes	2 meg	Excellent	Call *
Sarasota	Comp EZ									
	Traffic 241	yes	yes	yes	1 to 8	yes	yes	2 meg	Excellent	Call *
	ADR 1000	no	yes	yes	1 to 8	yes	yes	2 meg	Excellent	$2,000
	ADR 2000	yes	yes	yes	1 to 8	yes	yes	2 meg	Excellent	$2,200
	JR 163 &	yes	no	no	1 to 4	yes	yes	2 meg	Excellent	$330
	JR 164	yes	no	no	1 to 4	no	yes	2 meg	Excellent	$350
Schwartz (laser IR)	AS-II	no	no	no	one	yes	yes		Acceptable	$10,000
TimeMark	Delta IIIB	yes	no	no	1 to 2	yes	yes	22kb	Excellent	$1,095
	Delta IIIL	no	yes	no	1 to 2	yes	yes	22kb	Excellent	$1,295
	Lamba	yes	yes	yes	1 to 4	yes	yes	256kb	Excellent	$2,920
	Gama	yes	no	no	1 to 8	no	yes	2 meg	Excellent	$750
	Beta	yes	no	no	1 to 8	no	yes	2 meg	Excellent	$725
	Delta w/radar trailer	no	no	no	one	no	yes	NA	Excellent	$7,500 up

Note: User Interface = Excellent, Acceptable, or Poor

Table 14. Weigh-in-Motion Equipment.

Manu-facturer	Model	Loops	Piezo	Cap. Mat	Bending Plate	Hydr. Load Cell	Number of Lanes	Portable	Standard Memory	User Interface	Base Price
Aviar	TDL-500	yes	no	yes	no	no	1 to 4	yes	512kb	Excellent	$7,000
ECM	Hestia	yes	yes	no	no	no	1 to 8	no	1 meg	--	--
	Hestia-P2	yes	yes	no	no	no	1 to 2	yes	1 meg	--	--
	Hestia-P4	yes	yes	no	no	no	1 to 4	yes	1 meg	--	--
IRD	1070	yes	yes	no	no	no	1 to 4	yes	4 meg	Excellent	$10,000
	1060	yes	yes	no	no	no	1 to 4	no	4 meg	Excellent	$10,000
	4020	no	no	no	no	yes	1	no	NA	Excellent	$30,000+
	540 WIM	yes	yes	no	no	no	1 to 4	yes	128kb	Acceptable	$5,000
	1086	yes	yes	--	yes	--	1 to 4	yes	16 meg	Acceptable	$10,000
ITC	RAKTEL	yes	yes	yes	yes	no	1 to 4	either	16 meg	Acceptable	$10,000
PAT	DAW 50	no	no	no	no	yes	1 to 8	yes	4 meg	Excellent	$8,000
	DAW 100	--	yes	no	yes	no	1 to 8	yes	4 meg	Excellent	$8,000
	DAW 200	--	yes	no	--	no	1 to 8	no	4 or 8	Excellent	$10,000
	DAW 190	yes	yes	no	yes	no	1 to 6	no	4 or 8	Excellent	$11,000
PEEK	ADR 2000	yes	yes	no	no	no	1 to 8	yes	4 meg	Acceptable	$10,500
	ADR 3000	yes	yes	no	no	no	1 to 8	no	2 meg	Acceptable	$11,000

Note: User Interface = Excellent, Acceptable, or Poor

equipment. It should be noted that, in some locations, a pair of these "systems" is needed to fully instrument all lanes of one "site" on the roadway, with one system serving one direction of traffic flow and the other system serving the opposing direction. The current WIM equipment (i.e., one "system") can cover up to six lanes, so if the site has over six lanes, it requires more than one "system." Forty-nine systems are PAT and 41 are IRD. PAT systems are either DAW 100 (eight units), DAW 190 (five units), or DAW 200 (36 units). IRD systems are either 1060 (15 units), 1065 (three units), 1066 (four units), or 1067 (19 units). Several of these system types have since been updated to meet Y2K requirements. In summary, Caltrans has a total of 66 data collection WIM sites consisting of 88 bending plate systems and 2 piezo systems. IRD and PAT are currently the only WIM vendors that bid on Caltrans projects because of California's specification. Caltrans requires a five year manufacturer's warranty on bending plate components and their installation.

All of the data WIM systems are "continuous" in the sense of collecting data throughout the year, but there can be lapses in coverage due to power, phone, or WIM component operational problems. Caltrans typically downloads two weeks of data from each of the systems every month. This currently amounts to 500 million bytes of data each month. Caltrans routinely validates one week of the data. However, if someone requests two weeks for that month and the first week's validation proves acceptable, Caltrans considers the second week's data acceptable as well with only a "spot check" validation and releases it to the consumer. There are also a few "trend" sites across the state from which all daily data are downloaded and stored. Caltrans stores all downloaded data as individual daily files for each site. Intervals for data downloads depend upon the data storage capacity of each system and the volume of trucks on the roadways. Data collection avoids unusual traffic days like major holidays because they are not representative of "average" days.

In addition to the 90 data collection WIM systems, Caltrans has installed another 28 bending plate WIM systems (17 IRD and 11 PAT) and 30 piezo WIM systems (19 IRD and 11 PAT) in conjunction with the Weigh Station Bypass (PrePass™) program. Although a few of these WIM systems overlap with the data collection program, most cover only one direction and/or only the "truck" lanes and as such they are not used for routine data collection. Another reason for not using these systems for data is that, for weight screening, the weights are intentionally set to read 2 percent light. Otherwise, violation alarms are triggered excessively. For pavement loading analyses, this 2 percent makes a substantial difference in the number of ESALs.

The process of determining the number of WIM data collection sites has evolved over time; it began around 1986 when the Caltrans WIM program began. Several considerations led to the current sites and locations. First, the *Traffic Monitoring Guide* established 108 sites as the total number needed in California. The ultimate Caltrans plan, therefore, is to have 108 sites. During the first few years of the program, Caltrans was unable to build WIM sites except as part of a construction project to rehabilitate a section of roadway. Another consideration in establishing WIM sites was to cover the major road classes such as Interstate and U.S. highways. Finally, in 1994, the state was able to build WIM sites without being part of a highway construction project. This allowed filling in some of the gaps that existed at the time. The state added other sites as part of the LTPP program. Finally, Caltrans supplements WIM sites with AVC sites. The state initially installed these AVC sites on lower volume roadways. California can currently display WIM sites on a GIS map, but that is all that is currently done with GIS related to WIM sites.

Accuracy of WIM data is closely related to calibration and site pavement preparation. Caltrans estimates typical one-day samples of WIM gross vehicle weights to be within 2 to 4 percent of static weights. Although Caltrans utilizes the "percent violations" as a monitor of WIM accuracy, so many of the loaded commercial vehicles travel with one or more of their axle/axle groups so close to maximum allowable weight that the slightest "high side" readings by the WIM system will result in a very skewed reporting of weight violations. For the sake of better monitoring WIM system accuracy, Caltrans utilizes a "class 14," which is the five-axle truck trailer combination (3-2) considered to be a class 9 by the FHWA scheme. Due to the nature of commodities hauled and perhaps other factors, these trucks are typically either empty or fully loaded, not partially loaded. This feature makes them a good calibration "monitoring" vehicle when analyzing gross weight distributions from the data set.

The Caltrans WIM calibration process begins by using a single calibration vehicle to first ensure that the calibration factor adjustments are linear and to set such factors as closely as possible so that the WIM system accurately interprets static weights. Calibration using a calibration truck may occur only once–when the system is installed. The vendor is initially responsible for calibration when the setup is complete. LTPP wants a minimum of two calibration trucks, but California has typically used only one truck unless the results from the single truck are deemed unacceptable or non-representative of the truck traffic at the site. With the one truck, they basically make sure that the WIM is performing consistently. After the initial calibration, Caltrans uses classes 9, 11, and 14 data from the traffic stream and crunch into a weight distribution data set. Additionally, data analysts look for an average of 4.3 ft on drive tandem separation, class 11 overall length, and average gross weights by speed bin. Therefore, following the initial installation, Caltrans uses the overall traffic stream instead of individual trucks. The reason is that any one truck's weight can vary by 5 percent between passes.

Although Caltrans prefers using the five-axle tractor-semitrailer with airbag suspensions on both tandem sets, they have occasionally experienced some problems with calibration due to the rear tandems coming in light at the higher speeds. However, other suspension types often yield erratic results.

Caltrans does not install WIM systems in asphalt. If a WIM site is needed on an asphalt pavement roadway segment, Caltrans replaces a +/- 150 ft section of the pavement with PCC to make the site more reliable and durable. This would include 100 ft of concrete on the approach and 50 ft beyond the sensors. If the original pavement is concrete but not deemed to be structurally sound, Caltrans replaces a +/- 200 ft section of the PCC pavement. In all cases, the first layer of base material is also removed. Caltrans likes to have a minimum 250 ft of smooth pavement approach. In all cases, whether in asphalt or concrete original pavement, Caltrans grinds the pavement for smoothness. Caltrans uses calcium chloride in the concrete mix to accelerate the cure because they might only have a six-hour window to remove existing pavement, pour and finish the new PCC slab, and provide a four-hour cure time before reopening to traffic.

Since 1995, California has required a five-year warranty on bending plates and a two-year warranty on the electronics. Prior to 1975, IRD bending plates were experiencing moisture intrusion, resulting in a 37 percent failure rate and average life on plates of 18 months. When Caltrans imposed the five-year warranty, IRD was able to correct the problems.

There are currently only two full-time equivalents for managing the WIM data systems. Such personnel are responsible for site selection, project initiation, WIM layout and specification development, project design coordination and review, construction inspection, calibration and acceptance testing, data collection and processing, and system maintenance and/or maintenance coordination. There is a need to increase the number of personnel to four if Caltrans is to effectively maintain their data WIM program. There is also a plan to increase the total number of sites to 108 from the current number of approximately 66.

Vehicle Count/Classification. Each of the 12 Caltrans districts is responsible for collection and processing vehicle classification data, but each must also send data to Sacramento for storage and availability for general statewide use. Each of the 12 districts processes the data to put it into the same format. There are 150 permanent AVC sites located throughout the state; there are also 30 to 40 temporary counts done throughout a typical year. As with WIM, the classification sites can also be shown on a GIS map. All 150 of the permanent sites are telemetry sites and can be monitored generally year-round. Data collection for temporary sites is usually for a full one-week (seven day) period, beginning on Monday and ending on the following Tuesday.

Classification equipment used by Caltrans is predominately Peek ADR 2000 and 3000, but it also uses some Diamond-Phoenix units. The number and locations of AVC sites evolved over a period of years. Over that time, Caltrans looked for locations where significant changes in truck traffic occurred and where there were system changes that provided opportunities to install sensors in the roadway. Caltrans installed sites at beginning and end points of routes, at freeway-to-freeway locations if feasible, and to provide coverage of functional classes or roadways. Sometimes Caltrans upgrades count stations to permanent classification sites based on these factors.

Caltrans classification equipment is 95 percent accurate when everything is installed properly. The number of unclassified vehicles defines the accuracy level; if it starts to increase above 5 percent, Caltrans starts looking for the cause. One of the weaknesses of current Caltrans classification systems is piezoelectric sensors. Districts seek help from a number of sources when piezoelectric sensor problems occur. Some rely upon vendors to keep their sensors working, others rely on other districts for support, and the remainder rely on headquarters staff for help. Caltrans is very interested in systems that utilize inductive loop signatures rather than piezoelectric sensors to do vehicle classification. The San Diego district is working with a private company to classify vehicles using loop signatures. Caltrans is also interested in non-intrusive detectors for collecting some of the data, especially in areas where construction is prevalent and lateral traffic shifts render inductive loops useless. Caltrans is evaluating the Remote Traffic Microwave Sensor (RTMS) for this purpose.

The current vehicle count/classification program provides adequate coverage for vehicle-miles traveled (VMT), but not for accident exposure purposes. There needs to be 400 sites to accurately determine exposure, although major Interstate routes like I-5 and I-10 might have enough already. The number of people currently collecting the data throughout the state is 35, but there is a need for a total of 50 *(65)*.

7.3.2.3 Colorado

Colorado follows procedures outlined in the Traffic Monitoring Guide and the AASHTO Guidelines for Traffic Data Programs in its traffic data collection and projections most of the time. Coverage is not sample based. Essentially 100 percent of the state highway system in Colorado is counted over a three-year cycle. The state estimates 100 percent of the system annually. As a rule, the state does not check projections. The section that is responsible for the collection and analysis of vehicle classification data and WIM data is the Data Collection and Traffic Analysis Unit of the Research Branch. The state uses 22 vehicle categories at continuous WIM sites and three at portable and continuous classification sites. Their 22 classifications will compress directly into the FHWA 13-bin scheme. Where the state uses length classification, the categories are passenger vehicle, single unit, and combination.

Colorado reports the weight data to SHRP and FHWA and uses the data for pavement design. The state does not coordinate the data collection needed for HPMS, LTPP, and projects. Colorado sometimes collects data for specific projects, but when it does not, it uses system averages and/or analyst judgement. Colorado does not consider its traffic monitoring data to be statistically valid. The state updates traffic data between preliminary and final designs if the time span is more than one year. Traffic load forecasting is the responsibility of the Traffic Analysis unit of the Research Branch. It uses multiple truck classes in the projection. The forecasting procedure is done by linear regression for all areas except where the metropolitan planning organization (MPO) has developed traffic assignment models. Colorado does not have a program to compare actual traffic loadings to predicted traffic loadings. The state does not predict truck traffic separately from overall vehicle growth due to insufficient consistent classification data. Colorado does not use load factors that are specific to regions or to time of year. The last time truck factors were re-evaluated by the Colorado DOT was 1991. The state determines accumulated traffic loadings for rehabilitation projects basically by using the AASHTO Pavement Design Guidelines. The state does not make provision for updating traffic figures if the design timetable is not met. The pavement engineer does not modify traffic loadings in this state *(64)*.

7.3.2.4 Florida

Florida DOT (FDOT) selects classification sites such that, as a minimum, there is one classification site between major intersections on the National Highway System. The state follows procedures outlined in the Traffic Monitoring Guide and the AASHTO Guidelines for Traffic Data Programs in their traffic data collection and projections. Florida checks actual traffic against forecast traffic only as dictated by specific projects. The section that is responsible for the collection and analysis of vehicle classification data is the Central Office of Planning. The state uses FHWA scheme "F" with 13 vehicle categories. The section that is responsible for the collection and analysis of WIM data is the Central Office of Planning. Florida uses weight data for pavement design, truck weight studies, and for the Motor Carrier Compliance Office. For efficiency, the state coordinates within its central office the data collection needed for HPMS, LTPP, and projects. Florida occasionally collects project level data if special conditions call for additional data such as turning movements or ramp counts. In general, the state uses AADT for mainline projects. Florida ensures statistical validity by using permanent counts to adjust coverage counts. The state routinely updates traffic data between preliminary and final designs. Traffic load forecasting in Florida is the responsibility of the District Planning Offices. It uses truck percentage based on Scheme "G," classes 4 through 13. The process uses urban study models in most cases, but otherwise it bases growth on the comprehensive plan. The state does not predict truck traffic separately from overall vehicle growth. FDOT uses load factors that are specific to regions but not to time of year. FDOT re-evaluates truck factors annually. The state determines accumulated traffic loadings for rehabilitation projects by using its own procedure for all projects. The state makes provision for updating traffic figures if the design timetable is not met by re-evaluating design traffic figures. The pavement engineer does not modify traffic loadings in this state *(64).*

7.3.2.5 Idaho

Idaho DOT (IDOT) selects permanent classification sites based on staff assessment of data requirements from different regions within a state. The state follows procedures outlined in the Traffic Monitoring Guide and the AASHTO Guidelines for Traffic Data Programs in their traffic data collection and projections. However, it goes beyond what the TMG requires. Idaho has developed a more sophisticated and complete methodology of vehicle classification based on axle spacings. The state has also expanded upon the TMG guidelines in the areas of data editing and calibration. The section that is responsible for the collection and analysis of vehicle classification data is the Traffic Survey and Analysis Section. Idaho classifies vehicles by axle spacing but then summarizes by the FHWA 13 class scheme for reporting purposes. Idaho uses the weight data in a wide variety of ways. These include commercial vehicle volume statistics, satisfying needs of the general public, for pavement design, maintenance, and feasibility studies. For efficiency, the state coordinates the data collection needed for HPMS, LTPP, and projects. Idaho collects project level data upon request. The state updates traffic data between preliminary and final designs on a request basis. It uses multiple truck classes in the projection and a straight-line projection based on past trends. Idaho compares actual traffic loadings to predicted traffic loadings through its

ATR and portable count program. The state predicts truck traffic separately from overall vehicle growth by using separate commercial and non-commercial growth factors. IDOT uses load factors that are specific to regions but not to time of year. However, IDOT plans on adding time of year factors. Idaho re-evaluates truck factors semi-annually. The state determines accumulated traffic loadings for rehabilitation projects by using straight-line projections. The state makes provision for updating traffic figures if the design timetable is not met by updating traffic upon request *(64)*.

7.3.2.6 Illinois

Illinois DOT (IDOT) selects its portable and permanent classification sites according to the FHWA Traffic Monitoring Guide. However, in other ways, it exceeds TMG/AASHTO guidelines in that it collects a great deal of universe traffic data along with the HPMS data collection effort. These universe data allow publishing various highway statistics reports and traffic volume maps. Checks of traffic projections by planning and design personnel occur on a two-year cycle for the state primary system and on a five-year cycle for cities and counties. The collection of vehicle classification data by portable equipment is the responsibility of the Bureau of Planning in each of the nine highway district offices. Districts process the counts and submit them to the central office of Planning and Programming in Springfield for preparation of maps and published reports. The statewide Office of Planning and Programming, Bureau of Urban Program Planning retrieves permanent classification data via modem. The state uses 13 vehicle categories for submittal to the FHWA and eight categories to summarize travel by vehicle type in IDOT publications. IDOT personnel believe the 13 classes are excessive. The statewide Office of Planning and Programming collects WIM data from the 17 SHRP/LTPP sites. This office also implemented the portable WIM program when personnel resources are available. Law enforcement provides static weight data from permanent truck weigh stations and portable weight scales used by law enforcement. Illinois uses weight data for pavement design. When possible, Illinois coordinates at the district level the data collection needed for HPMS, LTPP, and projects. Illinois routinely collects project level traffic data. The state attempts to ensure statistical accuracy by comparing site-specific project data with area traffic volumes and patterns on the most recently revised traffic map. The state routinely updates traffic data between preliminary and final designs. Traffic load forecasting is the responsibility of the Bureau of Program Development, Traffic Studies Unit in each of the nine highway districts. Traffic load forecasts use two truck classes in traffic load projections: single-unit trucks and multiple-unit trucks. The projection considers past trends based on historical data as well as trip generation anticipated from site-specific and area economic development. Illinois compares actual traffic to predicted traffic by reviewing newly published maps and occasionally by special counts upon project completion. The state predicts truck traffic separately from overall vehicle growth on Interstate Highways and on expressways. It uses growth rates for three vehicles: passenger vehicles, single-unit trucks, and multiple-unit trucks. IDOT uses load factors that are specific to regions and time of year in relation to grain, surfacing mining, and other truck generators. The state determines accumulated traffic loadings for rehabilitation projects based on existing pavement condition and current and projected traffic volumes The state makes provision for updating traffic figures if it fails to meet the design timetable. Traffic forecasters are routinely asked to revise traffic data. The pavement engineer does not modify traffic loadings in this state *(64)*.

7.3.2.7 Indiana

Indiana DOT follows procedures outlined in the Traffic Monitoring Guide and the AASHTO Guidelines for Traffic Data Programs in their traffic data collection and projections. Backcasts of forecasts to check projections are rarely done. The section that is responsible for the collection and analysis of vehicle classification data is the Roadway Management Division. The state uses 13 vehicle categories at portable and WIM sites and four at permanent telemetry sites. The section that is responsible for the collection and analysis of WIM data is Roadway Management. Indiana uses weight data for research, for reporting to FHWA, and for design. For efficiency, the state coordinates within the same division the data collection needed for HPMS, LTPP, and projects. Indiana collects project level data when average coverage counts or details are not sufficient. Indiana considers review of its data by FHWA to be sufficient to ensure statistical validity. The state rarely updates traffic data between preliminary and final designs. Traffic load forecasting is the responsibility of the Pavement Design group in the Materials and Test Division. Indiana uses only one truck class in its projections, and it does not consider past trends and future economic activity in the area for the projection. Indiana compares actual with predicted traffic occasionally as part of its research program. The state does not predict truck traffic separately from overall vehicle growth. Indiana DOT does not use load factors that are specific to regions or time of year. Indiana has not re-evaluated its truck factors for 10 years. The state does not make provision for updating traffic figures if the design timetable is not met. The pavement engineer does not modify traffic loadings in this state *(64)*.

7.3.2.8 Iowa

Iowa DOT chooses its new classification sites using selected criteria to achieve the best possible coverage. IDOT staff plots each of the criteria on a map to show where needs lie. The criteria are: AADT, region, proximity to traffic generators, and area population. The state follows procedures outlined in the Traffic Monitoring Guide and the *AASHTO Guidelines for Traffic Data Programs* in their traffic data collection and projections. Iowa does not have a program to monitor actual traffic as compared to predicted traffic. The Traffic section in the office of Transportation Data is responsible for the collection and analysis of portable classification counts. The Telemetrics section of the office of Transportation Data is responsible for the collection and analysis of classification data from permanent stations. The state uses 13 vehicle categories. The section that is responsible for the collection and analysis of WIM data is the Telemetrics section in the office of Transportation Data. Iowa uses weight data for SHRP, but WIM data anomalies prevent use in design. To improve efficiency for all data needs, Iowa uses the same database for HPMS, LTPP, and projects. Iowa routinely uses its summer program coverage counts for specific project data. Iowa ensures statistical validity of data by following the procedures in the TMG and *AASHTO Guidelines for Traffic Data Programs*. The state sometimes updates traffic data between preliminary and final designs depending on the time span and the forecasted program year. Traffic load forecasting is the responsibility of Traffic Forecasting Section within the Office of Systems Planning. It splits forecast trucks into two classes for most projects, single units and combination trucks. They are further broken down by highway segment after the forecast into eight categories. Traffic projections for rural areas utilize historical data covering the 10,000 mile primary system for even-numbered years dating back to 1980. These data exist for three vehicle categories: passenger cars/pickups, single-unit trucks, and combination trucks. Urban projections mostly use MPO travel demand forecasting models. Iowa does not have a set program to compare actual traffic loadings to predicted traffic loadings but spot forecasts have been verified, especially on the Interstate system. Iowa predicts truck traffic separately from overall vehicle growth. The state does not use load factors that are specific to regions or time of year. The last time Iowa DOT re-evaluated truck factors was 1991. The state determines accumulated traffic loadings for rehabilitation projects by road rater information and by using forecasted ESALs. The state does not routinely update traffic figures if the design timetable is not met. However, Pavement Design personnel make the decision in each case on whether an update is needed. The pavement engineer does not modify traffic loadings in this state *(64)*.

7.3.2.9 Minnesota

Minnesota selected WIM sites based on SHRP needs and based on routes that had a range of truck volumes. It selected classification sites by continuing to use historic locations that had been monitored over time. The state in many cases exceeds requirements outlined in the Traffic Monitoring Guide and the AASHTO Guidelines for Traffic Data Programs in their traffic data collection and projections. The state has an in-house back casting program that checks predictions. The section that is responsible for the collection and analysis of vehicle classification data is Traffic Forecasting and Analysis. The state uses eight vehicle categories. Minnesota uses weight data for ESAL damage determination. Minnesota routinely collects project specific data along with historic site-specific data. The state routinely updates traffic data between preliminary and final designs. Traffic load forecasting is the responsibility of the Traffic Forecasting and Analysis Section. It uses multiple classes of trucks in the forecast. The forecasts utilize past trends as well as anticipated future growth in the area. Minnesota does not have a set program to compare actual traffic loadings to predicted traffic loadings, but this is done occasionally. The state occasionally predicts truck traffic separately from overall vehicle growth; it depends upon the location, data, and project. As a general rule, the state does not use load factors that are specific to regions or time of year. The last time truck factors were re-evaluated by Minnesota DOT was 1989. The state does not routinely update traffic figures if the design timetable is not met. The original forecast applies to the original design year and four years beyond. It reviews the forecast if it is more than two years old. The pavement engineer does not modify traffic loadings in this state *(64)*.

7.3.2.10 North Carolina

North Carolina (NC) bases the selection of both WIM and classification sites on there first being a need to collect truck data from the site. Another consideration is that traffic flow should have a constant speed, not stop-and-go. All proposed sites are accepted or rejected based upon the site pavement conditions. If the state intends to monitor truck weights, then the site must be located on a facility allowing trucks. If the site is part of the TMG truck study, the site must be randomly selected from HPMS sample segments or otherwise determined acceptable. The state follows procedures outlined in the Traffic Monitoring Guide and the AASHTO Guidelines for Traffic Data Programs in their traffic data collection and projections. The NC coverage count program exceeds the minimum requirements of the TMG.

NC does not follow a three-year cycle but counts routes every year. NC counts secondary routes on a two-year cycle. The state typically does not estimate a site that is not counted on a given year. Likewise, NC does not typically report one- or two-year traffic forecasts based on the growth factor process outlined in the TMG. NC does not have a process in place to check actual traffic against forecast traffic, at least not by the pavement designer. The Traffic Survey Unit (TSU), Statewide Planning Branch, is responsible for the collection and analysis of truck weight data as required for the TMG/HPMS and state needs. The Pavement Management Unit collects truck weight data for project specific needs. Pavement designers conduct analysis of weight data. The state uses 13 vehicle categories when using electronic recorders. The section that is responsible for the collection and analysis of WIM data for the TMG/HPMS is the TSU, Statewide Planning Branch. The Pavement Management Unit collects weight data for project specific needs. Pavement designers do analysis of weight data. North Carolina uses weight data for ESAL damage determination. For efficiency, the state coordinates the data collection needed for HPMS and LTPP in one unit. North Carolina routinely collects project level traffic data.

The state ensures statistical validity by following TMG/AASHTO guidelines as closely as possible. To accomplish this, minimum machine count duration is 48 hours, and manual counts of 16 hours are expanded using continuous count data grouped by either functional class or facility type. The state routinely updates traffic data between preliminary and final designs. Traffic load forecasting is the responsibility of the Statewide Planning Branch along with the Pavement Management Unit. The planning group prepares the project level design travel forecasts for transportation improvements. It provides travel forecast information as the number of passenger vehicles, dual axle trucks, and tractor-trailer trucks. The Pavement Management Unit uses either historical information or supplemental project data to establish future loading. The forecast uses multiple classes of trucks, dual axle trucks and combination trucks. Forecasts developed by the five modeling units are driven by future land use estimates that are endorsed by the state, municipalities, and counties involved. For rural areas and small urban areas, forecasters use either regression or growth factor techniques that include a review of past development trends.

The process also considers local official input regarding future growth potential. North Carolina's five planning units that are responsible for modeling compare actual traffic loadings to predicted traffic loadings. The state does not predict truck traffic separately from overall vehicle growth, but is stated as a percentage of the total traffic projection. However, NC Department of Transportation (NCDOT) recognizes the need to improve its truck forecasts and is considering a "truck purpose" in its statewide travel flow model. The state does not use load factors that are specific to regions or time of year. The last time truck factors were re-evaluated by NCDOT was 1990. The state does not use accumulated traffic loadings for rehabilitation projects. The state updates traffic figures if the design timetable is not met or if the traffic projection is more than two years old. The pavement engineer does not modify traffic loadings, but the Pavement Management Unit may question the reliability of the projection in some cases *(64)*.

7.3.2.11 North Dakota

North Dakota (ND) selects WIM sites based on functional class and area of the state. The state selects classification sites by highway links; it wants one count per highway link. The state does not follow procedures outlined in the Traffic Monitoring Guide and the AASHTO Guidelines for Traffic Data Programs in their traffic data collection and projections. ND does not have a process in place to check actual traffic against forecast traffic. The section that is responsible for the collection and analysis of vehicle classification data and WIM data is Traffic Data Collection and Roadway Data. The state uses 13 vehicle categories. North Dakota routinely collects project level traffic data. The state ensures statistical validity by following the TMG. The state routinely updates traffic data between preliminary and final designs. Traffic load forecasting is the responsibility of the Roadway data unit. It uses multiple classes of trucks in the forecast and considers past trends and future economic activity. ND does not have a set program for comparing actual traffic with predicted traffic. The state predicts truck traffic separately from overall vehicle growth. The state does not use load factors that are specific to regions or time of year. The last time truck factors were re-evaluated by North Dakota DOT was 1995. The state updates traffic figures if the design timetable is not met, although details were unavailable. The pavement engineer does not modify traffic loadings in this state *(64)*.

7.3.2.12 Ohio

Ohio follows procedures outlined in the Traffic Monitoring Guide and the AASHTO Guidelines for Traffic Data Programs in their traffic data collection and projections. The section that is responsible for the collection and analysis of vehicle classification data is the Traffic Monitoring Section. The state uses 13 axle classifications, five vehicle length classifications, and two RTMS classifications. The RTMS in the sidefire orientation gives two vehicle lengths: less than 50 ft and greater than 50 ft. Ohio uses weight data for pavement design/analysis, permits and fines of heavy vehicles, enforcement screening, and air quality. Ohio considers project level traffic data to be its first priority. The state ensures statistical validity by following the TMG. Ohio does not update traffic data between preliminary and final designs. Traffic load forecasting is the responsibility of the Pavement Design Section. It uses multiple classes of trucks in the forecast and past traffic trends only. Ohio does not have a set program for comparing actual traffic with predicted traffic. The state does not predict truck traffic separately from overall vehicle growth. The state does not use load factors that are specific to regions or time of year. Ohio DOT re-evaluates truck factors at least annually. The state determines accumulated traffic loadings for rehabilitation projects by regression analysis of historical loading data. The state typically does not update traffic figures if the design timetable is not met. The pavement engineer might modify traffic loadings in this state if there is knowledge of above-normal loadings on a particular route *(64)*.

7.3.2.13 Pennsylvania

Pennsylvania selects WIM and classification sites based on SHRP locations. The state follows procedures outlined in the Traffic Monitoring Guide and the AASHTO Guidelines for Traffic Data Programs in their traffic data collection and projections. Pennsylvania DOT does not have a process in place to check actual traffic against forecast traffic. The section that is responsible for the collection and analysis of vehicle classification data and WIM data is the Bureau of Planning and Research. The state uses 11 vehicle categories. Pennsylvania uses WIM data for SHRP and FHWA reporting requirements. The state collects project level data at the district level. The state does not update traffic data between preliminary and final designs. Traffic load forecasting is the responsibility of the Bureau of Maintenance and Operations. It uses multiple classes of trucks in the forecast and utilizes the traffic count program to forecast future traffic. Pennsylvania does not have a set program for comparing actual traffic with predicted traffic, but its count program has 100 percent coverage over state roads. The state does not predict truck traffic separately from overall vehicle growth due to insufficient data for development of accurate factors. The state does not use load factors that are specific to regions or time of year. The last time truck factors were re-evaluated by Penn DOT was in the 1980s. The state does not determine accumulated traffic loadings for rehabilitation projects. Instead, it predicts future traffic loadings for the estimated life of the rehabilitation based on current traffic loading and growth factors. The state updates traffic figures if the design timetable is not met and sufficient time has passed. The pavement engineer does not modify traffic loadings in this state *(64)*.

7.3.2.14 South Carolina

South Carolina (SC) selects portable WIM sites based on a random site selection process according to the TMG. Its permanent sites are based on construction or rehab projects and Interstate projects. Its classification sites are based on TMG requirements. The section that is responsible for the collection and analysis of vehicle classification data is the Traffic Count Unit. The state uses 15 vehicle categories. SC uses weight data for its annual report to FHWA and for its monthly report to the State Transport Police. The state coordinates the data collection needed for HPMS, LTPP, and projects in the way it schedules WIM sessions. South Carolina does not collect project level data, only the normal statewide traffic coverage. The state ensures statistical validity by providing full statewide coverage. The state does not update traffic data between preliminary and final designs. Traffic load forecasting is the responsibility of the Office of Planning. It uses multiple classes of trucks in the forecast, with economic growth being used for the primary predictor of traffic growth. South Carolina does not have a set program for comparing actual traffic with predicted traffic. The state does not predict truck traffic separately from overall vehicle growth because all classes appear to have similar rates of growth. The state does not use load factors that are specific to regions or time of year. The last time truck factors were re-evaluated by SC DOT was 1974. The state updates traffic figures if the design timetable is not met. The pavement engineer occasionally modifies traffic loadings following site investigations *(64)*.

7.3.2.15 South Dakota

South Dakota (SD) selects WIM sites based on functional class and availability of a steel girder bridge. It selects classification sites based on random sampling with consideration for SHRP sites and state needs. The state follows procedures outlined in the Traffic Monitoring Guide and the AASHTO Guidelines for Traffic Data Programs in their traffic data collection and projections. SD does not have a process in place to check actual traffic against forecast traffic. The section that is responsible for the collection and analysis of vehicle classification data and WIM data is the Office of Transportation Data Inventory. The state uses 13 vehicle categories. SD uses weight data for establishing ESALs for pavement design. For efficiency, the state coordinates the data collection needed for HPMS, LTPP, and projects in the way sites are selected. The state collects volume data at the project level. The state updates traffic data between preliminary and final designs if requested by the designer. Traffic load forecasting is the responsibility of the Data Inventory Office. It uses multiple classes of trucks in the forecast. Load forecasts rely on historical truck data for the last six years and not on economic activity. South Dakota does not have a set program for comparing actual traffic with predicted traffic. The state predicts truck traffic separately from overall vehicle growth. The state does not use load factors that are specific to regions or time of year. The last time truck factors were re-evaluated by South Dakota was 1996. The state does not make provision for updating traffic figures if the design timetable is not met. The pavement engineer does not modify traffic loadings in this state *(64)*.

7.3.2.16 Washington

The state of Washington uses 138 permanent traffic recorder (PTR, same as AVC) sites that generate vehicle classification data 365 days per year. They also conduct short counts, which are partially driven by HPMS data needs, using pneumatic tube counters. There are a total of 1800 short-count sites that are counted on a three-year cycle, so approximately 600 are counted each year. These are generally counted for 72 hours each. There are 45 weigh-in-motion sites dispersed based on the following criteria: 1) SHRP LTPP data needs, 2) groupings according to the following categories: urban, rural, arterial, and Interstate roadways. Locations were originally tied primarily to the different types of routes, even though all the types are not currently represented. WIM sites operate on a continuous basis.

Data polling and processing staffing is as follows. There are six full-time equivalents (FTE) for the PTR sites. These six positions are adequate for the current number of sites, although there is a need for one more person for an additional 25 sites that have been approved by the state legislature. There are four permanent positions and four permanent seasonal (nine months per year) positions responsible for installation and maintenance of the PTR sites. An additional crew of five permanent seasonal staff will start in March 2001, and they will be responsible for maintaining the additional 25 PTR sites. There are 13 additional persons for conducting short counts; this is barely enough to meet the various requirements of HPMS sites and all others. There is need for another four positions to do the job well. WIM counts are continuous counts with equipment that is permanently installed in the road, so the department assigns no additional personnel just for WIM data.

Equipment used by the state for short counts consists of 280 tube counters; these are GK 5000 and 6000 series units, and 22 Diamond Unicorn tube counters. The state uses 135 Diamond-Phoenix classifiers and three Golden River classifiers at PTR sites. The WIM units are predominantly IRD 1060 units using a few Dynax piezoelectric sensors, which have not been replaced yet. BL sensors, manufactured by Measurement Specialties, Inc., are replacing Dynax sensors. Besides the IRD piezoelectric systems, the state also has two bending plate systems and one site that uses Kisler quartz sensors. One complaint with the WIM system is the IRD software that is DOS-based. Downloading data requires reducing the operating speed on the laptop computer. There is also concern regarding operation of the IRD equipment in extreme temperatures. For that reason, the state installed fans and heaters for eastern Washington where cabinet temperatures can reach 105 degrees F in the summer and drop below freezing in the winter.. This solves some temperature-related problems, but these ancillary devices also cause circuit breakers to trip, requiring someone to reset the breaker.

The state has purchased four RTMS units to use in testing for vehicle counts in Olympia, Washington, and it is considering 3M microloops. Non-intrusive detectors are being considered now because of the difficulty of closing lanes to install on-roadway systems. Due to the heavy rainfall and fog in the western part of the state, the agency did not consider video image detection a viable detector type.

The accuracy being achieved in WIM, count, and classification data is approximately 95 percent. There was a problem with WIM that was attributed to Washington using its own weight tables and not the IRD defaults and site factors. The site was just beyond a downgrade and on a curve, causing steer axle weights to be heavy. Calibration of the IRD system for all axles and gross weights is based on steer axles, so other weights were too heavy. The state now uses a more appropriate site near a State Police static scale site where WIM output can be easily compared with static weights. If state personnel notice a significant change in any of the various data types, they immediately check the parameters in the data collection equipment or other variables and make adjustments.

There are a few isolated locations where the state needs site-specific vehicle classification data. One example is at the Tacoma-Narrows bridge where decision-makers need traffic data. Even though there was an existing site nearby, there was also turning traffic between the site and the bridge. Therefore, the state installed a permanent site to capture bridge traffic.

Washington personnel do not believe they need improvements in the number of classification sites or in the frequency of data collection. The state legislature's recent approval to add another 25 sites brought the number up to an adequate level. Classification data are collected 365 days a year and polled once each week. For WIM sites, the current number of 45 is sufficient. In fact, there are probably more than are truly needed. For example, there are some duplicates due to adding SHRP sites on the same route as other WIM sites *(66).*

7.3.2.17 Wisconsin

Wisconsin used HPMS, SHRP, and state program needs to establish WIM site locations, as long as site conditions were favorable. For classification sites, the state looks for desirable geometry where traffic is free-flowing. The state follows procedures outlined in the Traffic Monitoring Guide and the AASHTO Guidelines for Traffic Data Programs in their traffic data collection and projections. The section that is responsible for the collection and analysis of vehicle classification data and WIM data is the Data Management Services. The state uses 13 vehicle categories plus unclassified. Wisconsin uses weight data for HPMS/SHRP and for pavement design. The Wisconsin data collection plan considers the needs of both HPMS and LTPP, but not individual projects. It uses its three-year cycle counts and averages for specific project needs. Wisconsin ensures statistical validity by using the universe factor by traffic-based groups. The state routinely updates traffic data between preliminary and final designs Traffic load forecasting is the responsibility of the Traffic Forecast Section. It uses two classes of trucks in the forecast, single-units and combinations. Prediction is based on the TranPlan model and input from the University of Wisconsin. The state does not have a set program for comparing actual traffic with predicted traffic. The state predicts truck traffic separately from overall vehicle growth. The state does not use load factors that are specific to regions or time of year. Wisconsin DOT re-evaluates their truck factors annually. The state updates traffic figures if the design timetable is not met *(64).*

Tables 15 through 17 summarize WIM and classification equipment usage by most of these states. Table 18 is a summary of responses by the various states on ranking of procedures.

7.3.3 Traffic Load Forecasting Process

7.3.3.1 Florida

Florida Department of Transportation (FDOT) collects and stores a broad range of traffic data for use in design and maintenance activities. The central office, districts, local governments, and consultants collect volume and classification data, speed data, and commercial vehicle weight data. The Transportation and Statistics Office (TranStat), whose central office is in Tallahassee, is responsible for collecting, processing, storing, and reporting statistical traffic information for the state highway system. Each district collects traffic data, edits the data, and uploads the traffic data to the mainframe computer. They do this using road tubes, permanent loop detectors, or various other detection devices.

Table 15. WIM Equipment Utilization by States.

Weigh-in-Motion Equipment						3 yr Projection		Bridge WIM
State	No. Portable Sites	Type Used	No. Permanent Sites	Type Used	No. SHRP Sites	Port.	Perm.	
Alabama	15 (4 units used to cover sites once a year)	Truvelo TDL-500	30 Short-term use	14 PAT DAW 200/100 9 PEEK ADR 3000	18 (7 not equipped)	0	0	No
Colorado	78 Not project specific	Golden River (NLF)	12 Continuous use	IRD Piezo	12	NS	NS	No
Idaho	4 (45locations/8months)	Golden River	12 Continuous use	ECM	12	0	1	No
Illinois	0	None	17 Continuous use	Piezo-loop-piezo	0	0	0	No
Indiana	0	N/A	34 Continuous use	IRD-1060 LP	15	0	1	Yes
Iowa	0	None	21Continuous use	18 GK6000, 3 PEEK ADR	15	0	0	No
Minnesota	0	None	23 Continuous	All IRD Bending plate-18 sites Hydraulic load cell-5 sites	20 Permanent	0	0	No
N. Carolina	0 As needed for specific projects	Not specified	19 Continuous use	13 Peek ADR 3000 5 PAT DAW100, 1 IRD	14	0	50	No
N. Dakota	50 Not project-specific	Not specified	1	IRD Bending Plate	1	0	1	No
Ohio	2	Capacitance Mats (ITC)	21 Continuous	Mettler Toledo Scale PAT Traffic Corp. BP IRD (PIEZO)	10	0	5	Yes
Pennsylvania	8	Pat Traffic	1 Continuous	ECM	9	0	0	No
S. Carolina	99	90 TMG(30/yr), 9 SHRP	6 Continuous	All Interstate Rural	9			
S. Dakota	0	7	Continuous	4-PAT BP, 2 PAT Piezo, 1 IRD BP	4	0	6-8 Bridge	Summ 1997
Texas	83	Piezo (ECM)	17 (use one at a time, move)	Bending Plate (PAT) 2-Piezo (ECM)	83	0	8Piezo	No
Wisconsin	70+	PHT DAW 100	3 Continuous	1 IRD,2 Pat Bend. Plate	12/3	0	2	No
Florida	19	Piezoelectric	24 Continuous	Bend. Plate/ Piezoelectric	19-Port, 4-Perm	0	7	No

Source: Reference 64

Table 15. WIM Equipment Utilization by States (Continued).

State	Cal. Portable	Cal. Permanent	Calibration Procedure
Alabama	Each time moved	Not specified	Front axle on class 9 vehicles average 10,000 lb.
Colorado	Effort contracted out	Annually	5-axle semi ran until average of 10 consecutive readings of gross weight is within 10 percent of static wt.
Idaho	Annually	At installation	Perm -Repeated passes using a vehicle of known weight. Port - Compare 600 vehicles to static weight when they pass the scale. A calibration factor for each 10,000 lb weight group is developed that reflects the differences observed between static scale and portable system within each weight group.
Illinois	NA	July 1993	NA
Indiana	NA	Once per year	The manufacturer completes the annual calibration under a service contract.
Iowa	NA	Not specified	Systems are set to self calibrate off the front axle.
Minnesota	NA	At time of installation	Two-step process: 1) use a 5-axle semi test truck, calibrating the lane to it; 2) collect gross weight data for one week then examine distribution of 5-axle semis for unloaded and loaded vehicles. If peaks look reasonable, i.e. about 28-30 kips for unloaded and in the mid 70s for loaded, then OK.
North Carolina	Annually or as req'd, & each time moved	Annually or as required	5-axle semi is driven over sensors. Adjustment is made to bring each axle into a tolerable range. ADR3000 uses a self-calibration procedure.
North Dakota	Annually	Annually	Comparing gross vehicle weights with enforcement scale.
Ohio	Every 5 sessions	2/3 per year	OH uses a FHWA class 6 and 9 vehicles running in normal traffic with a known weight. Vehicle makes multiple passes at 3 different speeds and adjusts according.
Pennsylvania	NA	Biannually	Will be contracted out 2 times at each site per year.
South Carolina	Once a year	As needed	Portable- set-up downstream from State Transport Police permanent enforcement site, calibrate to static scales Permanent- Monitor class 9 steering axle weights and adjust as needed.
South Dakota	Not specified	Not specified	SD plans to do so, however, no formal procedure has been established.
Texas	Annually	Quarterly	Bending Plate: Use a 5-axle, fully loaded calibrated truck. Set calibration factors until the calibration truck repeats within 1000 lb of actual. Piezo WIM: Use a dump truck with weigh ticket. Engage in auto-calibration.
Wisconsin	Daily	Annually	Portable data are post process calibrated based on system average values obtained in original system acceptance calibration testing. Permanent uses 352 loaded.
Florida	NA	As needed	3 passes at 3 different speeds of a vehicle of known static weight. 3-axle dump and/or 5-axle type 9.

Source: Reference 64

Table 16. WIM Calibration Information.

	Calibration Frequency		
State [1]	Portable	Permanent	Calibration Procedure
Alabama	Annually	Annually	Accuracy of each site checked by manual classification count.
Colorado	Never	At installation	Speed of vehicles is compared to a radar gun. Loop separation is adjusted until vehicle speeds are within 2 mph of the radar gun.
Idaho	Not specified	Annually or semi	Manual classification count being performed and then compared to the classifier unit. Any necessary adjustments to sensors or equipment can then be made.
Illinois	At setup	At routine maint.	Adjustment is made to the machine to accommodate the density and speed of the traffic stream being sampled.
Iowa	NA	Not specified	8 hour manual count against each ATR at least every three years. If modified, it is counted again during the next year's schedule to check changes.
North Carolina	As needed	As needed	The technician will visually observe the traffic and adjust the sensors per vendor instructions.
North Dakota	When possible	When possible	Do manual comparison with permanent equipment and update class table in software.
South Carolina	At installation	At installation	Not specified.
Texas	Annually	Annually	Calibration for speed using Laser Range finder.
Wisconsin	6-12 months	6-12 months	Visual to automatic comparison by lanes validate by drive axle space on 3S2.
Florida	As needed	As needed	Speed and classification reading of the equipment is manually verified at installation and adjusted as needed.

[1] Indiana, Minnesota, Ohio, Pennsylvania, and South Dakota did not provide this information.

Source: Reference 64

Table 17. Vehicle Classification Equipment.

Vehicle Classification Equipment						3 yr Projection	
State	No. Portable Sites	Type Used	No. Permanent Sites	Type Used	# of SHRP Sites	Port.	Perm.
Alabama	2160 Project specific	Not specified	40	9 PEEK ADR 3000 14 PAT DAW 200/100 3 ITC, 7 PEEK ADR	18 (7 presently not equipped)	0	0
Colorado	100 Not project specific	Golden River Marksman (by length)	22	Diamond Unicorn Phoenix classifiers	0	Not specified	Not specified
Idaho	60-100 surveys per year	Not specified	116	22 Diamond/ 2 loop 82 Diamond Phoenix	12	0	3 to 5
Illinois	300 HPMS (3-year cycle, 100 counts per yr)	Peek Model 241	23	Peek 241 counter/classifier	0	0	35↢vol ↢ v&c
Indiana	8606	Not specified	58	Not specified	11	5423	88
Iowa	942 Interstate - 1/2 state 631 Pri., 436 Sec.	PEEK TraffiComp III TraffiComp EZ & tubes	74 by class; 31 FHWA 13 card, 43 3 class	50 TraffiComp III 24 Telac, 505c	Not specified	Not specified	2FHWA 13 card
Minnesota	1200	300/year	24	WIM sites	None	20	0
N. Carolina	300+ 500+ manual vehicle classification.	300 TMG/HPMS sites, 100+ sites project specific	11	PAT C100S 80 sites w/ piezo only collect volumes	11 PAT sites	0	15
N. Dakota	1000 Project specific	Not specified	17	Not specified	4	0	20
Ohio	100	Pieces of PEEK 241 Traficomp 3	11 by class 17 by WIM; 241	11 PEEK, 17 PAT and Toledo Scale; 241 L-P-L	N/A	150	20
Pennsylvania	NA	NA	9	NA	9 permanent	0	0
S. Carolina	300	TMG (100/year 3 yr cy)	1	NA	9		
S. Dakota	207	Not specified	Not specified	Not specified	16	0	0
Texas	85 Project specific	Road tubes	265 AVC 374 Vis. Man. Ct.	Road hardware is permanent, rcdr moved.	83	85-100	0
Wisconsin	400+	Peek TCE	35	Peek TCE	15 T Perm SHRP	Not spec	Not specified
Florida	1894	NA	177	NA	0-Port, 15- Perm.	Not spec	Not specified

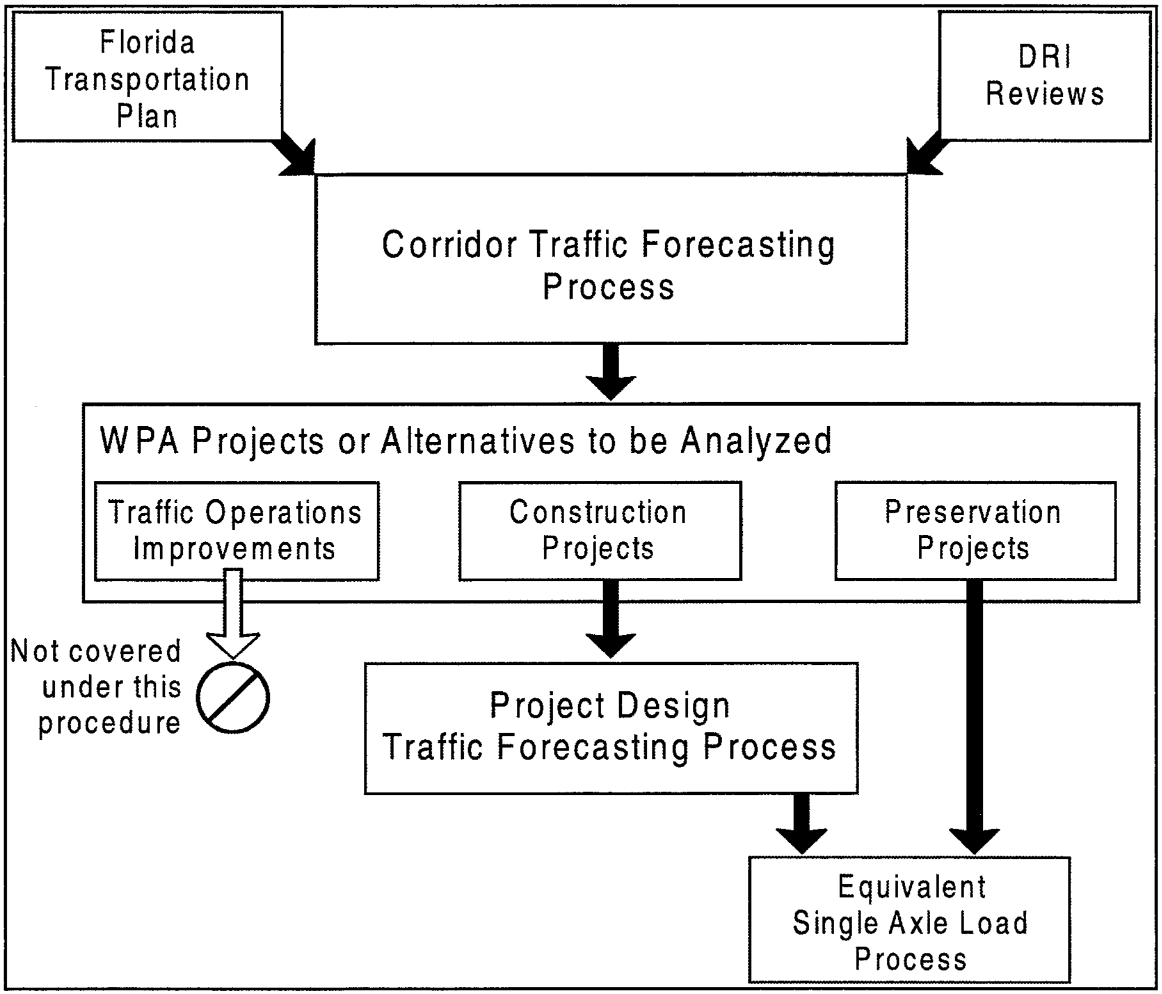
Table 18. State Ranking of Procedures.

	Procedures to identify WIM and classification site location.	Procedures to efficiently (low cost) calibrate WIM sites.	Procedures to determine sampling accuracy of WIM sites.	Procedures to forecast traffic data.	Revise TMG with procedures for WIM and AVC in general.	Importance of Weigh-in-Motion.	Importance of vehicle classification data.	Importance of past vehicle classification data.
Alabama	3	2	2	3	3	2	2	3
Colorado	5	1	4	1	3	1	1	4
Idaho	4	2	4	3	4	2	2	2
Illinois	1	3	4	2	3	4	1	2
Indiana	6	4	5	1	7	3	2	8
Iowa	3	1	1	3	3	2	2	2
Minnesota	1	1	3	MB	5	4	5	4
North Carolina	2	2	1	4	3	1	1	2
North Dakota	4	3	4	3	2	2	1	1
Ohio	5	5	5		2	3	1	3
Pennsylvania	3	3	3	2	3	3	2	5
South Carolina	2	1	3	2	3	4	1	1
South Dakota	3	2	4	1	3	1	1	2
Texas	3	2	2	1	4	1	1	3
Wisconsin	3	1	4	3	3	4	1	2
Florida	1	1	1	1	2	1	1	1
Average	3.06	2.12	3.13	2.07	3.31	2.38	1.56	2.81

Source: Reference 64

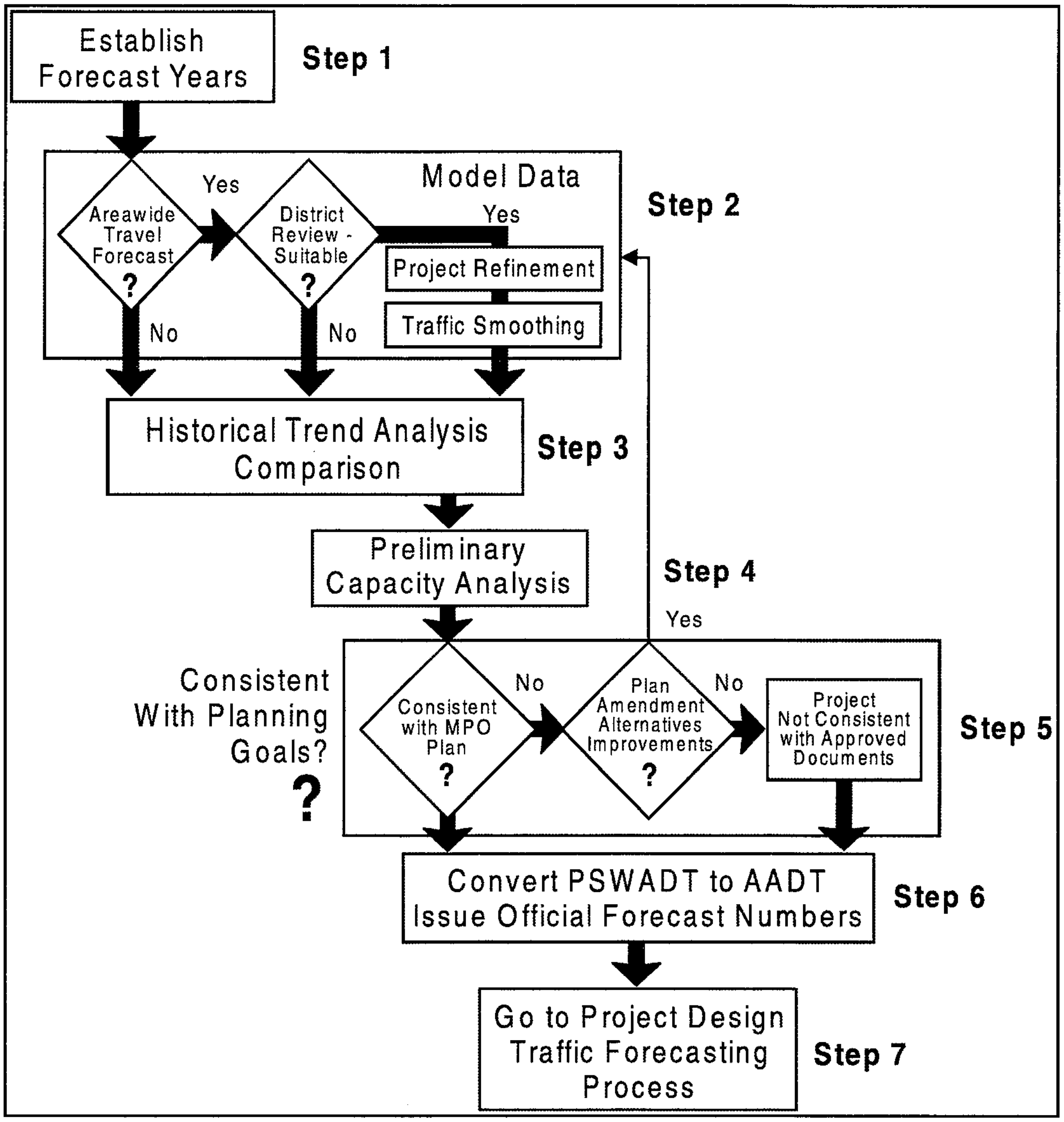
FDOT Travel Demand Process

This description of the FDOT planning process begins broad and then covers specifics. FDOT uses three basic forecasting processes, Corridor Traffic Forecasting, Project Design Forecasting, and the Equivalent Single Axle Load process. As Figure 33 indicates, the Florida Transportation Plan (FTP) and Developments of Regional Impacts (DRIs) designate where traffic studies will be performed. Construction projects require both the Project Design Traffic Forecasting Process and the ESAL process to be performed. Preservation Projects (usually resurfacing projects) only require the ESAL process. Corridor Traffic Forecasting and Project Design Traffic Forecasting projects require forecasts of AADT and DHV. Figures 34 through 36 illustrate these processes *(67)*.



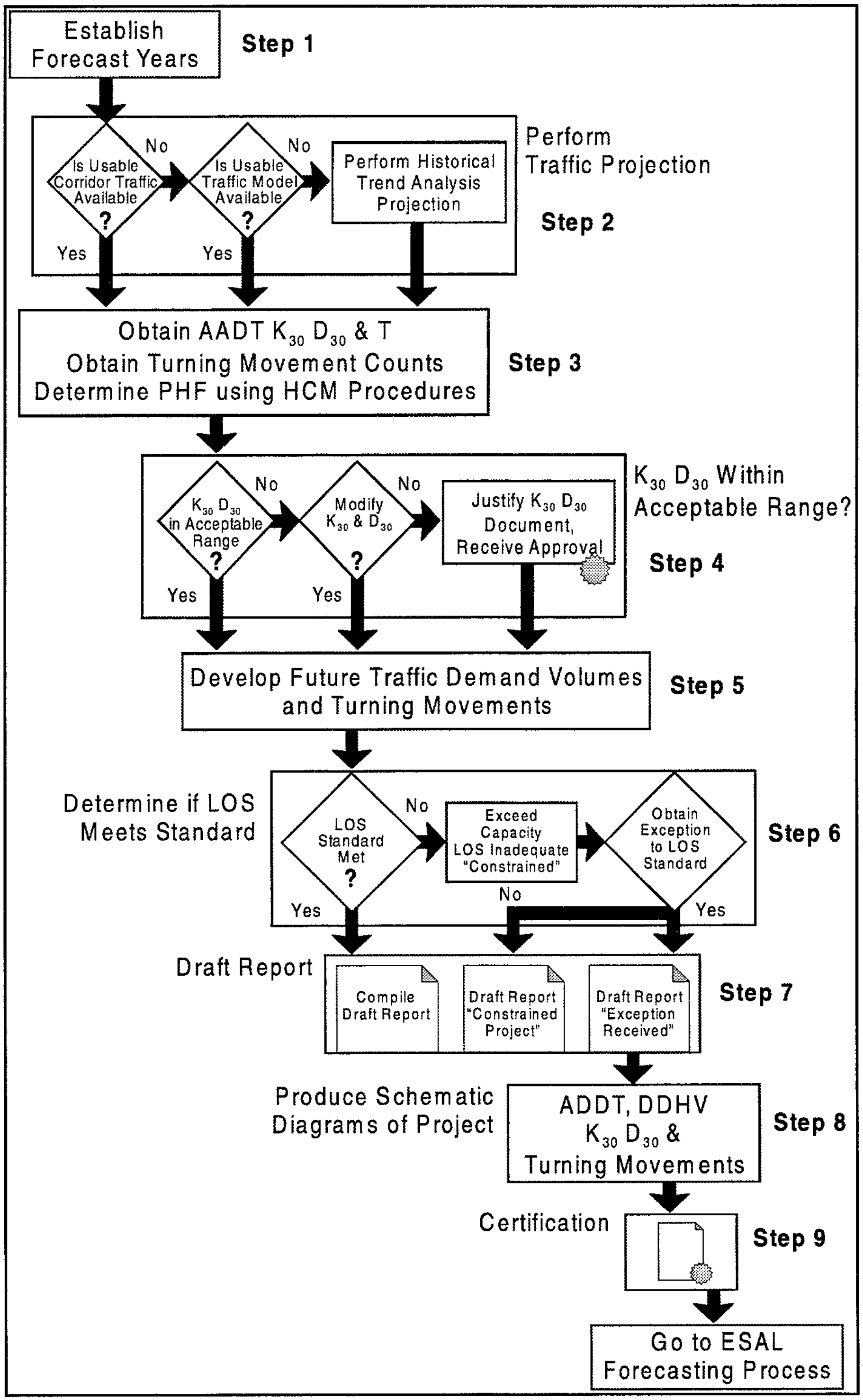
Source: Reference 67

Figure 33. Florida DOT Traffic Forecasting Process.



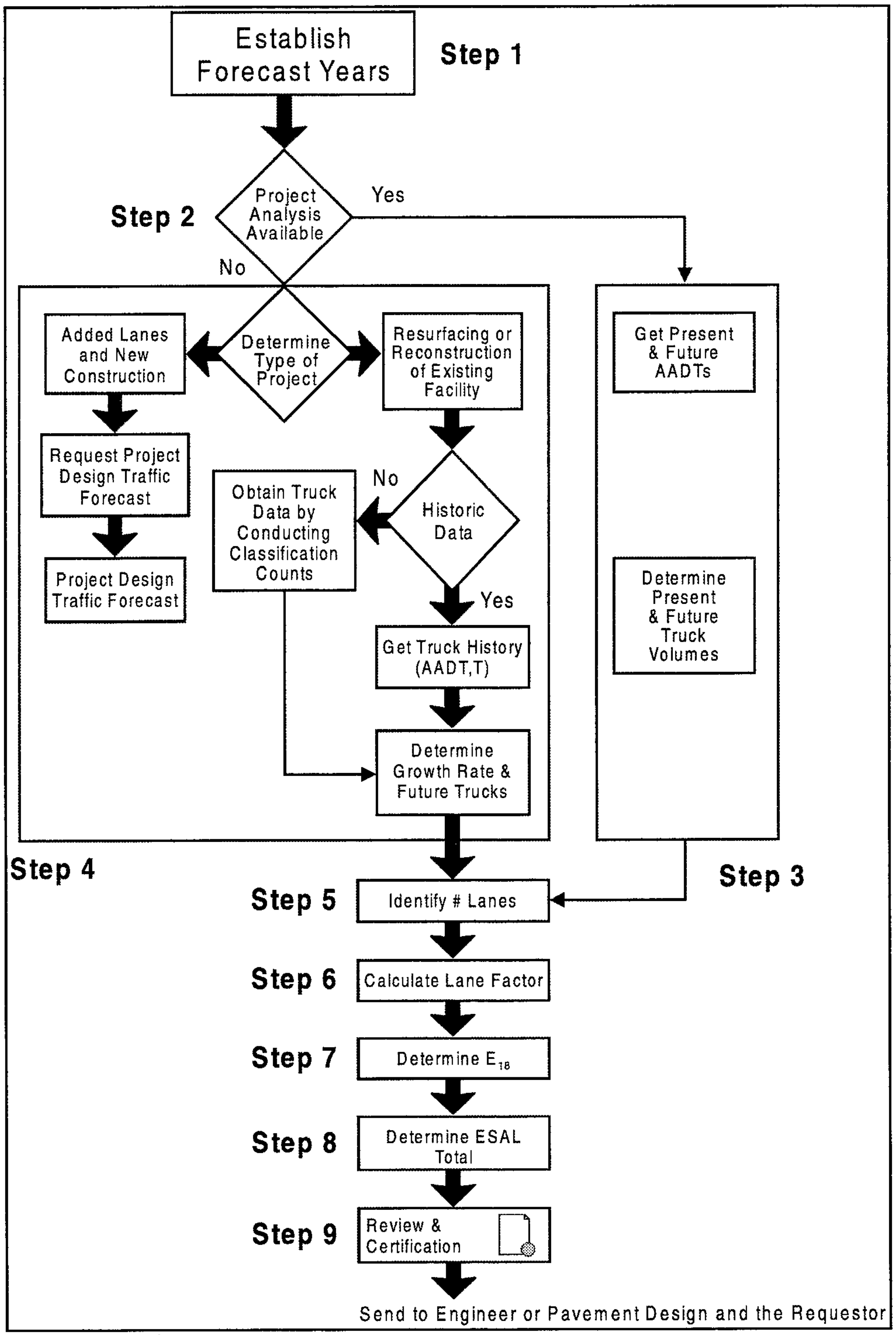
Source: Reference 67

Figure 34. Florida DOT Corridor Traffic Forecasting Process.



Source: Reference (67)

Figure 35. Project Design Traffic Forecasting Process.



Source: Reference (67)

Figure 36. ESAL Forecasting Process.

FDOT uses Corridor Traffic Forecasting to determine the number of lanes required within a corridor or system to meet projected traffic needs. FDOT requires it prior to the establishment of a new alignment or widening of existing facilities. Corridor traffic models are usually more specific than urban area models and more general than project-specific models.

The Project Design Traffic Forecasting process estimates traffic conditions used for determining the geometric design of a roadway or intersection and the number of 18 kip ESALs that a pavement will be subjected to over its design life. Project Design Traffic Forecasting is required for reconstruction, resurfacing, adding lanes, bridge replacement, and major intersection improvements. It is more site-specific in nature than Corridor Traffic Forecasting *(66)*.

FDOT requires ESAL Forecasting for pavement design for new construction, reconstruction, or resurfacing projects. Design for these activities is based on accumulated 18 kip ESALs.

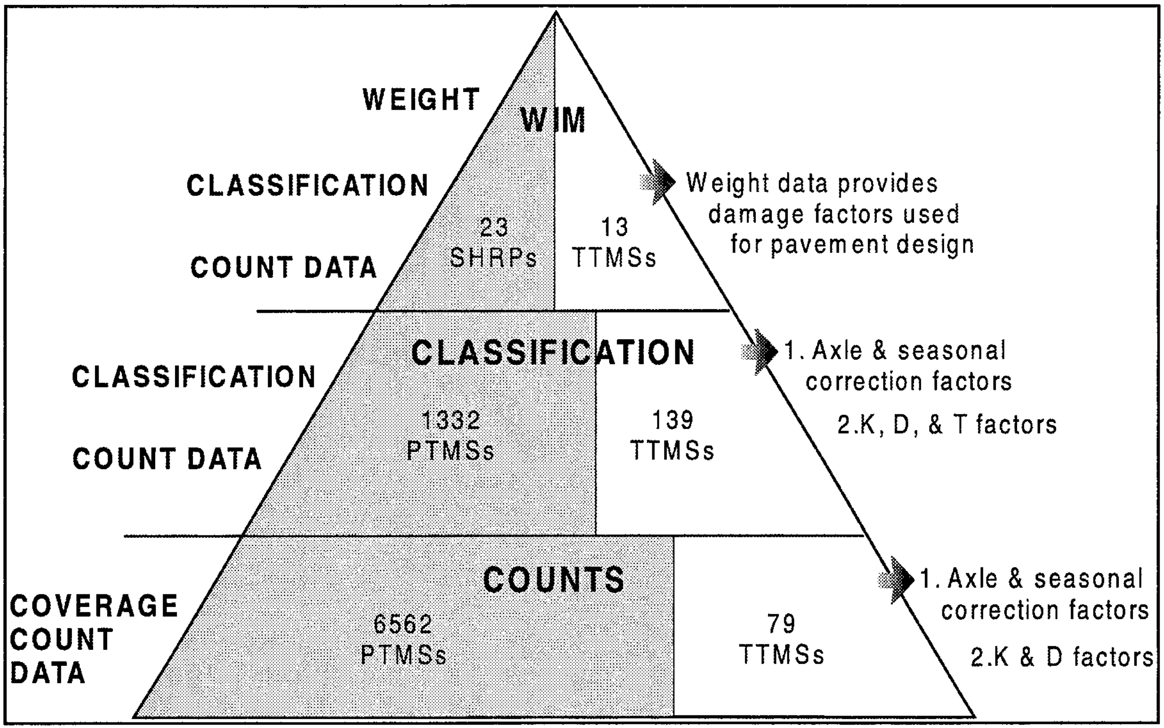
The following terms and topics are important to understanding the process used in Florida and elsewhere. The process used by FDOT to build and maintain their highway network involves these important concepts:

- traffic data collection equipment,
- data collection methods,
- axle correction factors,
- Annual Average Daily Traffic (AADT),
- design hour factor (K_{30}),
- directional distribution factor (D_{30}),
- truck percentages (T), and
- method for estimating AADT.

Figure 37 shows the count, classification, and WIM equipment used by FDOT to collect traffic counts and adjustment factors. The total number of sites in each category of WIM, classification, and count is broken down by Telemetry Traffic Monitoring Sites (TTMS) and Permanent Traffic Monitoring Sites (PTMS) *(66)*.

The methods used in conjunction with this equipment are discussed elsewhere in this document. Special emphasis is placed on truck percentages because it is the most critical factor related to pavement design. The estimated future truck volume is needed for calculating the 18 kip ESALs for pavement design. FDOT uses various definitions in its planning and design processes. These include:

T_{24} – The percentage of truck traffic for 24 hours (one day). It is the same as 24T+B as defined below.



Source: Reference (67)

Figure 37. Florida's Traffic Monitoring Sites Used in 1995 to Collect Traffic Counts and Adjustment Factors.

24-Hour Truck + Bus Percentage (24T+B) – The adjusted, annual 24-hour percentage of trucks and buses (Categories 4 through 13).

Design Hour Truck (DHT) – The percent of trucks expected to use a highway segment during the 30th highest hour of the design year. It is determined by dividing the adjusted, annual 24-hour percentage of trucks and buses (24T+B) by two.

DH2 – The adjusted, annual design hour medium truck percentage (DHT for Categories 4 and 5 only).

DH3 – The adjusted, annual design hour heavy truck percentage (DHT for Categories 6 through 13).

Traffic Adjustment Data Sources

The continuous count and classification program is designed to collect traffic data continuously throughout the year. The portable seasonal classification program collects classification counts for a short term (24 to 72 hours). According to FDOT's Design Traffic Handbook, this system collected traffic information at 7900 sites in 1995 throughout the state of Florida *(66).* Three types of counts comprise this program. These are Permanent Continuous Counts, Permanent Classification Counts, and Portable Seasonal Classification Counts.

TranStat staff uses permanently installed traffic counters dispersed throughout the state to provide data for Permanent Continuous Counts. Permanently installed inductive loops provide the necessary detection. These Telemetry Traffic Monitoring Sites continuously record the flow of traffic by hours of the day, day of the week, and month of the year and transmit the data to TranStat via telephone lines. Florida's continuous count program consists of 214 sites. As of January 1996, FDOT was working with local jurisdictions to bring the total number of continuous counters to over 300. Traffic information collected at these sites is used to determine AADT, K, and D.

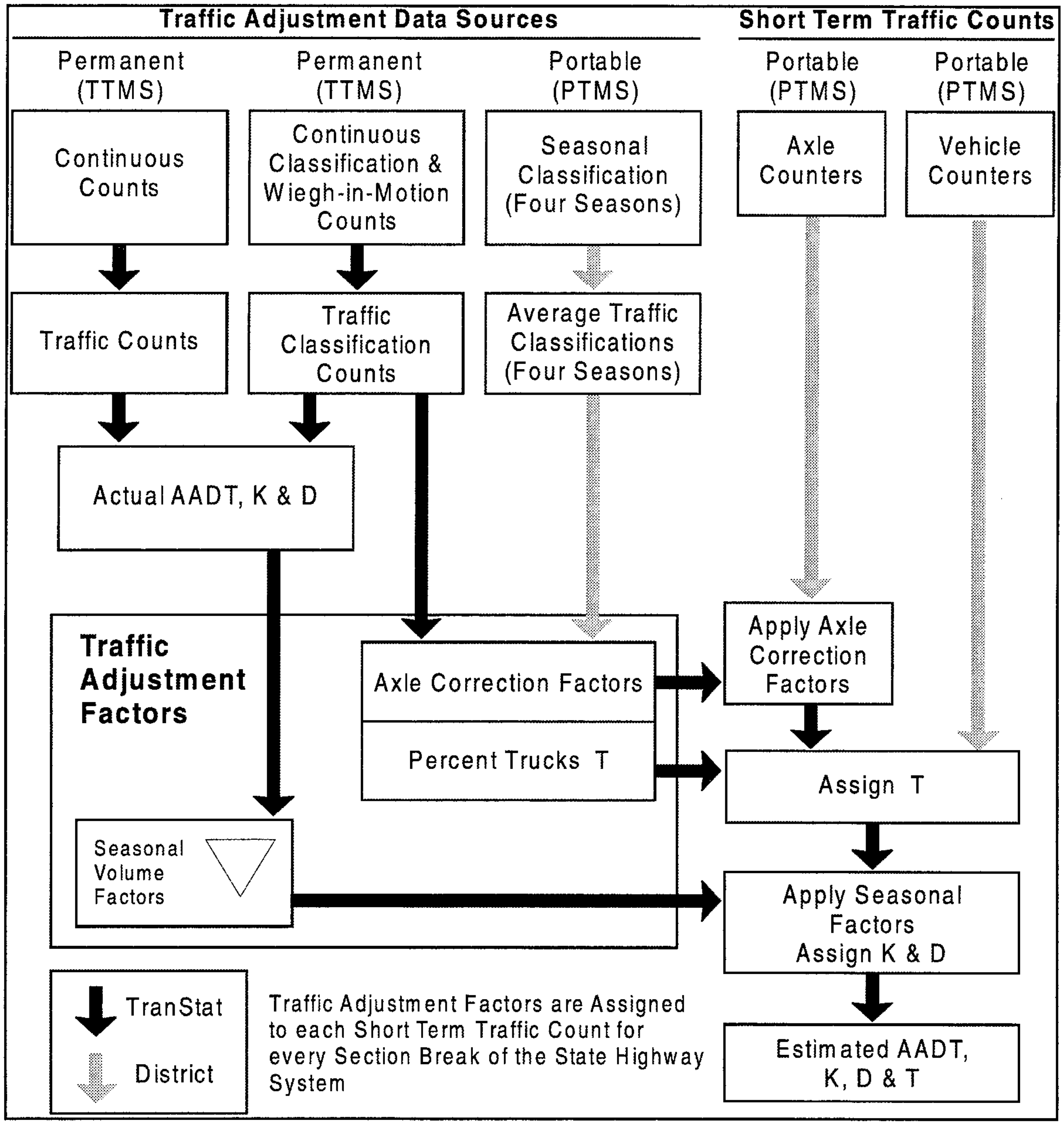
Equipment used for FDOT's Permanent Continuous Classification Counts consists of approximately 120 permanent classification counters. TranStat collects these data according to the FHWA Scheme F vehicle categories. Also, TranStat has a WIM program that provides both weight and classification data for producing AADT, K, D, and T factors.

FDOT has approximately 1000 locations in its Portable Seasonal Classification Count Program. These Portable Traffic Monitoring Sites are automatic traffic recorders that are temporarily placed at specific locations throughout the state to record traffic flow. These seasonal classification counts are conducted one or more times a year (24 to 48 hours each) as needed to record seasonal truck variation.

Short-Term Traffic Counts

FDOT districts, local agencies, and consultants perform short-term counts using portable traffic counting devices such as axle counters. Equipment typically used involves road tubes (rubber hoses), but magnetic detectors are also used for this purpose. These magnetic detectors adhere to the pavement in the middle of the lane and record vehicle length and speed in a variety of speed and length groups.

Figure 38 illustrates the use of these data. Information from permanent, continuous counters provides AADT, K, D, and T data. These same values are *estimated* for all other locations using portable counters. Data collected from Traffic Adjustment Data Sources provides information to develop the following traffic adjustment factors: Percent Trucks, Axle Correction Factors, and Seasonal Volume Factors. These adjustment factors are applied to short-term traffic counts taken by portable axle and vehicle counters to estimate AADT, K, D, and T for every section break of the FDOT highway system *(67).*



Source: Reference (67)

Figure 38. The Process Used to Estimate AADT, K, D, and T.

Quality Assurance Reviews (QARs)

TranStat personnel perform Quality Assurance Reviews in each district to monitor compliance with FDOT policies and standards. The districts are responsible for the following:

- Prepare project traffic forecasting reports.
- Submit copies of the written report to TranStat.
- Make sure of all the proper signatures.
- Have the report accepted by the requesting office.
- Participate in QARs.

QARs are supposed to focus on the manner in which project traffic forecast reports are prepared. Responsibilities of the Central Office of TranStat are as follows:

- Provide training for traffic forecasting to the districts.
- Review project traffic forecast reports produced by the districts.
- Conduct QARs for the State Transportation Planner.

Truck Forecasting Process

Structural design of a roadway pavement is primarily dependent upon the heavy axle loads generated by commercial traffic. Pavement design for new roadway construction, reconstruction, or resurfacing is based on accumulated 18 kip ESALs. FDOT conducts vehicle classification counts, which may be either part of its Vehicle Classification Reporting Program or a special Vehicle Classification study. FDOT uses vehicle classes 4 through 13 of the FHWA Classification Scheme "F" for the purpose of determining and forecasting ESALs and truck traffic.

FDOT combines WIM surveys with the vehicle classification data, along with other factors to estimate the accumulated 18 kip ESALs expected to accrue from the time the roadway is opened to the design year. Other factors include highway location (urban/rural), highway type (freeway/arterial, collector), number of lanes, highway direction, percent trucks, lane factor, and truck equivalency factor. The typical design period is 20 years.

Determination of Percent Trucks

For determining percent trucks (T_{24}), FDOT uses either a classification site located within the project limits, Historical Trend Analysis, or projection from its transportation modeling process, called Florida Standard Urban Transportation Modeling Structure (FSUTMS). T_{24} is the percentage of truck traffic for 24 hours (one day). If a vehicle classification site is available within project limits (or within approximately 1 mile to either side of these limits), FDOT uses the total percent of class 4 through 13 vehicles applied to traffic projections to determine future truck volumes. If no classification site exists within project limits, then FDOT recommends collecting field data for a period of 72 hours. The study should ensure data collection that is representative of an average day of truck traffic and any seasonal variations within the study area. If field data collection is not feasible, percent truck values can be obtained through FDOT's Roadway Characteristics Inventory (RCI). Normally, the value obtained for T_{24} is assumed to have a constant relationship to AADT. The predicted traffic loading to be furnished by the FDOT planning group is the cumulative 18 kip ESAL axle applications expected on the design lane *(67)*.

CHAPTER 8.0 EVALUATE ENHANCEMENTS PROVIDED BY GIS

8.1 INTRODUCTION

The use of a geographic information system can greatly improve information analysis and reporting of some applications. TxDOT has selected a GIS platform for standardization. The new Statewide Traffic Analysis and Reporting System (STARS) will be designed and constructed using the departmental GIS platform. The methodologies selected from this project could be enhanced by the use of GIS technology. This task sought to identify states utilizing GIS, then find out from them any enhancements provided by GIS to the process of traffic load forecasting and reporting.

8.2 METHODOLOGY

TTI contacted 46 states using the worldwide web and asked for information on the use of GIS. The specific questions asked had to do with the use or intended use of GIS for traffic load forecasting. The number of states providing information on use of GIS was 18. These states were Arizona, California, Colorado, Georgia, Indiana, Iowa, Kentucky, Maryland, Michigan, Minnesota, Montana, North Carolina, Oregon, Pennsylvania, Vermont, and West Virginia.

8.3 FINDINGS

Results of this effort indicated that no states are currently using GIS for traffic load forecasting, but some had interest in pursuing the idea. The information which follows on a few of the 18 states was considered noteworthy and might provide ideas that are useful to TxDOT as future opportunities arise for the expansion of the use of GIS in Texas.

8.3.1 Use of GIS by States

Georgia has not used GIS as a tool for the actual calculations of future traffic load data but it has vehicle classification, traffic count, WIM, and condition data link to a GIS system. Thus far, Georgia DOT has produced maps showing current conditions. GDOT will be continuing this effort in the future and is planning to integrate GIS with their pavement condition analysis system.

Contacts at the Iowa State University Center for Transportation Research and Education indicated that their use of GIS with respect to pavements is primarily in the area of pavement management. Specific activities include the following:

- use of GIS to integrate pavement history and automated distress data, and
- use of GIS to determine the costs and improvements of various maintenance strategies over time. Ultimately, these results will be used within pavement

optimization software as pre-defined maintenance activities, cost parameters, and condition improvements.

Indiana DOT is just now in the process of setting up a GIS system. It has not been implemented for any engineering or planning purpose as yet. Their aim is to begin using GIS late in the year 2000 or early 2001.

Kentucky DOT is experiencing problems with its base map. Kentucky agencies maintain 73,000 miles of state and local roads. Of that total, 27,000 miles are on the state system. Good data exist for interstate highways and for the rest of state-maintained system. The state-maintained system has smart lines they can attach data to. There are 120 counties and approximately 450 local communities. Officials are still struggling to get smart lines on local roads. They are experiencing significant edge matching problems trying to match one system to another. Project staff has been working on this problem for six to nine months, but progress is slow.

Kentucky officials have decided that most networked applications (e.g., statewide travel demand modeling, minimum path model, etc.) will ultimately use GIS, but they are not at the forefront. Once the base map is finished, they can move ahead. They plan on plotting roads with Level of Service D or worse or high accident locations and other key items. Those are the initial applications. One of the static applications will show ADT of 10,000 vehicles per day or higher. There will ultimately be some marriage of GIS with forecasting activity.

Michigan uses Caliper Corporation's TransCad for some of the GIS functions they need. For statewide transportation planning analysis, they use the appropriate modules of TransCad in the regional planning offices.

Currently, Montana Department of Transportation (MDT) uses the TRADAS software for traffic data collection and load forecasting. MDT has not seen any GIS applications available with this software yet and is unsure if the capability will be there in the future.

New York State DOT is currently working on improvements to their GIS network. The state does not currently have full coverage of all roadways, and they do not have WIM sites covered. A study recently addressed the problem of how to do in-between years to fill in data points (between actual data collection) using GIS.

North Carolina State University is conducting a study of functions being performed by GIS in the state of North Carolina. Results of this study should be available and may be helpful to TxDOT in identifying useful implementation of GIS. North Carolina is not currently using GIS for load forecasting, but it might include that feature in the future.

Oregon DOT is not using GIS technology for traffic load forecasting. It is using GIS to display the results from transportation modeling software but not for the use in pavement analysis. ODOT has built an application using GIS to analyze pavement condition, accident statistics, traffic volumes and other related data to help improve decisions around safety investments. ODOT is quite interested in seeing the results of this study.

8.3.2 A GIS Application

The New York State Department of Transportation (NYSDOT) originally established its traffic data collection program to satisfy the requirements of the *Traffic Monitoring Guide (5).* It consists of a continuous coverage count element as required by the Highway Performance Monitoring System. The NYSDOT system had 83 automated traffic recording sites and 11 WIM telemetry sites. The coverage count program relies on portable equipment and utilizes a three-year cycle administered by the Department's 11 regional offices. Classification counts on selected sections of the state highway system supplement these data *(68).*

The Transportation Research Division determined that the need existed for additional WIM sites in the state. The strengths and utility of GIS technology were part of the solution to identifying possible sites. The literature search confirmed the suspected need for the number of trucks by type and weight within the traffic stream on each highway segment. The variation and classification by percent, volume group, functional class, county, and roadway type could be used to categorize the roadway system that could be randomly sampled. Selection criteria for data monitoring site selection included: volume, percent of trucks, percent trucks by type, seasonal variation of truck traffic, interstate vs. intrastate trips, land use at origins and destinations, and ease of bypassing weight stations. Unfortunately, only a few items can be collected with automated count equipment, with the remainder being filled by a commodity flow survey. Given resource limitations, NYSDOT did not view the development of a statistical sampling plan to be feasible. It selected GIS as a suitable analysis tool.

The department had used GIS since 1990, applying it to identify the National Highway System and adding it to existing department mapping products. The department also developed a dynamically linked 18,000 mi roadway network representing the highway network and the higher classified roadways that are off that system. The system developed by NYSDOT utilized ARCVIEW software and the "join function" to attach areawide census data to Census Designated Place (CDP, incorporated places with population of 2500 or more) geography and linear highway system data. Thus, the department used a GIS package to examine the 1990 Census Transportation Planning Package (CTPP) data associated with workplace locations. The strength of GIS in this application is in its ability to display unrelated but geographically coordinated data to determine if a relationship exists *(68).*

The first step in this process was to identify industries that would generate heavy truck traffic and locate them within place-level geography in the GIS. Industry locations were not available on a statewide basis, but census data identifying locations where people worked were available in the 1990 CTPP. Place-level geography, available in the 1992 Topologically Integrated Geographic Encoding and Referencing (TIGER) line file, had to be associated with these industry (employment) locations in the CTPP. The premise used in evaluating this use of GIS was that these data from the CTPP could be used as surrogates for actual locations of industries likely to generate large vehicles. Industry categories were: mining, construction, manufacturing, transportation, and wholesale trade. CTPP Table B-3 contains the number of workers in industries likely to be served by heavy trucks and working in census place-level geography contained in the GIS.

In order to identify locations where additional WIM data collection is needed, the process located vehicle classification sites used within the past five years using GIS technology. These sites helped locate concentrations of FHWA F-scheme F8 to F13 vehicles (tractor-semitrailer combinations). These concentrations were important clues to identifying candidate locations for heavily loaded vehicles that could be melded with the industries mentioned earlier. The GIS offers the analyst a visual means for the concurrent display of linear and spatial data from different reference systems. Using shading or colors on the display, one can use the GIS to find the number of highway sections (with high numbers of F8 to F13 trucks) that intersect or are near to a census place with a relatively high percent of workers employed in the selected industries. The process used by NYSDOT showed that a relationship exists between selected industries and classification counts and that these industrial locations can readily be identified. A goal of the WIM data collection program is uniform areawide coverage within traffic volume groups and functional classes across the state. The GIS served as a visual tool to allow state personnel to establish additional WIM sites according to certain selection criteria such as location of existing WIM sites, region boundaries, state borders, and volume groups and functional classes not already represented.

In summary, GIS allows overlay and visual display of data attributes from multiple sources. In this case, it facilitated identification of potential WIM sites. This method and approach are readily transferable to other localities for similar decision-making processes as long as the basic components used by NYSDOT are in place and available to be used *(68)*.

CHAPTER 9. RECOMMENDATIONS FOR ENHANCING CURRENT TRAFFIC FORECASTING PROCESS

9.1 INTRODUCTION

This report presents many aspects of current traffic forecasting practice in Texas and elsewhere. There were also discussions regarding conditions or characteristics that can influence the design of pavements and bridges. This final chapter summarizes current practice in Texas, followed by selected enhancements based on study findings. Its organization is by current methodologies first, followed by enhancements that should be considered by TxDOT to improve the traffic load forecasting process. Appendix J summarizes forecasting practice in other states to suggest other potential enhancements not included below.

9.2 CURRENT TXDOT PRACTICE

The success of any data program begins with a well-designed collection plan and proper procedures to gather the information. In the context of traffic loads, vehicle classification and WIM are extremely important. WIM data supply the frequency of weights for specific vehicle classes. The department applies these data at locations where WIM data do not exist through that site's specific vehicle classification distribution.

9.2.1 Data Collection

- TPP collects truck weigh-in-motion data by lane at operating permanent sites on a quarterly basis for periods of 48 hours, in accordance to current *Traffic Monitoring Guide* (*5*) standards.
- A majority of WIM sites lie on the Interstate Highway System.
- TPP conducts a cursory review of the WIM data to ensure that the equipment was functioning normally. The proportion of unclassified vehicles (<10 percent is acceptable) and the expected weight of Class 9 (3-S2) vehicles (data not greater than 8 percent of 80,000 lbs) serve as indicators for normal functionality.
- TPP calibrates bending plate WIM sites by comparing a known static weight of the test vehicle to the dynamic weight recorded by the equipment. This requires multiple axle configurations and multiple passes. Expected axle weights must be within +/- 6 percent to be acceptable.

9.2.2 Data Analysis

After data collection comes validation and review for approval or rejection. This process is often referred to as data analysis. Currently, TxDOT staff manually review vehicle classification data against a range of criteria before approving the data.

- The data analysis performed on both the truck weight and vehicle classification data can best be characterized as data validation rather than a true analysis of the data.
- TPP gives truck weight data a cursory analysis review (trend analysis and professional judgment applied), then forwards the data to the reporting and forecasting steps.
- TPP scrutinizes vehicle classification data more thoroughly than truck weight data through the application of 20 criteria elements and the application of professional judgment.
- In some vehicle classification criteria, analysts use three previous years of data for comparison.

9.2.3 Weight Data Forecasting

Providing design-level data is the function of the weight data forecasting process. The results of this process are used to appropriately design pavement structures to meet the estimated damage from truck traffic over the design life of the pavement. Significant over- or under-prediction of pavement loading here can result in unnecessary investment or premature failure, respectively.

- The RDTEST68 program generates the design life ESALs and ATHWLD for both flexible and rigid pavements.
- Project designers must use axle weight distribution tables based on statewide data rather than geographically appropriate data.
- Percent Trucks, Axle Factor, Load Equivalency Factors, and Percent Single Axles remain constant throughout the design period.
- The current process uses one growth rate (ADT growth rate) for all truck classes.

9.2.4 Data Archival

Data archival has long been an important item in statewide traffic data programs. Only recently has data archival gained increased attention from professionals involved in Intelligent Transportation System (ITS) activities. Urban traffic management centers know too well the amount of data generated by continuously operating equipment. A similar information overload will occur if truck weight and vehicle classification data programs are upgraded to continuous operations.

- Data analysts convert truck weight data into the FHWA Card format and forward the data to the Data Management Section for further report processing.
- The department permanently retains all final vehicle weight and vehicle classification data.

9.2.5 Data Reporting

- The current reporting system generates quarterly VTRIS reports for FHWA.

9.3 ENHANCEMENTS TO IMPROVE TXDOT PRACTICE

9.3.1 Data Collection

9.3.1.1 Suggested Enhancements

- Determine natural variability of human observers collecting vehicle classification data to carry through analysis and forecasting processes.
- Adopt a vehicle classification equipment unclassified rate of 5 percent indicating a need for equipment calibration or servicing. This will also improve vehicle classification data analysis by reducing the allowable unclassified rate from 10 percent to 5 percent.
- Conduct replication counts for manual and automated vehicle classification to assess differences in classification results.
- Conduct more frequent equipment calibration to ensure that it is reading traffic and recording data properly.
- Conduct more project-level site vehicle weight data collection to determine direction differences, when warranted.
- Conduct spot validation of vehicle weight by class at a selected number of project sites to ensure equipment accuracy and to make needed adjustments in a timely manner.
- Require equipment warranties especially on WIM equipment and install all WIM equipment in 300 ft of milled reinforced concrete pavement.
- TPP(T) should consider the use of non-intrusive data collection devices to supplement its in-pavement systems and establish guidelines for their use.

9.3.1.2 Essential Enhancements

- The department needs additional truck weight sites under both the current and draft versions of the new Traffic Monitoring Guide (*9*).
- Additional truck weight sites should be selected based on roadway type (urban v. rural) and geographic area.
- Calibration with additional axle configurations should be considered to improve performance in other vehicle classes.
- Develop monitoring tools to evaluate the calibration of WIM equipment through analysis of gross vehicle weight distributions of 3S2 trucks. Include additional preliminary WIM data screening tools to include (1) an average of 4.3 ft on drive tandem separation, (2) Class 11 overall length, and (3) the average gross weights by speed bin from the general traffic stream instead of individual trucks.

- Coordinate the classification algorithms between AVC and WIM equipment to reduce any ambiguity between the classification schemes.
- TTP(T) should establish a plan to implement its new *Traffic Data Request Guide for Highway Pavement and Geometric Design* (*69*) to improve the data request process.

9.3.2 Data Analysis

9.3.2.1 Suggested Enhancements

- Determine market and natural shifts in vehicle use through classification and weight record analysis and estimate their impacts on project-level pavement design.
- Retain vendor formats of raw data to facilitate quality control to improve equipment performance and design improved maintenance schedules.
- The department should not aggregate continuous WIM data.

9.3.2.2 Essential Enhancements

- Integrate continuous vehicle classification and a limited continuous truck weight data program to develop temporal adjustment factors as suggested in the draft *Traffic Monitoring Guide 5th Ed.* (*9*).
- Develop more formalized procedures for data analysis to minimize the amount of professional judgment in special cases.

9.3.3 Weight Data Forecasting

9.3.3.1 Suggested Enhancements

- Develop specific vehicle class or a minimum of four broad class growth rates as suggested in the 1996 FHWA Pavement Performance Review and in the draft *Traffic Monitoring Guide 5th Ed.* (*9*)
- Quickly adapt forecasting processes to meet procedures outlined in the *2002 AASHTO Pavement Design Guide for 2002* (*59*) and gradually phase out ESAL and ATHWLD calculations.
- Monitor the number and frequency of overweight trucks by both integrating WIM and video technology and building links to Motor Carrier Division's Overweight/Oversize Permit Office.
- If additional WIM sites cannot be installed quickly, consider more widespread installation of continuous vehicle classification to facilitate use of LEF for each class.
- Derive axle weight distributions using all continuous data, when available, over a specified period (month, quarter, or year).

9.3.3.2 Essential Enhancements

- Develop regional weight distribution tables for a variety of road types and road uses as suggested in the draft *Traffic Monitoring Guide 5th Ed.* (*9*).
- Develop class specific growth rates for Classes 5-13 and incorporate the rates into forecasting processes.
- Monitor the propagation of spread tandems due to their higher damage to pavement per pass of its class equivalents. One way is to separate the spread 3S2 truck configuration from other Class 9 vehicles by adopting a special Class 14 vehicle (as done in California). TxDOT should also conduct additional research to measure the impact of these vehicles on axle factors and percent single axles.

9.3.4 Data Archival

9.3.4.1 Suggested Enhancements

- Retain the more detailed data in the format provided by the equipment manufacturers. Many advantages (better querying, equipment performance, speeds, etc.) exist for utilizing this expanded data set compared to the FHWA Card 7 format.

9.3.4.2 Essential Enhancements

- Acquire a data storage system capable of retaining 12 GB of annual continuous truck weight data when the truck weight program is expanded to meet *Traffic Monitoring Guide* (*9*) recommendations.
- Utilize TxDOT's core technology architecture by adopting Oracle and developing database applications for both the truck weight and vehicle classification programs.

9.3.5 Data Reporting

9.3.5.1 Suggested Enhancements

- Periodic reporting of cumulative ESALs for roadway sections could improve prediction of rehabilitation and maintenance needs.
- Reporting the number of overweight (based on standard legal limits for specific vehicle types, not by actual permitted loads) trucks on roadway sections may be useful to both TxDOT districts and the Department of Public Safety. District staff would have the ability to monitor the roadway's response performance to heavy loads. DPS would have the ability to selectively enforce the roadway for both safety and permitting purposes.

9.3.5.2 Essential Enhancements

- Continue to meet FHWA truck weight reporting requirements.

- Develop reporting procedures to generate temporal (time-of-day, day-of-week, and seasonal) adjustment factors. The *Traffic Monitoring Guide* (*9*) requires these factors.
- Develop reporting procedures to generate axle load distributions by axle sets (single, tandem, tridem, and quad) by vehicle classes (FHWA Classes 4-13). The *2002 AASHTO Pavement Design Guide for 2002* (*59*) requires these distributions.

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APPENDIX A

EQUIPMENT SETUP AND DATA RETRIEVAL FOR HESTIA ELECTRONICS AT TELEMETRY SITE

Before Setup

Turn off machine
Press enter-turn on display
Display will read: "REC" "CHG" - Graphic

1. Press Quit
2. Press Yes, Enter
3. Press Yes, Turns Off Display

Disconnect Cables

Complete Hestia Work

Upon return, connect and turn machine back on (in this order)

Machine Setup

1. Press Enter, display will read: "CHG" – Graphic.
2. Press Setup, If "00" is displayed, then the machine has been reset.
3. Press Enter through program to "Start Now."
4. Press Enter.
5. Press Yes, Enter.
6. At the "Armed" prompt, Press YES button, Enter.
7. The display indicates "Arm", "Rec" will not show on display until hour changes.

Download PAT

PAT or PATRCLE
-automatic↵
-setup↵
-general↵
-71

Mode: Will come up
Enter 6↵
-make sure it says req. interval 60 then:↵

-screen with month and day will come up
-find code for dates
-Hit 73

-Screen comes up his S, mode comes up
-Put in code (will start)

-When finished screen will come back. Hit S again for another day desired.

710 disconnect

APPENDIX B

EXAMPLE OF PAT SOFTWARE STATUS REPORT WHICH IDENTIFIES WEIGHT VIOLATIONS AND INVALID MEASUREMENTS

DISTRIBUTION OF WEIGHT VIOLATIONS AND INVALID MEASUREMENTS FOR VEHICLE CLASSES 4-15

Site No: 516
Date: 1/25/99
Location: LYTLE ATASCOSA COUNTY
County: 13
State-ID: 48
Lanes(s): 1
Direction: 2

Classification	Total Vehicle Counted	Vehicles With Invalid Measure	Total Vehicles Weighed	Total Vehicles Overwt.	Percent Vehicles Overwt.	Number Of Weight Violations			
						Axle	Tandem	Gross	Bridge
4	39	0	39	12	31	12	0	0	0
5	434	13	421	3	1	3	0	0	0
6	143	6	137	13	9	9	8	0	8
7	0	0	0	0	0	0	0	0	0
8	26	2	24	0	0	0	0	0	0
9	58	13	45	1	2	1	0	0	0
10	1401	68	1333	154	12	21	134	36	142
11	7	0	7	1	14	0	1	1	1
12	52	1	51	1	2	1	0	0	0
13	11	0	11	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0
15	31	7	24	1	4	0	1	1	1
Totals	2202	110	2092	186	9	47	144	38	152

Number Of Vehicles With Data Errors: 2
Speed: 2 Weight: 0

Percent Vehicles Not Classified (Class 15): 1.4

Percent Vehicles With Invalid Measurements: 5.0

APPENDIX C

PAT EQUIPMENT CALIBRATION AND CORRECTION FACTORS COMPUTATION PROCEDURES

CALIBRATION

At Office:

Before leaving office
-Fill out calibration sheet.
-Get factors for each lane and speed from computer in office.

On Site:

Hook up electronics in cabinet to computer also printer and etc.
-Turn on
-PAT↵
-Shows on screen remote↵
-F1
-to direct↵

Mode: Comes up
Hit #8=views are traffic (see if working)

*Ready to start calibration
↵ Brings up mode:, hit #7 ↵
-Lane: comes up
    -either hit 1, 2, 3, 4 on keyboard
    -or, it will be 0000 & you will
    → to position of lane you want and enter
    a #1 in that lane position↵
* Wait for calibration truck
-Check weight and measurement on screen against your
calibration truck factors you already have.

* If not right, use two runs-average-and use correction
factors calculated to change it. Do the following before conducting another calibration test using the calibration truck↵

Mode: Will come up
-Enter "0" ↵
-scan down the individual lanes for particular lane and speed, enter new factor↵
-go through all the lanes and then mode comes up again.
-enter #7↵
-enter lane # ↵ ↵ ↵ ↵

*Wait for calibration truck

*After each run-print out
-If you miss the truck,
Hit ALT H & then ALT 76, use arrow key to bring back to view print,
Then ESC takes you back to NOG Screen
-#3 note sheet had information on calculating factors

*AFTER CALIBRATION-
Make two copies of lane factors (in computer)
Mode: 0↵ Print them out.
One for cabinet, one for office

Write on all information sheets
Site #
Locations
Date
Persons Calibrating
Which Calendar Quarter?

LAST, make sure mode is on 8 and site is working before you leave.

Calibrate at 50 MPH - on one sheet (each lane)
Calibrate at 60 MPH - on one sheet (each lane)

Correction Factors Computations

GVW (Weight of Calibration Truck 75.4 divided by weight show on comp=
Factor (107 or 115 or 98, etc.)
Multiply(") times weight factor (1050, 1100) already in computer
Note: Weight too heavy lower factor
-Too light, factor goes up and then down some
-Too heavy, factor goes down and then up some

Enter mode "0" and arrow down to lane selection
-Change lot and 2nd factor to your calculation
(When calibrating at 50 mph)
-Change 3rd factor only (When calibrating at 60 mph)

Go through all lanes until mode comes up, start over.

Data Collecting on Mon., Tues., or Wed., Thurs.

Modes:	0	Reprogram
	3	You enter algorithms (When three hit 710)
	6	Downloads (Check which #s are for what day) (S+ days or day- When finished hit F3)
	8	Views (All) (Single Vehicle Yes↵
	7	Lane Selection (for calibrating, Use "1" or "0"s)
	8	Station Password (If the PAT system will not work, do the following) Mode:↵ No I↵ Put in what ever password is in the right corner of the display.

APPENDIX D

AVC EQUIPMENT SETUP AND DATA RETRIEVAL PROCEDURES

AVC 241 EQUIPMENT TO COLLECT "VEHICLE TYPE CLASSIFICATION" DATA FOR SHRP

Before Setup

In order to operate the AVC 241 equipment, the battery must be fully charged. Battery chargers are provided for this purpose. To check the battery voltage, turn the machine on and press the button labeled "TEST."

Connect the battery charger if the voltage is lower than 6 volts. Note: The battery requires 72 hours to recharge, and the counter must be turned on.

The 241 has to be programmed to collect specific types of data using specific sensors. Use the following instructions to program the 241 to collect "Vehicle TYPE Classification" for SHRP.

The five steps necessary to program and operate the classifier are:

1. configuring the machine,
2. setting up the machine,
3. tuning the loops,
4. setting the sensor distance and loop length, and
5. removing the setup.

Machine Setup

To set up the configuration for the AVC 241 equipment, press the key labeled "CONFIG" and respond to the prompts as follows:

WHEN YOU SEE MACHINE FUNCTION PROMPT	YOU ENTER
1. USA Date	Yes
2. Time	Hour & Minute (Military Time)
3. Date	Month, Day, Year (mm dd yy)
4. Communications On?	Yes
5. Baud	300 Baud (Solar), 1200 Baud (A/C Power)
6. 7-Bit	Yes
7. Parity	Yes
8. Even Parity	Yes
9. 1 Stop Bit	Yes
10. Type	Epson
11. Grand Total	No
12. Midnight Total	No

13. 24 Hour Total	No
14. Hour Total	No
15. Interval Total	No
16. Column Total	No
17. Units	Feet & mph

How to Tune Loop

Although the 241 will support eight loops, you only need to be concerned about the one loop in Lane 1 for SHRP data collection.

To tune loop:

1. Press the key labeled "LOOP." Never Press the "0" (zero) key. This will tune all of the loops, even ones that are not used.
2. Press Set Button.
3. Press the #1 Button.
4. Press the Quit Button.

Setting the Loop Distance and Length

1. Press the key labeled "VIEW."
2. Press the key labeled "TEST."
3. At the "Sensor Dist" prompt, type 6.0, and press ENTER.
4. At the "Length" prompt, type 5.5, and press ENTER.
5. Press the key labeled "QUIT" twice.
6. At the "Quit Armed" prompt, select NO, and press ENTER.
7. At the "Shut-Off" prompt, select Yes, and press ENTER.

After setting the loop distance and length, use the "VIEW" key to observe the counter in operation.

To check loop operation, press the "LOOP" key. If the loop is working properly it will darken as a vehicle passes over it.

How to Remove the AVC 241 Equipment

When data collection has been completed, use the following procedures to remove (pick up) the classifier.

1. Press the key labeled "VIEW" to check the machine operation by observing traffic passing over the sensors.
2. Press the key labeled "QUIT." The "QUIT RECORDING NOW" prompt will be displayed.

3. Press the left arrow key to change the “NO” to “YES” or Press the “Yes” key
4. Press ENTER. The “SHUT-OFF NOW” prompt will be displayed.
5. Press the left arrow key to change the “NO” to “YES”
6. Press ENTER. The machine is now turned off.

WHEN CHARGING THE RECORDER, THE TOGGLE SWITCH MUST BE ON.

How to Clear the AVC 241 Equipment Memory

After data files have been successfully loaded to computer or diskette, use the following procedure to clear the classifier memory:

1. Press the key labeled “COPY.”
2. At the following prompt,

You See Prompt	*You Respond*	*Resulting Prompt*
“COPY DELETE”	Enter	“COPY CLEAR”
“DELETE – NO”		“CLEAR NO”

3. At the “COPY CLEAR” prompt, press the left arrow key. The “NO” will change to “YES.”
4. Press ENTER. The “CLEAR MODULE” prompt will be displayed.
5. At the “CLEAR MODULE” prompt, press the left arrow key. The “CLEAR MODULE” will change to “CLEAR MEMORY.”

You See Prompt	*You Respond*	*Resulting Prompt*
“COPY CLEAR”	<-(left arrow)	“COPY CLEAR”
“CLEAR MODULE		“CLEAR MEMORY”

6. Press ENTER.
7. At the following prompt, press the left arrow key. The “NO” will change to “YES.”

You See Prompt	*You Respond*	*Resulting Prompt*
“COPY CLEAR”	<-(left arrow)	“COPY CLEAR”
“Are you sure? NO”		“Are you sure? YES”

8. Press ENTER. The machine memory is now cleared. ALL data files have been ERASED!

AVC 241 EQUIPMENT SETUP WITH PIEZO-LOOP-PIEZO AND ROAD TUBES

Setup (Piezo-Loop-Piezo)

Lead Setup - Yes
Class Table: Texas6 - Enter
Are you sure - Yes
Remove Module
ID - Enter 12 digit ID number
STN - Enter 12 digit STN number
Interval - 60
Peak Int. 1 - No
No. of Lanes - # of lanes connected to the machine
Piezo - Yes
AUX Contacts -
Lane Layout - 1 1
Heading 1
Column - Type
Summate - No
Heading 2
ROW - Lane
Summate - No
Heading 3
Section - None
Start Now - No, then enter start time and start date
Never End - No, then enter end time and end date
Armed - Yes

VIEW - "Allows you to see vehicles being classed"
Test - "Allows you to adjust sensor distance"
Sensor Distance - 8.0 (You have to do this for each lane.)
Loop Length - 6.0 (You have to do this for each lane.)

Configure

Note: This stays the same with piezo & loops or road tubes.

View (Powers up machine)

Test Battery
Quit
Copy (If necessary, delete files or clear memory, see copy page if you need to delete files)
Quit

Reset
Insert TX VI Module

Config
USA Date - Yes
Time - Enter Correct Military Time
Date - MM-DD-YY
Comms On - No
Grand Total - No
Midnight Total- No
24 Hour Total - No
Hour Total - No
Interval Total - No
Column Total - No
Feet & mph

After “Config” go to “Setup”

Copy

Press Copy
Copy delete Yes “Enter”
Mark the files to be deleted by pressing “Set”
Use “Dec” or “Inc” button to move to other files if needed.
Press “Enter” when files are marked.
Delete Marked “Enter”
Are you sure Yes “Enter”
Marked files are now deleted.

Setup (Road Tubes)

Load Setup - Yes
Class Table: Texas6 - Enter
Are you sure - Yes
Remove Module
ID - Enter 12 digit ID code
STN - Enter 12 digit STN code
Interval - 60
Peak Int 1 - No
No. of Lanes - Road Tubes will always be 2 lanes
Piezo - No
AUX Contacts - 1
Lane Layout - 11
4 RT. In Lane - No
Directional - Yes
Heading 1
Column - Type
Summate - No
Heading 2
ROW - Lane
Summate - No
Heading 3
Section - None
Start Now - Yes
Never End - Yes
Armed - Yes

VIEW - "Allows you to see vehicles being classed."
TEST - "Allows you to adjust sensor distance."
Sensor Distance - 8.0 (Or whatever the distance between tubes)
Loop Length - ?.? (You have to do this for both lanes)

APPENDIX E

TxDOT'S TPP(T) TRAFFIC DATA REQUEST FORM

TRAFFIC DATA REQUEST FORM

DISTRICT________________ **COUNTY**________________ **CSJ**________________

HIGHWAY / LIMITS ____
____

DISTRICT PRIORITY____________________ EST. LETTING DATE________________

EXISTING NUMBER OF LANES____

PROPOSED NUMBER OF LANES____

DISTRICT CONTACT PERSON____________________________

TELEPHONE NUMBER________________________________

PLEASE ATTACH A 8-1/2" X 11" LOCATION MAP

The following to be completed: (please mark information to be provided)

__________ 1. Basic Highway Traffic Data for pavement design.
(No line diagram analysis required).

- A. Base year / Beginning year __________
- B. Forecasted 20 year __________
- C. Forecasted 30 year __________
- D. Directional Distribution(percent)
- E. K-Factor
- F. Percent Trucks ADT / DHV
- G. Average Ten Heaviest Wheel Loads (ATHWLD)
- H. Percent Tandem Axles in the ATHWLD
- I. One direction cumulative 18 KSA at the end of 20 years / 30 years For Flexible Pavement and Rigid Pavement
- J. Slab Thickness (8" unless otherwise specified)
- K. Structural Number (3 unless otherwise specified)

__________ 2. Vehicle classification for environmental studies (Air and Noise Analysis).

__________ 3. Line Diagram Analysis (straight line turning movements; please provide line diagram).

__________ 4. Complete Corridor Analysis (Includes basic highway traffic data for pavement design and environmental studies and detailed schematic turning movements; please provide detailed schematic).

NOTE: If complete corridor analysis is requested, please attach a traffic schematic diagram.
Please make note of any known proposed development that will be a traffic generator.

APPENDIX F

RDTEST68 PROGRAM FLOWCHARTS

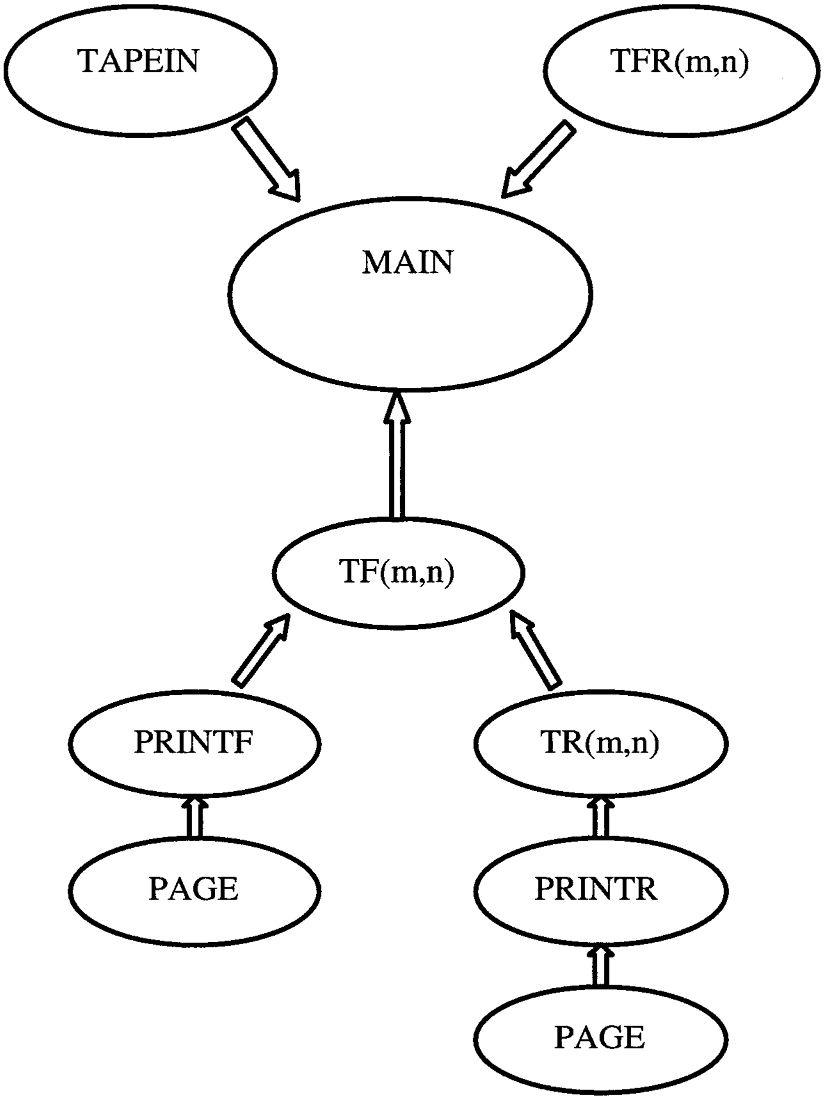
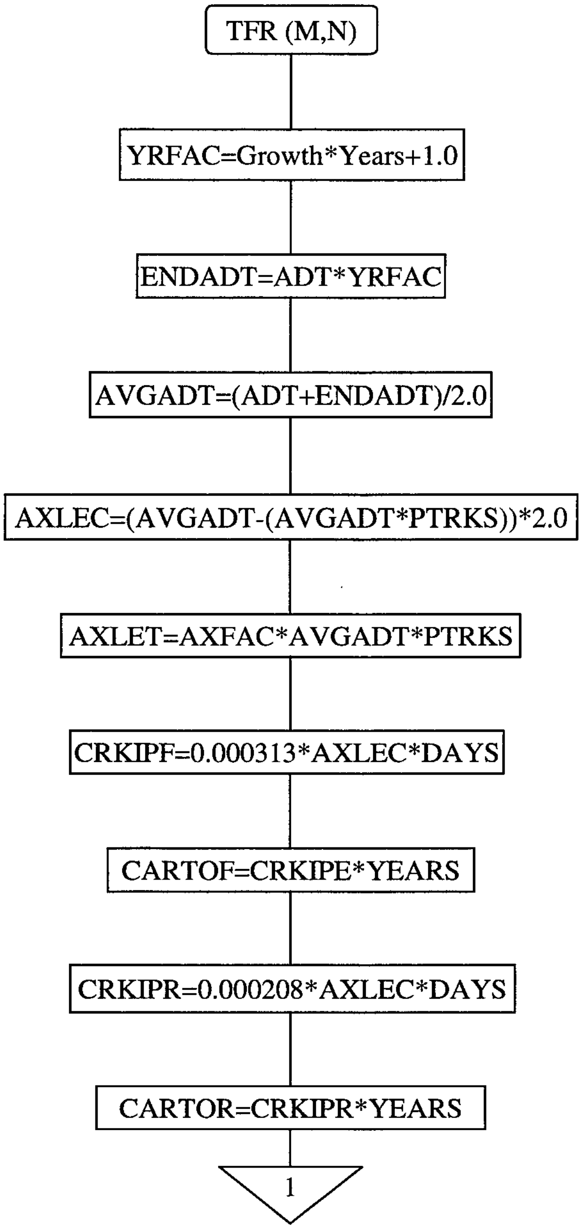


Figure 39. RDTEST68 Program Flow Relationships.



CALCULATE FACTOR

CALCULATE ENDING ADT

CALCULATE AVERAGE ADT
FOR THE DESIGN TIME

CALCULATE NUMBER OF CAR AXLES

CALCULATE NUMBER OF TRUCK AXLES

CALCULATE FLEXIBLE KIPS PRODUCED BY
CARS IN 1 MONTH OR 1 YEAR.

CALCULATE FLEXIBLE KIPS PRODUCED
BY CARS IN THE TOTAL DESIGN TIME

CALCULATE RIGID KIPS PRODUCED
BY CARS IN 1 MONTH OR 1 YEAR

CALCULATE RIGID KIPS PRODUCED
BY CARS IN THE TOTAL DESIGN TIME

Figure 39. RDTEST68 Program Flow Relationships (Continued).

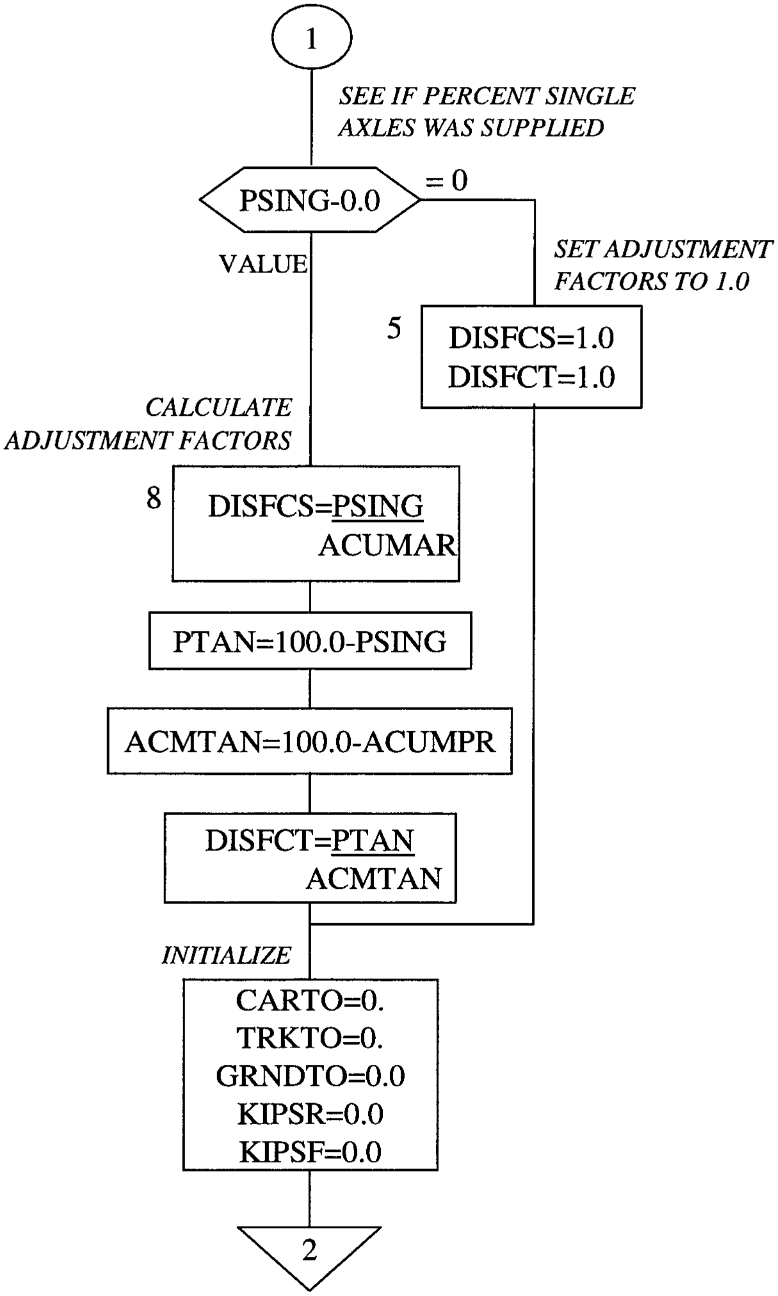


Figure 39. RDTEST68 Program Flow Relationships (Continued).

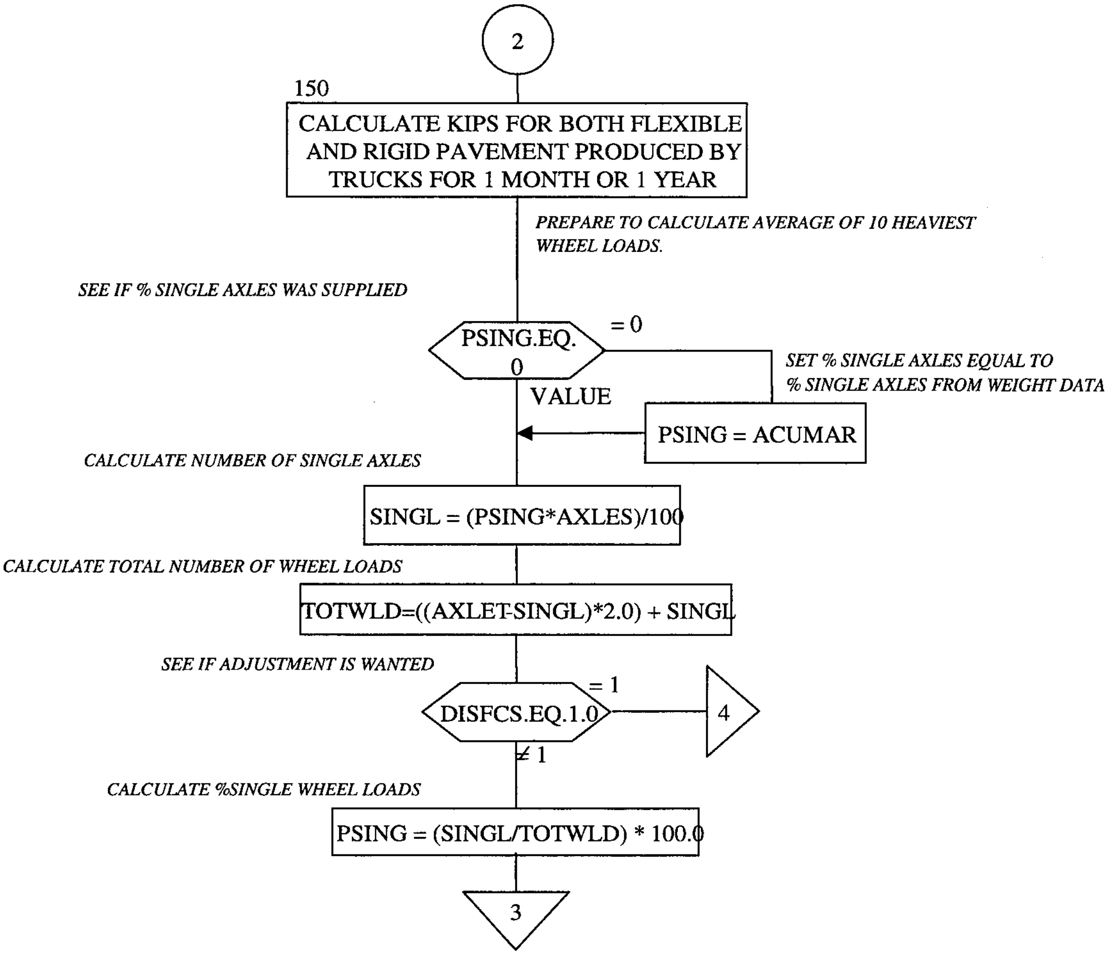


Figure 39. RDTEST68 Program Flow Relationships (Continued).

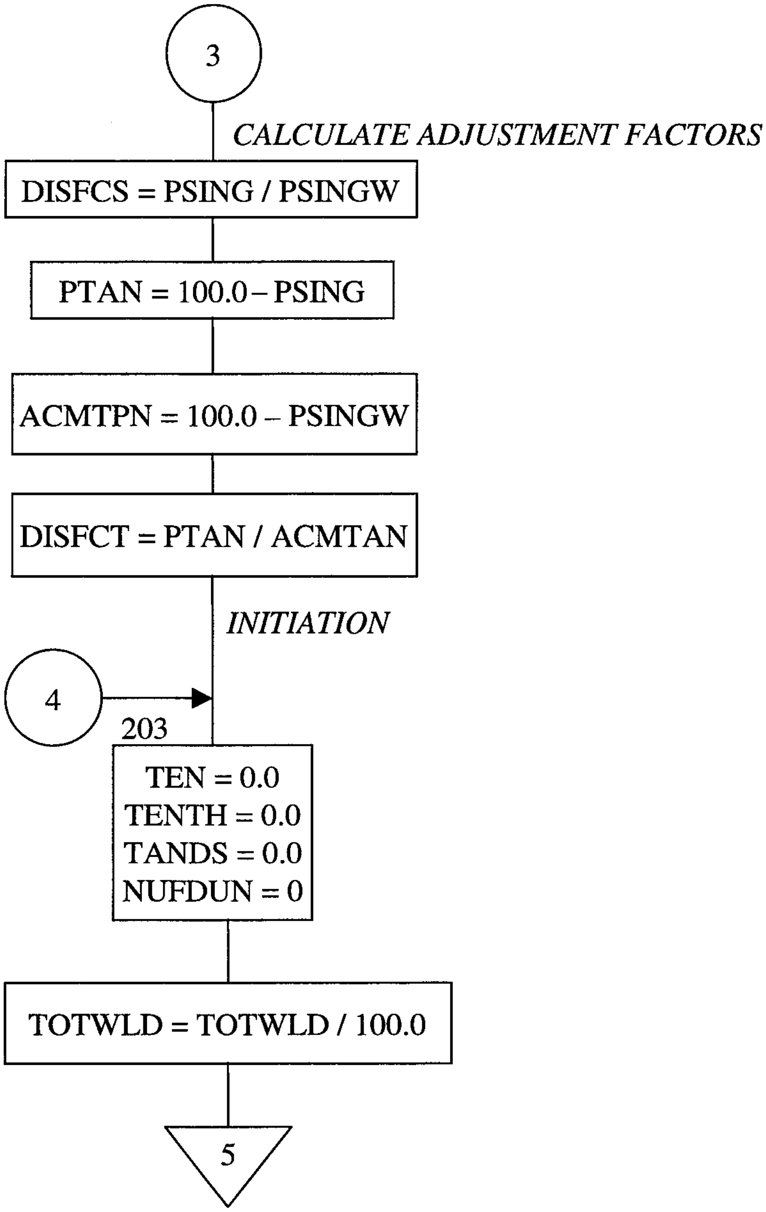


Figure 39. RDTEST68 Program Flow Relationships (Continued).

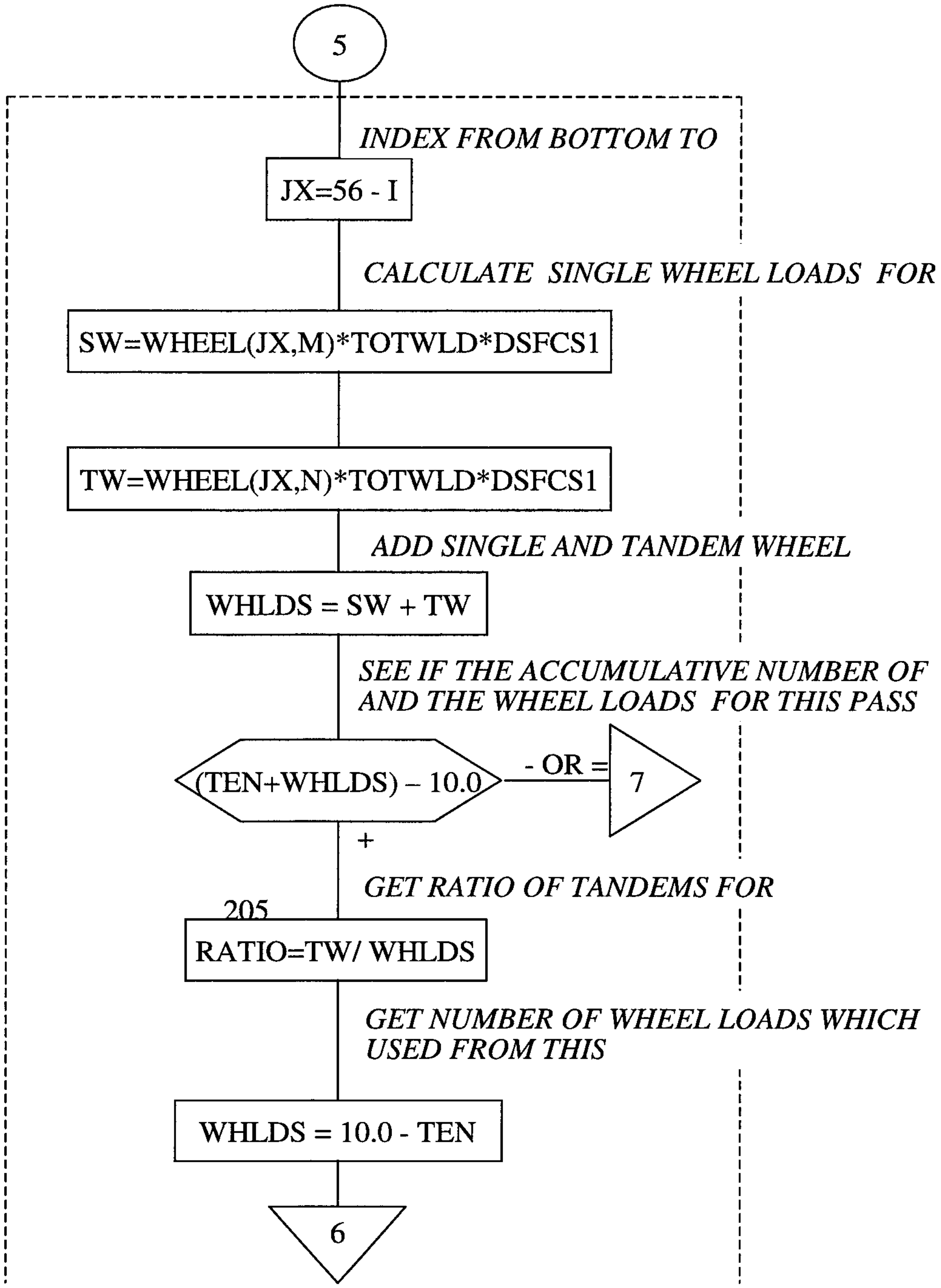


Figure 39. RDTEST68 Program Flow Relationships (Continued).

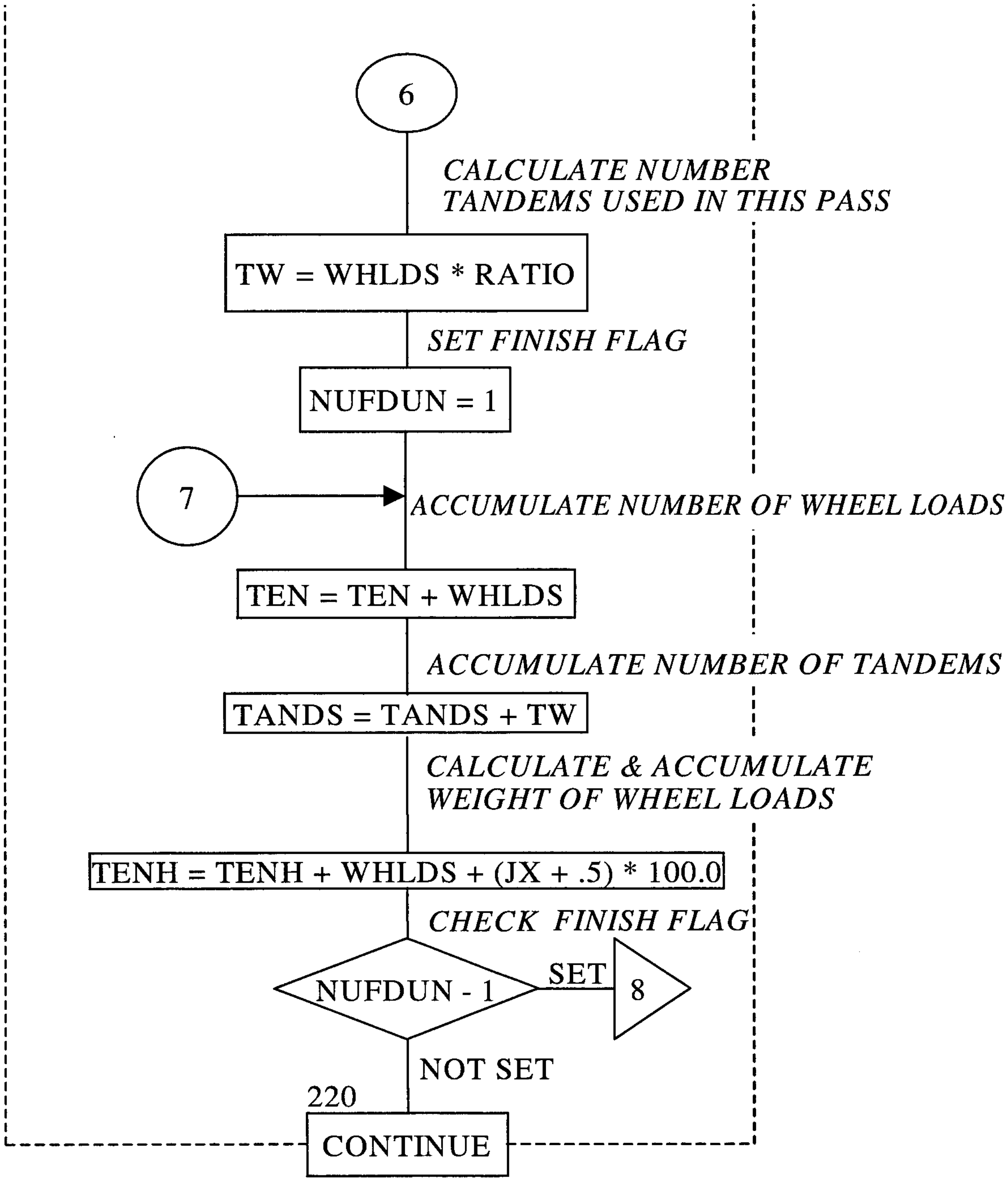


Figure 39. RDTEST68 Program Flow Relationships (Continued).

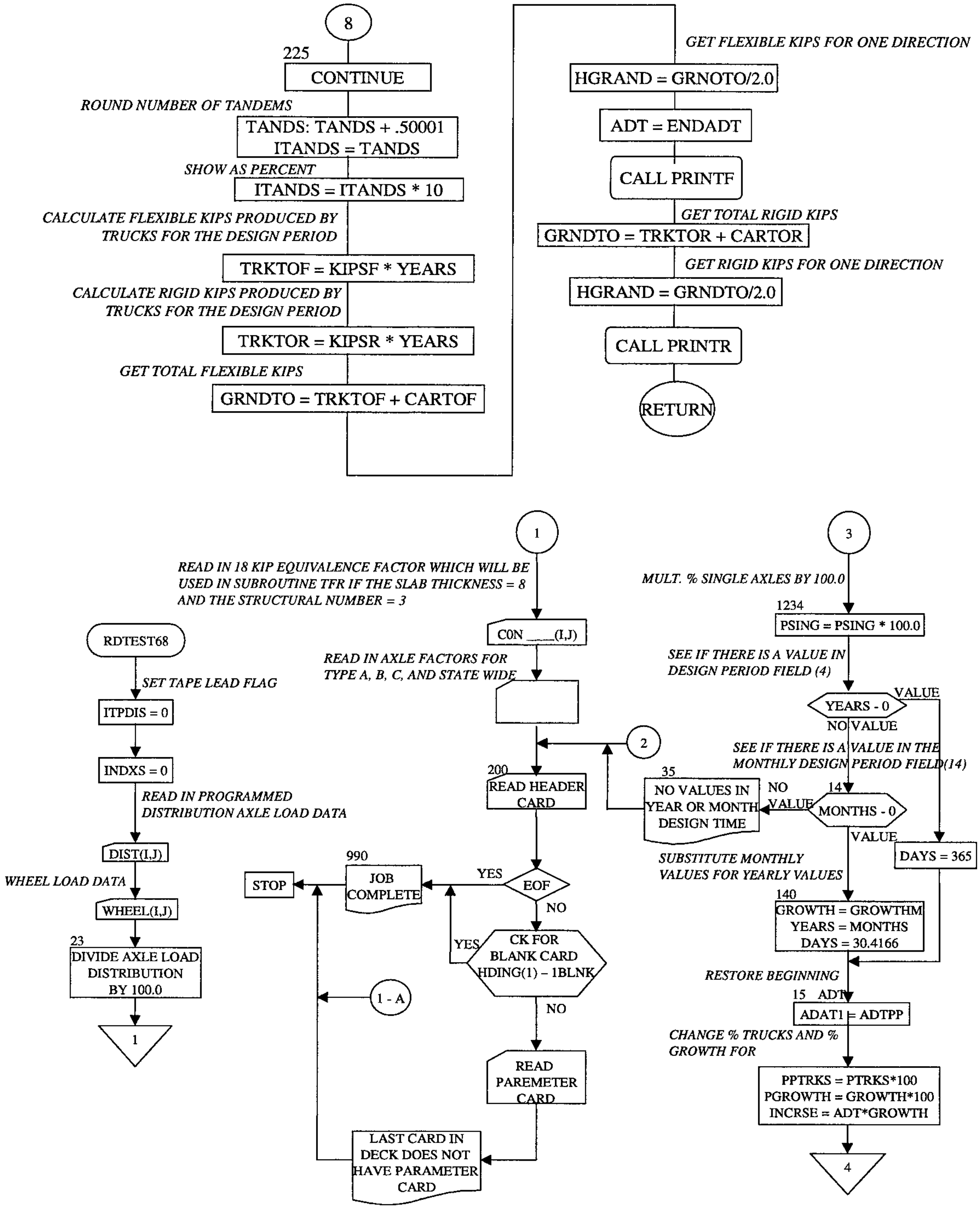


Figure 39. RDTEST68 Program Flow Relationships (Continued).

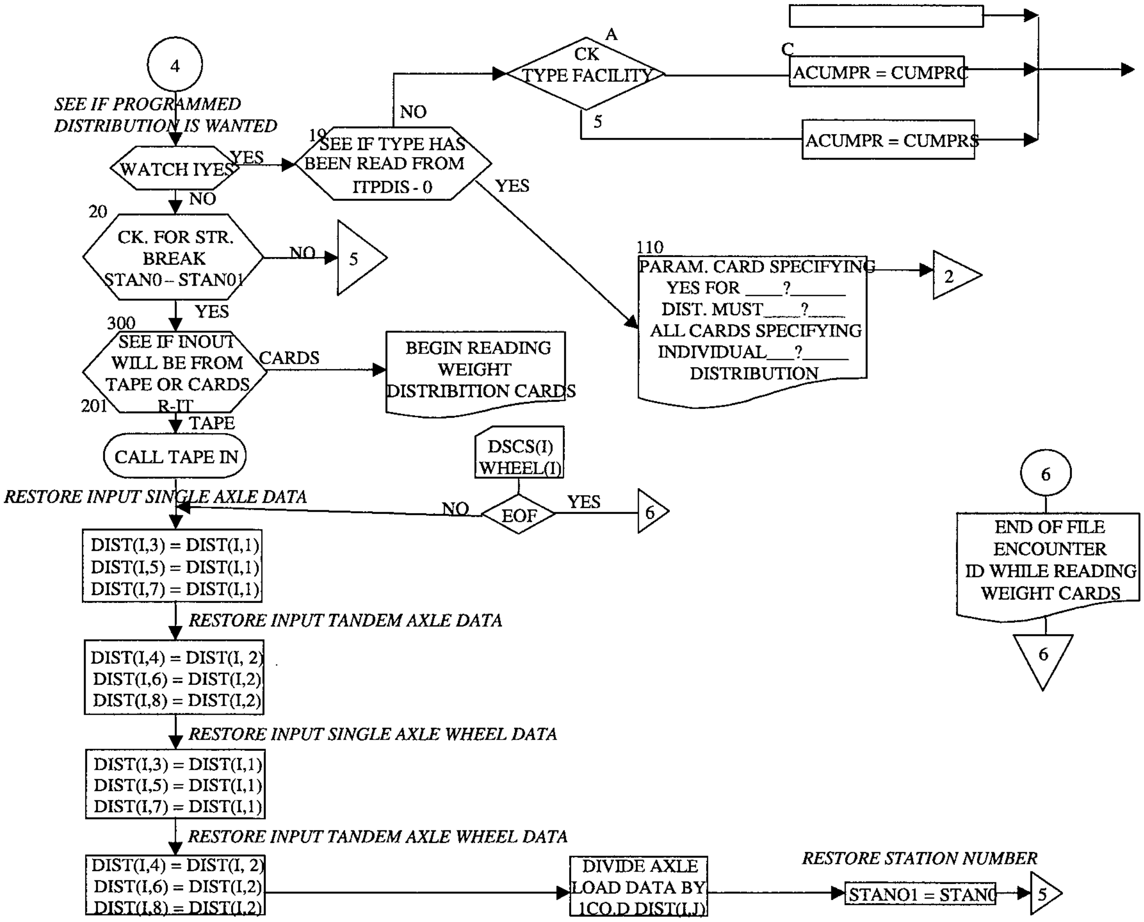


Figure 39. RDTEST68 Program Flow Relationships (Continued).

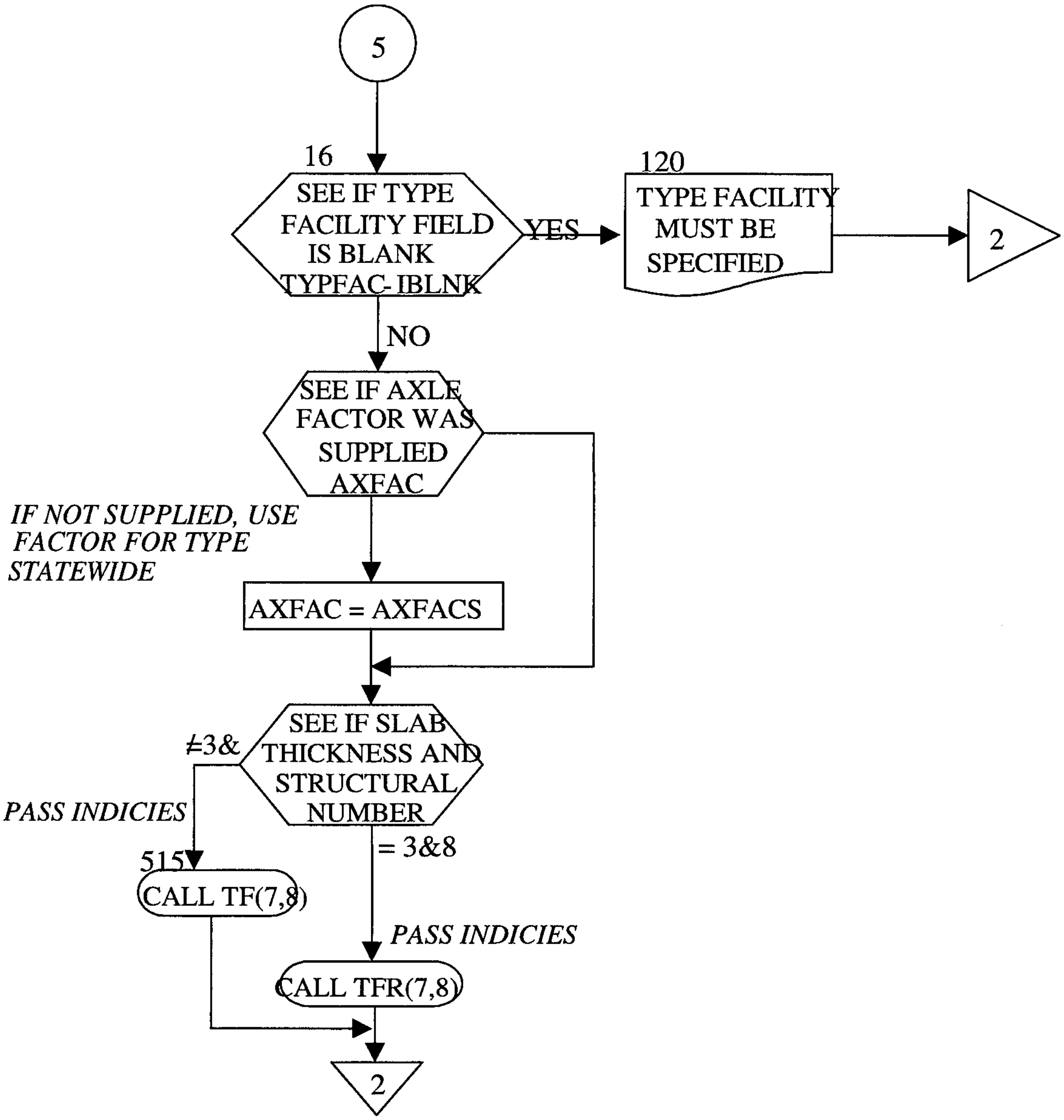


Figure 39. RDTEST68 Program Flow Relationships (Continued).

TF(M,N)

THE FLOW OF SUBROUTINE TF IS IDENTICAL TO SUBROUTINE TFR. HOWEVER THE EQUIVALENCE FACTORS, FOR SLAB THICKNESS OF SOMETHING OTHER THAN 8 AND STRUCTURAL NUMBER OF SOMETHING OTHER THAN 3, ARE CALCULATED.

SUBROUTINE TR(M,N)

THE ONLY DIFFERENCE BETWEEN THE FLOW OF SUBROUTINE TR AND TF IS THE FACT THAT SUBROUTINE TR DOES NOT CALCULATE THE ATHWLD.

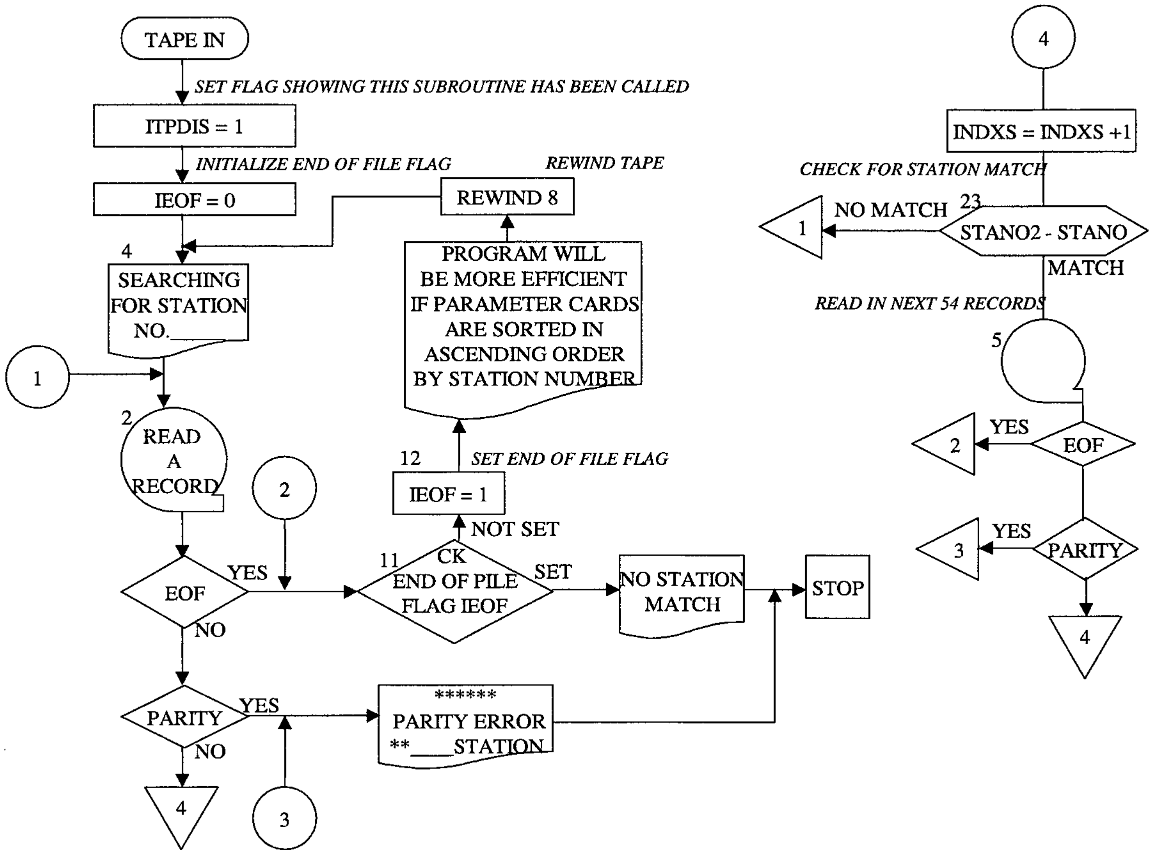


Figure 39. RDTEST68 Program Flow Relationships (Continued).

APPENDIX G

RDTEST68 VARIABLE LISTING

Variable	Definition
ADT	ending avg. daily traffic
ADT1	initial ADT
ANTIS	18 kip equivalency factor for single axles
ANTIT	18 kip equivalency factor for tandem axles
AVGADT	avg. avg. daily traffic over design period
AXFAC	axle factor
AXLEC	number of car axles
AXLET	number of truck axles
CARTOF	tot 18k ESAL for cars (over flexible design life)
CARTOR	tot 18k ESAL for cars (over rigid design life)
CRKIPF	18k ESAL produced by cars in 1 mo or 1 yr (flexible pavement)
CRKIPR	18k ESAL produced by cars in 1 mo or 1 yr (rigid pavement)
D	structural number
ELOS	log of 18 kip equivalency factor for single axles
ELOT	log of 18 kip equivalency factor for tandem axles
ENDADT	ending avg. daily traffic
GRNOTO	2 direction ESAL for rigid pavement
GROWTH	annual traffic growth factor
HDING	card heading
HGRAND	tot 18k ESAL, all vehicles, 1 directioin
IEOF	end of file flag
IGRAND	1 direction ESAL (to nearest 1000) for rigid pavement
INCRSE	increase in traffic per year
INDXS	counter
ITANDS	percent tandems in ATHWLD
ITENH	avg of ten heaviest wheel loads daily (ATHWLD)
ITPDIS	flag for showing TAPEIN run
JX	index marker for wheel load groups
K	DHV-30th highest hour
KIPSF	kips flexible
KIPSR	kips rigid
NUFDUN	finish flag
PGROTH	percent increase in traffic per year
PPTRKS	percent trucks
PSING	percent single axles
PTAN	percent tandem axles
PTRKS	percent trucks
RATIO	ratio of tandem wheel loads
S	slab thickness
SINGL	number of single axles
STANO	station number
STANO1	station number
STANO2	station number
SW	single wheel loads for weight group
TANDS	accumulative number of tandem axle weights
TEN	accumulative number of wheel loads
TOTWLD	tot. number of wheel loads
TRKTO	truck total
TRKTOF	tot 18k ESAL for trucks (over flexible design life)
TRKTOR	tot 18k ESAL for trucks (over rigid design life)
WHLDS	total of single and tandem wheel loads
YEAR	design years
YEARS	design time in years
YRFAC	cumulative annual traffic growth factor

APPENDIX H

FHWA CARD 7 AND SAMPLE VENDOR FILE FORMATS

FHWA Card 7 Truck Weight Record

Columns	Width	Description
1	1	Record Type
2-3	2	FIPS State Code
4-9	6	Station ID
10	1	Direction of Travel Code
11	1	Lane of Travel
12-13	2	Year of Data
14-15	2	Month of Data
16-17	2	Day of Data
18-19	2	Hour of Data
20-21	2	Vehicle Class
22-24	3	Open
25-28	4	Total Weight of Vehicle
29-30	2	Number of Axles
31-33	3	A-axle Weight
34-36	3	A-B Axle Spacing
37-39	3	B-axle Weight
40-42	3	B-C Axle Spacing
43-45	3	C-axle Weight
46-48	3	C-D Axle Spacing
49-51	3	D-axle Weight
52-54	3	D-E Axle Spacing
55-57	3	E-axle Weight
58-60	3	E-F Axle Spacing
61-63	3	F-axle Weight
64-66	3	F-G Axle Spacing
67-69	3	G-axle Weight
70-72	3	G-H Axle Spacing
73-75	3	H-axle Weight
76-78	3	H-I Axle Spacing
79-81	3	I-axle Weight
82-84	3	I-J Axle Spacing
85-87	3	J-axle Weight
88-90	3	J-K Axle Spacing
91-93	3	K-axle Weight
94-96	3	K-L Axle Spacing
97-99	3	L-axle Weight
100-103	3	L-M Axle Spacing

Sample Vendor (ECM/Hestia) File Format

Field	Description
MO	Month
DA	Day
YE	Year
HO	Hour
MI	Minute
SE	Second
A2	
A1	
SN	Station number
LN	Lane number
VAL	Validity of measurements
CA	Vehicle category or classification
GR81	
SPEE	Speed
LENG	Vehicle length
ESAL	"ESAL" coefficient
TODT	Total distance from first to last axle
TWT3	Total vehicle weight
DTB1	Distance from bumper to first axle
WT13	First axle weight
DT12	Distance from first axle to second axle
WT23	Second axle weight
.	
.	
.	
.	
DTXY	
WTY3	

APPENDIX I

TEXAS LEGAL WEIGHT LIMITS

Maximum legal gross weight cannot exceed 80,000 pounds.

Maximum legal weight for a single axle cannot exceed 20,000 pounds.
Maximum legal weight for a tandem axle group cannot exceed 34,000 pounds.
Maximum legal weight for a tritandem axle group cannot exceed 42,000 pounds.

Permissible Weight Table

Distance in Feet	*2 axles*	*3 axles*	*4 axles*	*5 axles*	*6 axles*	*7 axles*
4	34,000					
5	34,000					
6	34,000					
7	34,000					
8	34,000	34,000				
8+	38,000	42,000				
9	39,000	42,500				
10	40,000	43,500				
11		44,500				
12		45,000	50,000			
13		45,500	50,500			
14		46,500	51,500			
15		47,500	52,000			
16		48,000	52,500	58,000		
17		48,500	53,500	58,500		
18		49,900*	54,000	59,000		
19		51,400*	54,500	60,000		
20		52,800*	55,500	60,500	66,000	
21		54,000*	56,000	61,000	66,500	
22		54,000*	56,500	61,500	67,000	
23		54,000*	57,500	62,500	68,000	
24		54,000	58,700*	63,000	68,500	74,000
25		54,500	59,650*	63,500	69,000	74,500
26		55,500	60,600*	64,000	69,500	75,000
27		56,000	61,550*	65,000	70,000	75,500
28		57,000	62,500*	65,500	71,000	76,500
29		57,500	63,450*	66,000	71,500	77,000

30	58,500	64,000*	66,500	72,000	77,500
31	59,000	65,350*	67,500	72,500	78,000
32	60,000	66,300*	68,500	73,000	78,500
33		67,250*	68,500	74,000	79,000
34		68,200*	69,000	74,500	80,000
35		69,150*	70,000	75,000	
36		70,100*	70,500	75,500	
37		71,050*	71,050	76,000	
38		72,000*	72,000*	77,000	
39		72,000*	72,500	77,500	
40		72,000*	73,000	78,000	
41		72,000*	73,500	78,500	
42		72,000*	74,000	79,000	
43		72,000*	75,000	80,000	
44		72,000*	75,500		
45		72,000	76,000		
46		72,500	76,500		
47		73,500	77,500		
48		74,000	78,000		
49		74,500	78,500		
50		75,500	79,000		
51		76,000	80,000		

*These figures were carried forward when Senate Bill 89 of the 64th Texas Legislature amended it on December 16, 1974. The amendment provided that axle configurations and weights that were lawful as of that date would continue to be legal under the increased weight limits.

+These figures apply only to an axle spacing greater than 8 feet.

APPENDIX J

SURVEY OF STATE PRACTICE FOR TRAFFIC LOAD FORECASTING

Summary Results of Pooled Fund Survey *(63)*

1. **States that follow TMG requirements:**

- 13 of 15 survey states adhere to procedures outlined in the TMG.
- One state exceeds many of TMG requirements.
- One state monitors 100% of sites on a three-year cycle and estimates 100 percent each year.
- NC counts primary routes every year, secondary routes every two years.

2. **States where the pavement designer backcasts traffic:**

- AL, SD, and FL do this only as requested or as needed.
- IL does this routinely on two- or five-year cycle.
- MN has an in-house backcasting program.
- Other states do not do backcasts.

3. **How WIM data/information is used:**

- AL, CO, ID, IL, IN, PA, SD, WI, and FL use for pavement design, HPMS/SHRP/LTPP requirements, and research.
- IA uses WIM data for SHRP but not for design due to anomalous data.
- OH uses WIM data for pavement design, permits and fines, enforcement screening, air quality.

4. **States that collect project-level traffic data:**

- AL, ID, IL, IN, MN, NC, ND, OH, and PA collect project-level data.
- CO sometimes uses project-level data; otherwise it uses system averages and/or judgments.
- FL occasionally collects project-level data if warranted (e.g., ramp counts).

5. **Criteria used in states to make the method statistically valid:**

- CO does not believe the methods are statistically valid.
- IL validates site-specific data by comparison with system volumes and patterns.
- IN uses FHWA review.
- IA, ND, and OH follow procedures in the TMG.
- NC follows TMG/AASHTO guidelines, minimum count duration 48 hours then adjusted by data from continuous count sites grouped by either functional class or facility type.
- WI collects a universe-factor by traffic based groups.
- FL uses coverage counts adjusted using factors developed by permanent counts.

6. **States that update traffic between preliminary and final design:**

- AL, IL, NC, ND, WI, and FL update their traffic between preliminary and final design.
- ID and SD only update on request.
- CO and IA update only if time lapsed exceeds some preset value.
- IN rarely updates traffic.
- Other states do not do this.

7. States that use at least two truck classes in the projection of future traffic loadings:

- CO, IA, ID, IL, MN, NC, ND, OH, PA, SC, SD, WI, and FL use more than one truck class (FL uses Scheme "G" (4 to 13).
- IL and IA use two classes in projections, SU and combinations. IA forecasts SU and combinations separately for most projects, then splits into four bus and four truck categories.

8. States that include in the forecasting procedure considerations of past trends and future economic activity in the area:

- AL uses both recent and long-term trends (10 to 15 yrs).
- CO uses linear regression for all areas except where urban planning models are used.
- ID uses straight line growth factor based on past trends.
- IL districts utilize past trends plus trip generation from site-specific development.
- IA uses a history file back to 1980 for PC, SU, and combinations for mostly rural forecasts and as reference in urban areas. IA coordinates with others on urban forecasts.
- MN considers trends and future development.
- NC uses future land use estimates; rural and small urban areas use regression or growth factor analysis.
- ND, SC, and WI include trends and future economic activity; OH uses trends only, and WI uses Tranplan and University of Wisconsin economic models.
- FL uses urban study models or growth plan as needed based in comprehensive plan.

9. States that have a program to monitor actual traffic as compared to predicted traffic for selected sections of highway:

- IN performs occasionally as part of research; IA checks Interstate system occasionally.
- ID uses verification of predicted traffic based on ATR and portable counts.
- IL uses periodic comparison of published traffic maps with predictions, occasionally supplemented by special counts.
- MN compares vehicle classification data when available with forecasts.
- NC uses five planning units to monitor measured traffic and compare to predicted traffic.

10. States that project truck growth separately from vehicle growth:

- AL does only for Interstates and other high-volume controlled access routes.
- IA, ND, SD, and WI project trucks separately.
- ID uses separate commercial and non-commercial growth factors.
- IL predicts truck volumes separately from passenger vehicles on Interstates. IL expresses future volumes for all vehicles in terms of PC, SU, and combinations.
- MN sometimes predicts separately depending on the location, data, and project.
- NC does not do this currently but it plans to in the future. Trucks are currently considered as a percent of total ADTs, but plans are underway to develop a statewide travel flow model that will consider truck purpose.

11. States that use truck load factors that are <u>region</u> and <u>time-of-year</u> specific:

- AL uses these only in one coal-producing area.

- ID uses region-specific factors and will soon use time-of-year factors.
- IL uses these factors for seasonal grain harvests and regional coal mining.
- FL uses regional factors, but not time of year factors.

12. States have reevaluated their truck factors over the following intervals:

- AL, ND, SD, and FL have reevaluated within five years.
- CO, IN, IA, and NC have reevaluated within 10 years.
- MN and SC have reevaluated beyond 10 years.
- ID re-evaluate truck factors semi-annually.
- OH and WI evaluate truck factors at least annually.

13. States that have growth factors for each of the truck classifications:

- AL does not, but will have in 3 to 4 years.
- IL has separate factors for SU and MU in specific areas.

14. States determine accumulated traffic loadings for rehabilitation projects:

- AL and CO use the AASHTO procedure.
- ID uses straight line projections based on past weight data trends.
- IL bases on existing pavement condition and projected traffic volumes.
- IA uses road rater information plus forecasted ESALs.
- NC and PA do not use accumulated traffic loadings for rehab projects.
- OH uses regression analysis of historical loading data.
- FL adjusts rehabs slightly to account for growth trends.

15. States that have provisions for updating traffic figures if the design timetable is not met:

- AL updates annually until project is let to contract.
- ID updates traffic figures upon request.
- IL routinely accepts forecaster requests when the timetable lags.
- IA has no formal process for this. Pavement design determines each case on its merits.
- MN does design forecast for a design year and four more years, then reviews if over two years old.
- NC Pavement Management section requests new forecast if over two years old.
- ND, SC, WI, and FL have processes in place but did not provide details.
- PA pavement engineer may request an update.

16. States in which the pavement engineer modifies traffic loadings:

- NC Pavement Management unit may evaluate.
- OH does this if there is knowledge of above-normal loadings.
- SC does this.