An Evaluation of the Technical and Economic Performance of Weigh-In-Motion Sensing Technology

by

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I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Deteriorating roadway conditions have drawn attention to the need to develop an accurate and practical system to control increasing excessive traffic volumes and traffic loads. In practice, traffic volumes often exceed predicted volumes, and truck overloading occurs frequently. Overloading pavements can result in premature deterioration, early or mistimed maintenance activities and eventually higher life cycle costs. As a part of an Intelligent Transportation Systems (ITS), especially in the area of Commercial Vehicle Operations (CVO), Weigh-In-Motion (WIM) has been focused on using state-of-the-art sensing technology to continuously collect vehicle weights, speeds, vehicle classes, and various types of traffic data as vehicles travel over a set of sensors (embedded or portable), without interruption of traffic flows. It is the process of measuring the dynamic tire forces of a moving vehicle and estimating the corresponding tire loads of the static vehicles. WIM technology is imperative for weight enforcement, road network design and management, as well as road safety.

The overall purpose of this thesis is to examine the feasibility of using WIM in northern environments such as Canada's. In response, one contribution of the thesis is to develop an economic model for WIM values that include costs due to premature pavement deterioration, benefits of weight enforcement and traffic data collection, benefits of WIM compared to conventional static weigh stations, and benefit-cost ratios of WIM values from road users and non-road users' perspectives. Another contribution is to examine the technical performance (accuracy) of a particular WIM system. Results of field data collection and analysis are presented in this examination. This thesis also compares the advantages and disadvantages of different WIM systems, with respect to cost, accuracy, applicability, reliability, and sensitivity. Future trends and research potential of WIM are also discussed.

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Chapter 1

Introduction

1.1 Background

Roads are essential for a nation's social well being and economic strength. There has been a rapid increase in road traffic volume in North America in recent years. In order to stay efficient and competitive, transport companies have adopted trucks fleet that are larger in terms of both loading and size. This is a concern because overloaded trucks can cause damage to the road network, reduce pavement service life, and reduce the overall service level of a pavement system. Moreover, overloaded trucks can result in more traffic accidents [Wang and Wu 2004], disorder in transportation systems, and eventually more cost to road users, road agencies, and the public. Furthermore, the current condition of pavement infrastructure in North America is at a critical state because of over usage of the infrastructure, poor maintenance, and limited budgets. According to the ASCE (American Society of Civil Engineers) 2005 Report Card for America's Infrastructure, the service level of highways in America is at the level of C or D (C = Mediocre and D = Poor). This urgent problem focuses attention on the need to develop an accurate and practical system to meet the needs of traffic control.

Since the 1950s, WIM systems have been developed as an advanced technology to improve the capacity and effectiveness of static weigh stations, not only for traffic monitoring and weight enforcement, but also for the data requirement of up-to-date pavement design protocols, pavement management, and transportation safety. The utmost advantage of a

WIM system is that it does not require trucks to stop and allows heavy but not overweight vehicles to bypass the scales, thus improving operating efficiency. WIM systems acquire vehicle weights, axle loads, axle spacing, speed, and other vehicle information as vehicles drive over sensors. WIM technology has been widely used in Europe, North America, Australia and New Zealand. Besides pavements, the application of WIM has been extended to railways and bridges.

A WIM system consists of weight sensors/scales, inductive loop detectors, and a data acquisition system (DAS) in a roadside cabinet. Retrieving and analyzing data requires software which comes with the data logger of the DAS. There are three basic types of WIM sensors: piezoelectric sensors, bending plates, and load cells. The operational principle of WIM sensors is that the dynamic tire force is proportional to the physical measurements recorded by sensors, such as voltage, strain, and resistance. A WIM system is often used with weigh stations to prescreen overweight trucks at a high processing rate. Weigh stations are used to confirm the overload.

1.2 Research Motivation

WIM measures the dynamic tire force of a moving vehicle. It more accurately represents what a pavement is subjected to than a static weight. However, converting the value of dynamic force to static weight is still used in recording traffic information and evaluating the accuracy of a WIM system. Since more factors are involved as a vehicle is moving than in the case of a static vehicle, it is more difficult to quantify the accuracy of a WIM system. Influence factors could include pavement roughness, vehicle suspension and speed, interaction between a pavement and a vehicle at the location of the WIM sensor, temperature, and the sensor itself. In practice, ASTM (American Society for Testing and Materials) defines the accuracy of each type of WIM as a certain tolerance for a 95% confidence level. The Gross Vehicle Weight (GVW), for instance, measured by a piezoelectric sensor shall fall within 15% of the true weight for 95% of the trucks measured. Currently, there are no perfectly accurate WIM scales, and measurement methods for accuracy are varied.

As new technologies are introduced, a critical concern is the economic value of the

new technology and the cost-effectiveness compared to conventional options. The question of benefits of a new technology in terms of society, economy and environment is also important. With limited budgets, economic analysis helps to make the best decision. With tight budget constraints, concerns need to be addressed and demonstrated quantitatively and objectively: such as how an overload spectrum impacts on pavement life cycle cost; how efficiently or cost effectively WIM systems work compared to static weigh stations; what are these benefits to users, agencies, the public, and how much. Economic analysis can help to assess the benefits and costs of applying WIM technology.

1.3 Research Scope and Objectives

The overall objective of this thesis is to examine the feasibility of using WIM technology for effective pavement design and management and effective weight enforcement in a northern environment such as Canada's. The scope of the thesis is two fold: technical performance of a particular WIM system and economic performance for general WIM values. Comparisons are made with conventional weigh stations when applicable. Field observations are presented to quantify the performance of a particular WIM system. Figure 1.1 illustrates the structure of the thesis. It involved the following tasks:

1. Literature review of the current practice of WIM and related pavement design and management concepts
2. Problem identification of WIM systems
3. Field data collection
4. Data analysis of a particular WIM system performance
5. Discussion of benefits and costs of WIM systems, compared to traditional weigh stations
6. Life cycle cost analysis of excess traffic load on pavement design and maintenance, operations

7. Benefit-cost analysis of WIM based on the values of weight enforcement, delay reduction, and road safety
8. Development of an economic model for WIM value analysis
9. Validation of the model with a real WIM project
10. Discussion of future research and improvement of WIM systems

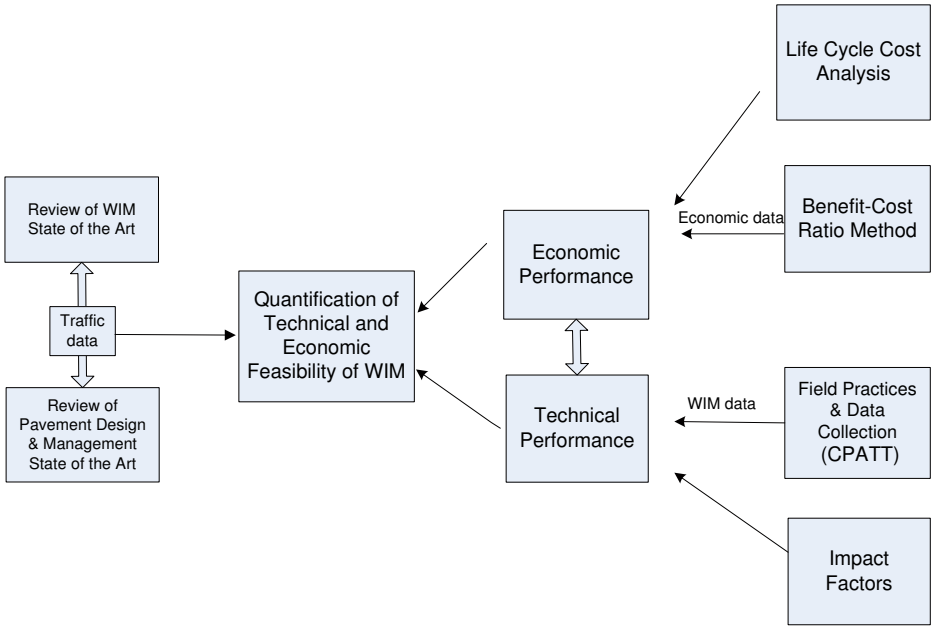


Figure 1.1: Thesis Framework

1.4 Methodology

For the purpose of investigating and understanding WIM accuracy, a piezoelectric WIM system at the CPATT (Centre for Pavement and Transportation Technology) test track was examined. The CPATT test track is located at the Regional Municipality of Waterloo's Waste Management facility, which is approximately 7 km driving from the University of

Waterloo. A static weigh station is also available at the site. This configuration is ideal to compare WIM measurements with the actual truck weights that are readily available from the static scales.

For the purpose of life cycle cost analysis for WIM values, the Mechanistic-Empirical Pavement Design Guide (MEPDG) is used to run simulations of pavement design and estimate pavement performance under excess traffic axle loads. International Roughness Index (IRI), rutting index, and corresponding Performance Serviceability Index (PSI) are used to demonstrate the impact of overload on pavement deterioration. In addition, current economic analysis tools for ITS investments are applied to aid in evaluation of the benefit-cost ratio for various WIM values, including delay reduction, weight enforcement, and safety benefits.

1.5 Organization of the Thesis

The organization of this thesis is as follows:

In Chapter 2, different types of WIM sensors (piezoelectric sensor, bending plate, and load cell) are described and compared, with respect to cost, accuracy, applicability, reliability and sensitivity. Factors, including roughness and vehicle condition that affect accuracy are discussed. Best practices for a WIM system are presented regarding site selection, installation, and calibration.

This chapter also presents a literature review of current pavement design protocols including the new MEPDG compared to the old AASHTO Design Guide, the significant impact of traffic load on pavement damage and pavement management, and the importance of WIM data for MEPDG inputs and performance predictions.

Chapter 3 describes the piezoelectric sensors and the data acquisition system at the CPATT WIM site of the University of Waterloo. A model of the data acquisition process is presented. Field data are collected to examine the accuracy of the WIM system. Statistical analysis and results are presented. The lessons learned from field experience are discussed.

Chapter 4 discusses the various aspects of WIM benefits. First, the MEPDG and life cycle cost analysis are applied to examine the impact of excess traffic load on pavement design and management. Secondly, costs and benefits of WIM are assessed. Economic

analysis tools for ITS are discussed. Particularly, SCRITS (SCReening for ITS) is applied to develop an economic model of WIM with respect to delay reduction, weight enforcement, and road safety. Finally, a benefit-cost ratio of WIM value analysis is accomplished.

Economic data from industry sources is presented in Chapter 5. The economic model is to be validated in this chapter. Tradeoff of the economic feasibility of WIM are discussed.

New materials, new technologies, and other future research of WIM are discussed in Chapter 6.

Chapter 7 provides conclusions and recommendations.

Chapter 2

Literature Review

2.1 Weigh-In-Motion Technology

A WIM system is comprised of a set of sensors and supporting instruments that are designed to measure the presence of a moving vehicle and the related dynamic tire forces at specified locations with respect to time; estimate tire loads, calculate speed, axle spacing, vehicle class according to axle configuration, and other parameters of a vehicle; and process, display, store, and transmit this information. This standard applies only to highway vehicles [ASTM 2002]. Therefore, it is important to note that the accuracy of a WIM system depends on not only the sensor itself and its physical environment, but also the other supporting instruments and software that are to estimate the measurements.

A WIM system consists of weight sensors/scales, inductive loop detectors, and a computer interface in a roadside cabinet. Depending on applications, optional peripheral devices can include Automatic Vehicle Identification (AVI) interfaces, video cameras, and modems. Weight sensors that weigh vehicles are the key hardware in the system. These sensors can be portable or permanently installed depending on system requirements. There are three basic types of WIM sensors:

- Piezoelectric sensors,
- Bending plates, and

- Load cells

Inductive loop detectors are used to detect approaching vehicles and measure axle spacing and vehicle speed. The computer interface is usually a data logger equipped with a microprocessor. It monitors and stores the traffic flow data (including axle spacing, gross vehicle weight, and vehicle speed) that can be either retrieved on site or transmitted wirelessly from a remote location to a central office. ASTM classifies WIM systems as Type I, II, III, or IV, as shown in Table 2.1 [ASTM 2002]. The classification is according to speed ranges, data gathering capabilities, and intended applications. Table 2.2 [ASTM 2002] shows functional performance requirement for WIM systems, from Type I to Type IV.

Table 2.1: ASTM WIM System Classification

	CLASSIFICATION			
	TYPE I	**TYPE II**	**TYPE III**	**TYPE IV**
Speed Range	16 - 113 km/h (10 - 70 mph)	16 - 113 km/h (10 - 70 mph)	24 - 80 km/h (15 - 50 mph)	24 - 80 km/h (15 - 50 mph)
Application	traffic data collection	traffic data collection	weight enforcement station	weight enforcement station
Number of Lanes	up to four	up to four	up to two	up to two
Bending Plate	X	X	X	X
Piezoelectric Sensor	X	X		
Load Cell	X	X	X	X
Wheel Load	X		X	X
Axle Load	X	X	X	X
Axle-Group Load	X	X	X	X
Gross Vehicle Weight	X	X	X	X
Speed	X	X	X	X
Center-to-Center Axle Spacing	X	X	X	X
Vehicle Class	X	X		
Site Identification Code	X	X	X	X
Lane and Direction of Travel	X	X	X	
Date and Time of Passage	X	X	X	X
Sequential Vehicle Record Number	X	X	X	X
Wheelbase (front to rear axle)	X	X		
Equivalent Single-Axle Load	X	X		
Violation Code	X	X	X	X

A WIM system serves mainly two functions for highway preservation: traffic data collection and weight enforcement. It is a major tool used to collect traffic data automatically, including vehicle weight, volume, classification and speed. Traffic flow information is critical for highway management, traffic operation and control, and structural design of pavements and bridges. For example, Type I and Type II WIM systems can be used to

Table 2.2: Functional Performance Requirement for WIM Systems

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

*Lower values are not normally a concern in enforcement

calculate Equivalent Single-Axle Loads (ESALs). It is a measure of pavement axle load damage and an important input for pavement design. In addition, WIM systems can be used to pre-weigh all trucks to detect suspected weight violators who are then directed to static weigh stations, thus protecting pavements from accelerating deteriorations. Since overloaded vehicles are more often involved in fatal accidents [Wang and Wu 2004], WIM systems also contribute to road safety as a subordinate function. Compared to static weigh stations, WIM systems provide a higher processing rate.

2.1.1 WIM Applications/Projects in North America and Europe

WIM was first introduced in Canada in Alberta in 1982. Since then, its usage has been increasing steadily. In Manitoba, several WIM systems were installed in the 1990s. A performance study [Zhi et al. 1999] showed that the historic performances of these WIM systems are outside the conformity specified by ASTM E2-1802, due to a large number of unreasonable data. In Ontario, the Ministry of Transportation Ontario (MTO) tried using WIM as one of the tools to inspect commercial vehicles in an effort to preserve Ontario's roads. In the United States, WIM technology is more widely and successfully applied to preserve the road network. For instance, in Texas, there are 21 permanent WIM sites to collect traffic data to provide a vehicle loads database.

WIM sensing technologies have been widely used not only in North America, but also in Europe. Established WIM vendors include Electronique Control Measure (ECM), Golden River Traffic Ltd., International Road Dynamics (IRD), Kistler Instrument Corp., Mea-

surement Specialties Inc., and Peek Traffic-Sarasota. During the 1990s, the Federal of. European High Road Institute initiated the WAVE (Weigh-in-motion of Axles and Vehicles for Europe) project and the COST 323 project [Jacob 2002a, Jacob 2002b]. WAVE implemented field tests of various WIM systems in cold regions to rank the durability and performance of WIM systems. The resulting ranking order is PAT, Kistler, Data-instrument, and Oyomni. COST 323 implemented testing in Switzerland to compare the capability and the stability of WIM systems. The resulting rank order is German PAT (a combined system of Switzerland Kistler and PAT), Micros, ECM, Peek, and Golden River.

2.1.2 Advantages and Disadvantages of Different WIM Sensors

The following section describes the basic structure components and underlying functioning principles of WIM sensor technologies. Comparison is made with respect to cost, applicability, reliability, and sensitivity of these sensors. Among many issues, accuracy is the main technical issue.

Piezoelectric Sensors

A piezoelectric WIM system consists of at least one sensor and two inductive loops (Figure 2.1), embedded in road cut or portable. The piezoelectric sensors usually are encapsulated in an epoxy-filled metal channel, such as aluminum. It is placed in the travel lane perpendicular to the direction of travel enabling the wheels of one axle to hit the sensor at the same time. In the case of quartz piezoelectric sensors, one sensor is used for each of the two wheel paths in a lane. The inductive loops are placed upstream and downstream of the sensor. One inductive loop is placed upstream from the scale to detect an approaching vehicle and triggers a sequence of events: WIM sensor signal detection, amplification, and collection. The other loop is placed downstream to determine the vehicle speed and axle spacing based on the time it takes the vehicle to traverse the distance between the loops. The distance between the two loops can not be less than the required minimum distance. Axle spacing, number of axles, vehicle length and weight enable the system to classify vehicles.

When a mechanical force is applied to a piezoelectric sensor, it generates a voltage

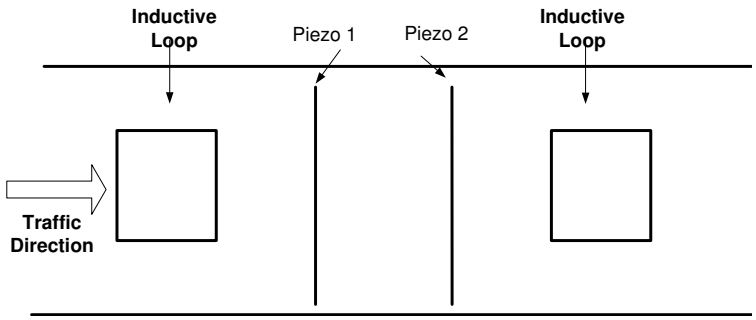


Figure 2.1: Example of Piezoelectric Sensor Layout

Figure 2.2: Piezoelectric Sensor

that is proportional to the force or weight of the vehicle. As a vehicle passes over the piezoelectric sensor, the system records the electrical charge generated by the sensor and calculates the dynamic load. Static load is estimated from the measured dynamic load with appropriate calibration parameters. This system is classified as an ASTM Type I or II system depending on the intended use of the device and the number of sensors placed in the lane [CTRE 1997]. Figure 2.2 [ORNL 2000] is an example of a piezoelectric sensor, a product of Measurement Specialties Inc. The sensor is 3.5 m in length, 1.5mm thick and 6.5 mm wide.

Bending Plate

A common configuration of blending plate is shown as Figure 2.3. The blending plate scale consists of two steel platforms for each wheel path of the traffic lane, installed with two inductive loops. The loop's inductance changes and produces a readable signal when a vehicle passes over it. The scale is placed in the travel lane perpendicular to the travel direction. The function of inductive loop is the same as that for the piezoelectric sensors. Bending plate scales can be portable or installed permanently with excavation into the road structure.

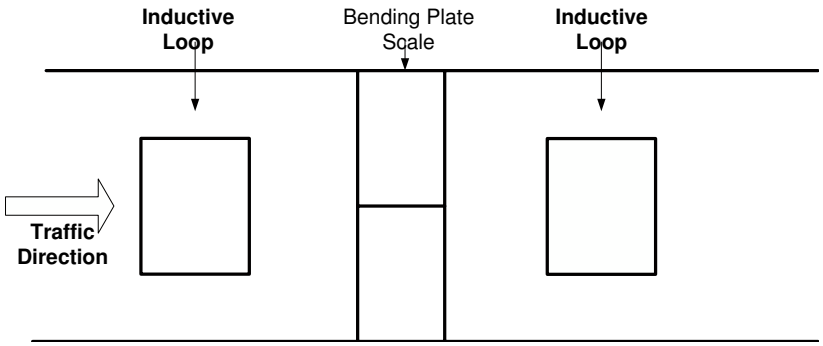


Figure 2.3: Example of Bending Plate Layout

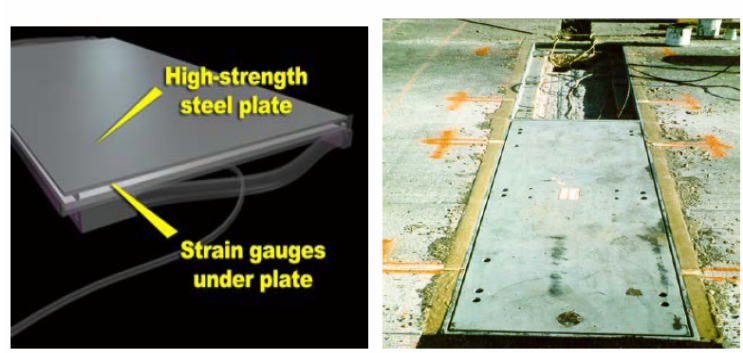


Figure 2.4: Bending Plate

A bending plate utilizes metal plates with strain gauges mounted underside of the metal

plates [CTRE 1997], as shown in Figure 2.4 [ORNL 2000]. When a vehicle passes over the bending plates, the strain gauge on each plate measures the amount of strain, and the WIM system calculates the dynamic load that causes it. Static load is then estimated by the measured dynamic load with appropriate calibration parameters. The calibration parameters account for influences factors, such as vehicle speed, suspension dynamics and speed [CTRE 1997]. Bending plate is classified as an ASTM Type I, II, III, or IV system depending on the intended use of the device and the number of scales placed in the lane.

Load Cell

A typical load cell WIM system consists of a single load cell that has two in-line scales, at least one inductive loop, and one axle sensor (Figure 2.5). Similar to bending plate, the load cell is placed in the travel lane perpendicular to the travel direction. The purpose of the inductive loop placed upstream of the load cell is to detect approaching vehicles and alert the system. The axle sensor is placed downstream of the load cell to determine axle spacing and vehicle speed [CTRE 1997]. It utilizes technology based on the change of sensor resistance with pressure [Klein 2001].

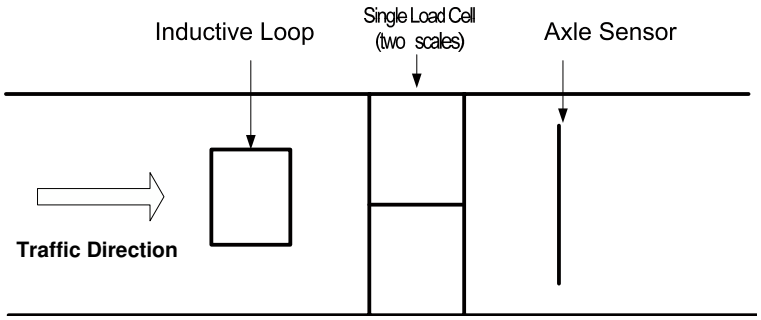


Figure 2.5: Example of Load Cell Layout

Load cell WIM systems utilize a single load cell with two scales to detect and weigh the right and left side of an axle simultaneously. A load cell is comprised of durable material such as steel and a strain gauge attached to it. The strain gauge consists of a wire that transmits electric current. As the cell is subjected to load, the wire under the strain gauge is compressed slightly and altered. The change in the wire results in a resistance difference

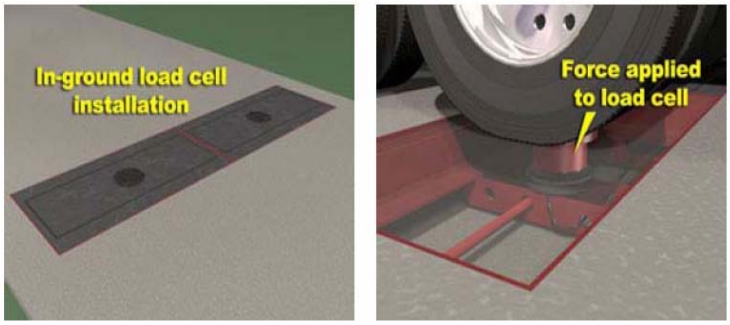


Figure 2.6: Load Cell

to the current. Then, the system measures the variance in the current and calculates weight measured by each scale and then sums them to obtain the axle weight [IRD 2001]. Figure 2.6 [ORNL 2000] shows a simulation of a load cell subjected to load. A load cell is classified as an ASTM Type I, II, III, or IV system depending on site design.

Comparison of the WIM Sensors

To compare these different sensing techniques, the following characteristics are considered:

- Cost - The purchase cost of equipment, installation, and annual operating and maintenance costs;
- Accuracy - Relative performance accuracy, tolerance for 95% confidence level [ASTM 2002];
- Sensitivity - The response of sensors to various factors including pavement roughness, temperature, vehicle suspension, and vehicle speed.
- Reliability - The ability of the system to perform the required function in routine and hostile circumstances; primarily depending on performance of the sensor itself over the entire life cycle of a system, but may also include the data acquisition subsystem of a WIM system.
- Applicability - The nature of sensor technologies for particular industrial application.

Based on studies by [Bushman and Pratt 1998, White et al. 2006], and the functional performance requirements for WIM systems defined by ASTM E2-1802, the three basic sensor technologies (including quartz piezoelectric sensors) are compared with respect to the aforementioned characteristics. The comparison is presented in Table 2.3. The table illustrates that the accuracy and expected service life of these sensors are crudely related to their cost. In the order of load cell, bending plate, and piezoelectric, the accuracy and expected service life decrease as the costs decrease. For instance, the accuracy of load-cell based WIM is 2.5 times higher than piezoelectric, but the initial installation cost is more than five times of that of piezoelectric according to Bushman's study [Bushman and Pratt 1998]. The terms Low, Medium, and High in the table are relative due to the difficulty of reliable quantification and should be treated with some degree of skepticism given the pace of change of these technologies. It is important to note that the piezoelectric system is applied more in traffic data collection than weight enforcement stations because of relatively low accuracy. To overcome the sensitivity to the impacting factors, new materials have been developed, such as quartz piezoelectric sensors. This type of sensor does not fatigue as quickly and the impact of temperature is negligible [Klein 2001]. Quartz piezoelectric sensors have been proved to meet or exceed the weight accuracy specified by ASTM for Type I [White et al. 2006], and their cost is competitive with the load-cell based WIM systems.

In summary, a bending plate is a strain-based scale with relatively inexpensive installation and intermediate performance; load-cell based WIM provides a very accurate and easily maintainable system at a higher equipment and installation cost; conventional piezoelectric sensors provide the lowest accuracy with relatively the lowest cost. The quartz piezoelectric potentially offer high accuracy at a reasonable cost, but more data is required to state this conclusively. These three types of WIM sensors employ different techniques and have their advantages and disadvantages depending on the requirements of different applications. To select an appropriate WIM sensor, it is important to consider various criteria, including application, desired weighing accuracy, vehicle volume, the output data required, the peripheral equipment desired, and the vehicle flow near the scales.

Table 2.3: WIM Sensors Comparison

		Piezoelectric sensor	**Bending plate**	**Single Load Cell**	**Quartz Piezoelectric sensor**
Cost (per lane)	**Initial Installation Cost (US$)**	Low (around $9,000)	Medium (around $20,000)	High (around $50,000)	Medium (around $20,000)
	Annual Life Cycle Cost (US$)	Low (around $5,000)	Medium (around $6,000)	High (around $8,000)	High
Accuracy (GVW, 95% Confidence)		±15%	±10%	±6%	±10% (100% confidence)
Sensitivity		High	Medium	Medium	Non sensitive to temperature, but highly to roughness
Expected life		4 years	6 years	12 years	Expected > 15 years
Reliability		Low	Medium	High	Medium
Applicability		Traffic data collection[1]	Weight enforcement, Traffic data collection	Weight enforcement, Traffic data collection	Weight enforcement, Traffic data collection

2.1.3 Site Selection, Installation, and Calibration

One of the purposes behind the development of WIM technologies is to achieve accurate load data by measuring moving vehicles. However, there are many factors involved in WIM performance requirements, including site selection (geometric design, pavement condition, and site location), system installation, and system calibration.

Site Selection

The dynamic tire force results from complex interaction between vehicles and road surface. The state of a vehicle driving over a sensor is hard to control and therefore selecting a site

[1]Traffic data includes axle load, axle-group load, Gross Vehicle Weight, speed, center-to-center axle spacing, vehicle class, site identification code, lane and direction of travel, data and time of passage, sequential vehicle record number, wheelbase (front to rear axle), ESAL, and violation code [ASTM 2002].

with proper geometric design and pavement condition is critical for the accuracy of a WIM system. Geometric design of pavement, including horizontal curvature, grade, cross slope and lane width of pavements, can influence longitudinal and transverse offsets on vehicle behaviors. The ASTM standard sets geometric design requirements for each type of WIM system (Table 2.4), which provides a foundation for using dynamic load measurements to accurately estimate static load [CTRE 1997].

Pavement conditions, especially surface smoothness (affected by cracking, potholes, and rutting), affect the bouncing of a vehicle and change over time. Experience has indicated that a Portland Cement Concrete (PCC) pavement structure retains its surface smoothness over a longer period of time than an asphalt pavement structure under heavy traffic at a WIM site [ASTM 2002]. In addition, vehicle speeds and changes in speeds also affect the actual loads applied to a pavement. The ideal condition is achieved when loads are applied to a smooth and flat road surface by perfectly round and dynamically balanced rolling wheels at a constant speed [Lee 1988].

Besides the specific geometric design and pavement condition of a site, the general characteristics of a potential site for WIM are very important to meet established WIM system requirements. These characteristics of a site include availability of access to power and phone, adequate drainage and traffic conditions. Traffic conditions require avoiding stop-and-go traffic, slow-moving traffic, and lane changing [CTRE 1997].

Table 2.4: ASTM Standard (E 1318-94) Geometric Design Requirements

Characteristic	**Type I**	**Type II**	**Type III**	**TypeIV**
Horizontal Curvature	radius $\geq$ 1740m 46m before/after	radius $\geq$ 1740m 46m before/after	radius $\geq$ 1740m 46m before/after	radius $\geq$ 1740m 46m before/after
Roadway Grade	$\leq$ 2% 46m before/after	$\leq$ 2% 46m before/after	$\leq$ 2% 46m before/after	$\leq$ 1% 91m before/after
Cross Slope (lateral)	$\leq$ 2% 46m before/after	$\leq$ 2% 46m before/after	$\leq$ 2% 46m before/after	$\leq$ 1% 46m before/after
Lane Width	3 to 4.5m 46m before/after	3 to 4.5m 46m before/after	3 to 4.5m 46m before/after	3 to 4.5m 46m before/after

System Installation

In addition to the site selection requirements, proper installation is a key factor to ensure that a WIM system will function within specifications throughout its site design life [CTRE 1997]. A poor installation will cause serious problems, such as no signal detection and high signal noise. Traditional installation requires high quality pavement materials to minimize the dynamic effects of the vehicle-infrastructure interaction. The ASTM standard suggests that the installation and maintenance of WIM equipment follow the recommendations of the system vendors. For a specific sensor installation, the equipment vendors shall provide installation instructions to follow. For example, IRD has the designate installation manual for its BL (Brass Linguini) Class 1 Piezo Installation.

In practice, the common goal of the installation requirements is to provide the expected site design life. The quality of installation is strongly related to the life cycle cost of embedded sensors. "States Successful Practices Weigh-in-Motion Handbook" from the Center for Transportation Research and Education (CTRE) suggests general installation principles and general steps. The handbook provides a methodology to (1) conduct initial tests for assuring sensor functionality, (2) prepare the road such as saw cutting for in-pavement components, (3) install sensors and other components, and (4) conduct final tests including sensor performances by driving a truck over the sensors. Researchers recommended identifying a "bad" sensor prior to installation in order to save time and money.

The other critical question is how many sensors are to be installed per km of a pavement, where will a designer install or embed sensors in a pavement, and what is the appropriate method to install a specific sensor. For example, rut-depth measurements of pavements have been in an unsettled state, because there is little consensus on the number of points to measure (how many sensors to install). Although AASHTO provisional standard requires a minimum of five sensors, many agencies still use three. There is research [Simpson 2003] promoting at least nine, whereas some vendors have moved to 30 or more. In research, models may be applied to optimize sensor placement for different performance criteria.

System Calibration

Since weighed vehicles are moving, the dynamic tire force results from the interaction among vehicle components, WIM-system sensors, the road surface surrounding the sen-

sors, and other elements. A system calibration is conducted to offset the site-specific effects including pavement temperature, vehicle speed and pavement condition, eventually, to ensure the estimation of weights is as close as to the corresponding static weights as possible. However, as Figure 2.7 [IRD 2001] conceptually illustrates, a discrepancy normally exists between the statically recorded weights (Ws) and dynamically recorded weights (Wd) of a vehicle. For example, drifting (the output signal slowly changes independent of the measured property) of WIM weight distribution is experienced by many WIM systems, and is an indicator of an overweight or underweight calibration problem. In addition, the drift is different from site to site [Zhi et al. 1999]. Therefore, it is very important to carry out periodic calibration in order to assure the accuracy of a WIM system.

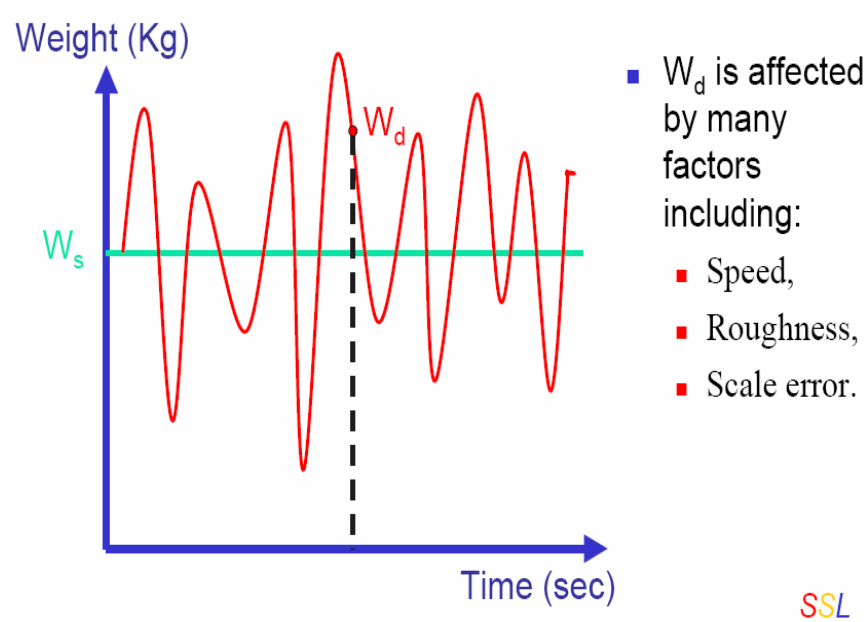


Figure 2.7: Dynamic and Static Weighing

A system calibration must be applied immediately after the initial installation of a WIM system at a site. Recalibration of a system should follow reinstallations, considerable maintenance, significant changes of site conditions and WIM system components (including software and software settings). Unusual data patterns can also indicate a need

for recalibration [ASTM 2002]. ASTM E2-1802 recommended a general WIM calibration procedure. It requires two loaded, pre-weighted and measured test vehicles, each making multiple runs over the WIM-system sensors in each lane at specific speeds. Based on the differences between the estimated values and the respective reference values (such as the differences for vehicle speeds, axle loads, axle spacings, and GVWs), calibration factors can be derived from these measurements.

2.1.4 Factors Impacting Accuracy

WIM sensors are normally embedded in roads at specific sites. They are subjected to the surrounding environmental conditions and traffic conditions. For example, pavement temperature, moisture, deflection, and vehicle dynamics can all impact how the sensors reflect the actual measurements of vehicles, that is, the accuracy. To assure accuracy, it is important to address the factors that WIM sensors are sensitive to.

Temperature

Like most sensors, current WIM sensors are temperature sensitive, their signal strength for a given axle force is not uniform with temperature changes. It is due to the material properties of the sensor itself and the pavement responses caused by temperature. Practices have found that WIM sensors embedded in asphalt pavements perform less consistently than those in concrete [ASTM 2002]. One reason is asphalt pavements softening in hot weather. In addition, if a WIM sensor is used outside allowed temperature range, the sensor outputs can not be guaranteed to meet certain specifications. Field experiences from CPATT WIM site proved that there is small chance to successfully calibrate piezoelectric sensors over a long period of time due to the impact of temperature variation over time. Calibration of a WIM system has to involve compensating for the impact of temperature changes.

In practice, temperature sensors are usually installed along pavement layers with WIM sensors in order to examine temperature impact on the measurements. New materials such as quartz sensors do not generally fatigue and the impact of temperature on the sensor itself are negligible. Their performances and costs are competitive with the load

cells [Klein 2001]. It would be an enormous improvement if a WIM sensor's performance is consistent with temperature drifts, or its output is independent of temperature drifts.

Roughness

Since weighed vehicles are moving, road surface roughness plays a role that excites vehicle dynamics: short wavelength roughness affects axle motion, and long wavelength roughness affects vehicle body motion. The worse the roughness is, the larger the scale error is.

Roughness, also referred to as "smoothness", is a measurement of the small-scale variations in the height of a physical surface. ASTM E867 defines pavement roughness as "the deviation of a surface from a true planar surface with characteristic dimensions that affect vehicle dynamics and ride quality". Two ranges [Karamihas et al. 2004] of pavement roughness are stated as influencing scale errors from the Long-Term Pavement Performance (LTPP) program :

- "Short range" roughness, covering the range of a pavement that includes about 10 ft (3.05 m) preceding the scale, the scale itself, about 1 ft (0.31 m) beyond it; the corresponding roughness is called Short Range Index (SRI);
- "Long range" roughness, covering the range of a pavement that includes about 80 ft (24.4 m) preceding the scale, the scale itself, about 10 ft (3.05 m) beyond it; the corresponding roughness is called Long Range Index (LRI).

Originally, the suggested threshold value for LRI and SRI is 0.789 m/km. To minimize dynamic motions and thus improve the accuracy of traffic data collected at WIM sites, the LTPP program established an approach to set up the threshold values of pavement roughness, prior to and immediately past the scale (Apparently, roughness near the scales is more important). The purpose of this LTPP study is to find smoothness specifications/limits of sites that could produce considerable research-quality data.

Vehicle

As a moving vehicle interacts with the pavement where sensors are embedded, many properties of the vehicle could impact the accuracy, for example:

- The class of the vehicle used, including vehicle suspension system, tire types and pressures, axle number, etc.
- The speed of the vehicle (local speed, highway speed, etc.)
- The loading schemes of the vehicle (unloaded, loaded, overloaded, etc.)

A study [Sun and Deng 1998] has proved that assuming constant vehicle speeds, the variation of dynamic loads measured by a WIM system can be obtained as a function approximately proportional to $\sqrt{C_{sp}}$, the ratio depends on the dynamic properties of the vehicle, where C_{sp} is the roughness index.

2.2 Pavement Design and Management

Pavements are critical infrastructures for traffic access in order to sustain a nation's economy and social well-being. As an important part of Pavement Management System (PMS), traffic data aids in the design and maintenance of pavement structures to assure required serviceability and reliability. Overestimation of design traffic results in conservative pavement designs that are not cost effective, while underestimation of design traffic results in premature failure and excessive maintenance and rehabilitation costs. Using traffic data to support pavement design models and management, engineers need to consider the required types of data, the sensitivity of a pavement performance prediction model to these data input, and importantly, how to obtain the required traffic data.

2.2.1 Pavement Design

A pavement is built for the purposes of load support, along with pavement smoothness, and drainage. It is very important that pavement design accounts for the expected lifetime traffic loads that are the main cause of pavement damage over time. For example, the force on a pavement exerted by a delivery truck is much higher than that of a car, thus the damage to the pavement. In practice, there are two ways to quantify loads: Equivalent Single Axle Loads (ESALs) and load spectra. The concept of ESALs is used to predict number of load repetitions, which equates the damage to a pavement structure from axles

of all configuration and weights to the damage of a single-standard, 80kN (18 kips), dual-tired axle. It is based on the empirical results of the AASHTO Road Test. Load spectra is defined as the actual number of load passes by axle configuration and load interval over the defined time increment [Bracher 2004]. Since it represents the actual loads on a pavement, it is desirable input for high reliable pavement design. Without proper pavement design, pavement construction and management could result in pavement malfunctions and high cost.

Pavement design requires not only layer thickness design, but also proper mixture design and drainage design. It counts many factors in the design process: mainly subgrade, environment, load, and drainage. Pavement design methods have developed from empirical design (AASHTO Design Guide) to mechanistic-empirical theory based design (MEPDG). The AASHTO Design Guide is based on empirical performance equations from the 1950's AASHTO Road Test. It has many limitations, including the lack of consideration of the climate factor on pavement performance, limited time span of only 2 years, limited traffic volume of less than 1.5 million per year, and the design method is based on 1950's materials and construction and 1950's vehicles. It can not accommodate current significant traffic changes (traffic volume and vehicle size), new pavement materials and structures. MEPDG is designed to overcome these limitations. However, currently MEPDG is not intended for routine pavement design or for commercial purposes. Table 2.5 presents a comparison of the AASHTO design guide and the MEPDG. Besides these national design guides, there are municipal and local design methods, for instance, the MTO (Ministry of Transportation Ontario) pavement design standard specification, the city of Edmonton's local design specification, and other local specifications.

2.2.2 Pavement Management

Pavements deteriorate over time. To slow the deterioration rate and improve pavement condition, pavement management consists of a series of maintenance and rehabilitation activities during the service life of a pavement. Maintenance involves different methods and technologies to prolong the service life by slowing down the deterioration rate. Maintenance strategies can be non-structural overlay, patching and coat seal. Beyond a certain point as routine maintenance is not effective for deficient pavements, rehabilitation is used

Table 2.5: AASHTO Pavement Design Guide vs. MEPDG

	1993 AASHTO Guide	**2002 MEPDG**
Traffic inputs	• ESL • Constant growth rate	• Axle load spectra • Traffic volume adjustment factors (monthly, hourly distribution, traffic growth) • Axle load distribution factors
Methodology	• Based on design serviceability loss • Empirically based procedures founded on road test data	• Predict pavement performance as a function of traffic, climate, material, and structural
Software	• Several interfaces	• MEPDG Design Guide 2002 • One interface
Advantages	• Simplified design method	• Integrated effect • More accurate performance prediction • Proven theory based • One computer program with same interface • All documentation accessible
Disadvantages	• Can not represent current pavement conditions • No address of environmental effect • Ignore the temporal variation in damage accumulation • No truck volume adjustment based on monthly/hourly truck volume distribution • Less accurate, less reliable	• Not intended for routine pavement design • Not to be used for commercial purposes

to reverse the deterioration and recover pavements by replacing pavement materials. In practice, overlay is a typical method to increase pavement structural capacities. Both maintenance and rehabilitation are to assure the best service level, such as ride comfort and public safety. Figure 2.8 [WAPA 2002] shows the intention of maintenance and rehabilitation. The light curve illustrates that without maintenance and rehabilitation, a pavement first deteriorates slowly then deteriorates at an increasing rate. While, under regular maintenance and rehabilitation, the pavement deterioration follows the dark curve, which shows better pavement conditions and longer service life.

Traffic loads account for most of pavement deteriorations such as rutting and fatigue cracking. A study of Road Administration Department of USA verified the Fourth Power Rule, stating that pavement damage caused by truck axle load is by nth power, n is between 4 and 5. As shown in Figure 2.9 [Santero et al. 2005], as the axle load exceeds a certain weight limit, a sharp increase of pavement damage emerged. Therefore, it is very important

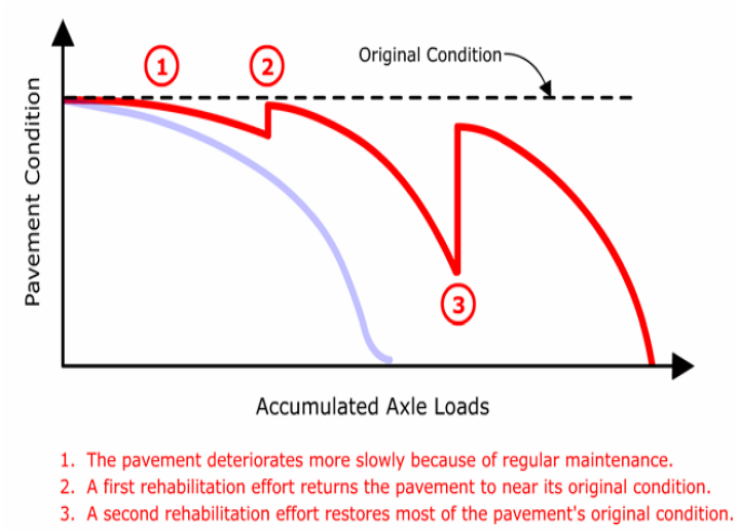


Figure 2.8: The Function of Pavement Maintenance and Rehabilitation

to effectively and efficiently collect and analyze traffic data and successfully control traffic loads for cost-effective pavement preservation.

2.2.3 Mechanistic Empirical Pavement Design Guide (MEPDG) and WIM

MEPDG, a theory-based mechanistic-empirical method, is designed by using pavement performance predicting models and the reliability concept. It has received widespread attention under the National Cooperative Highway Research Program (NCHRP) 1-37A project. The design begins with a trial design using initial estimates of layer thickness, material characteristics and many other inputs. The trial section is analyzed using pavement responses and a distress model, and the outputs are accumulated damage over time. If the trial design does not meet the performance criteria under certain reliability, the design is modified and analysis is rerun until a satisfactory result is obtained [NCHRP 2004]. The method accounts not only for the actual traffic distribution, but also for site specific climate data, material properties, and design features to predict pavement condition through performance indicators, such as roughness, cracking, and rutting. It is not merely a thickness

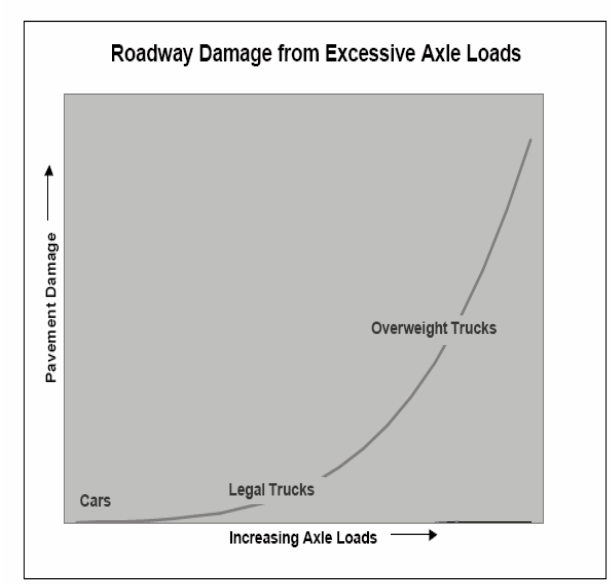


Figure 2.9: Road Damage and Excessive Axle Loads

design procedure, but also allows designers to better control pavement functional distress.

It is desirable to consider progressive deterioration over the pavement life-cycle in terms of traffic loadings [Haas 1997]. In this design guide, traffic data utilize combination of axle configurations and loading spectra as opposed to ESALs. Traffic data is categorized into three traffic input levels in a hierarchical structure, from Level 1 (site specific detailed traffic data) to Level 3 (national average poor traffic data).

To collect these traffic data, Weigh-In-Motion (WIM), Automated Vehicle Classification (AVC), and Automated Traffic Recorders (ATR) are widely adopted, especially WIM. Both permanent weight data collection and temporary short duration collection generally accommodate WIM [Schultz et al. 2005]. For instance, axle load, axle spacing, and initial two-way AADTT (Average Annual Daily Truck Traffic) are calculated from WIM measurements. In practice, the Minnesota Department of Transportation is launching a project called MnRoad, where there are 25 sites of WIM to collect various traffic data for many projects and research purposes. WIM data are significant for collecting Level 1 data, and presently WIM is the key tool to collect axle load spectrum.

Chapter 3

Data Collection and Analysis

3.1 CPATT WIM Site Description

The test site of CPATT is located at the Regional Municipality of Waterloo's Waste Management facility, 925 Erb Street West, Waterloo. The test track is two-lane and identified in Figure 3.1 [Tighe et al. 2003]. The site is close to the University of Waterloo. In addition, there are static scales of the Waste Management facility at the entrance of the test track, such that accurate vehicle weights are readily available. These make the site an ideal location for WIM research. Figure 3.2 shows a dump truck stopped to be weighed on the static scale. A piezoelectric WIM system was instrumented on the two-lane Stone Mastic Asphalt (SMA) section of the test track in September, 2003. The system mainly consists of two piezoelectric sensors and two inductive loops on each lane, and a roadside cabinet housing the WIM electronics. SMA offers a durable and smooth road surface for an ideal WIM site. The SMA section shows little cracking or rutting with an overall acceptable pavement condition. Figure 3.3 is a drawing of the layout of the piezoelectric WIM site. The northbound (Lane 1) was installed with piezoelectric sensors 1 and 2 (direct to the static scales), and southbound (Lane 2) was installed with piezoelectric sensors 3 and 4. There is a clay deposit at the end of southbound section of the test track.

There are two main types of loads at the site. During clay hauling, empty vehicles travel over piezoelectric sensors 3 and 4 to the clay deposit, and vehicles are loaded while traveling back over piezoelectric sensors 1 and 2. Most of the vehicles are 3-axle heavy

Figure 3.1: Regional Municipality of Waterloo's Waste Management Facility

Figure 3.2: Static Scales Beside CPATT Test Site

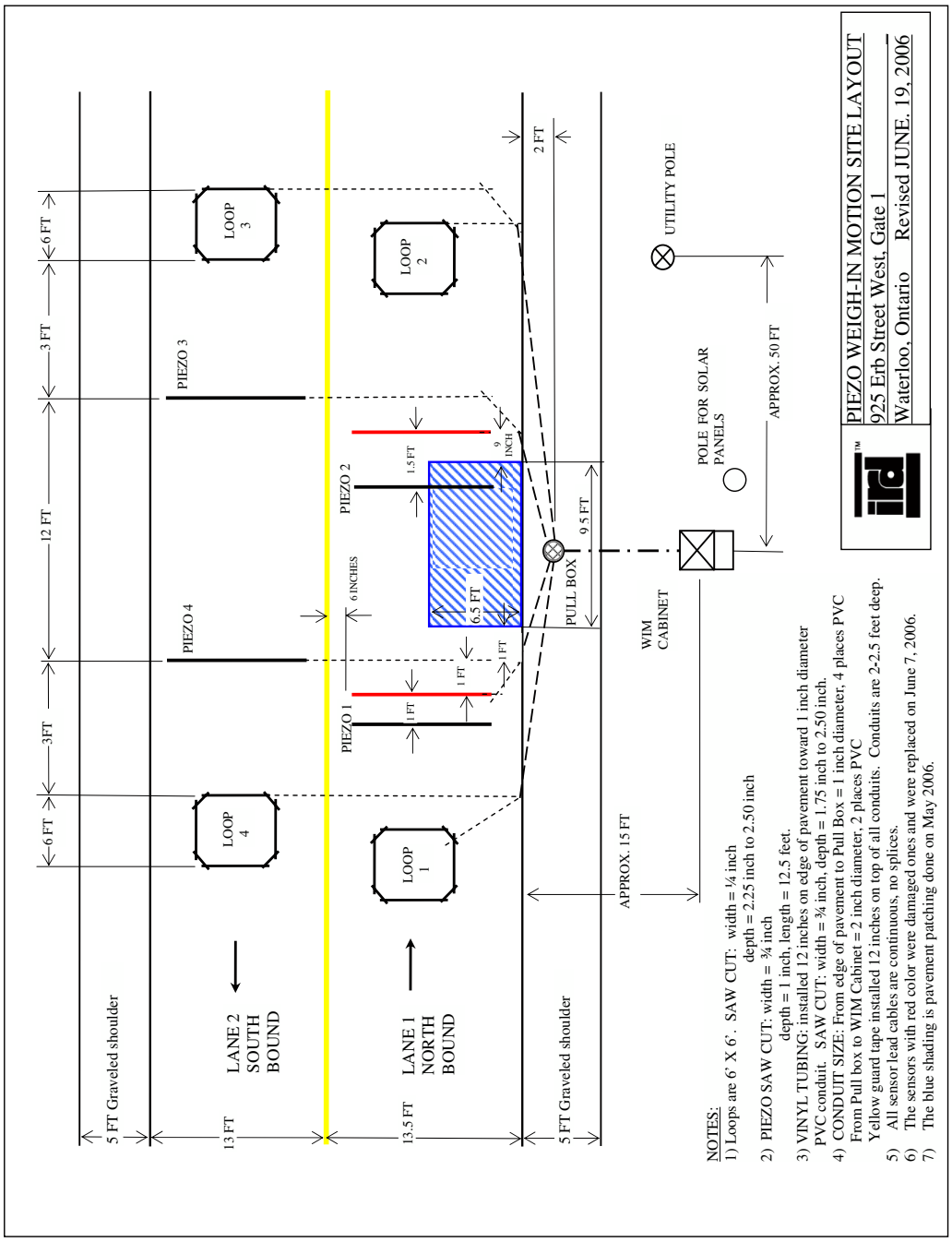


Figure 3.3: PIEZO Weigh-In-Motion Site Layout

duty trucks, weight over 30 tons. The other type of vehicle is mainly passenger vehicles with 2 axles. There are also small number of dump trucks in both directions. Starting in 2008, waste hauling vehicles will travel over the site.

3.2 Piezoelectric Sensors and Roadside Electronics

Figure 3.4 shows photoes of the WIM site with the piezoelectric sensors and the inductive loops embedded, and the roadside WIM cabinet with solar charging panels, taken immediately after the installation. The model of the sensors is BL Class I Piezoeletric, a product of Measurement Specialties, Inc. The sensor itself is comprised of a center core and outer sheath made of brass, insulated with highly compressed piezoelectric copolymer polarized ceramic. It is 3.5 m in length to cover the full lane width, and the active zone is 3.35 m. It develops consistent signal along its entire length proportional to the weights applied. To obtain accurate sensor measurements, the effort of driving on the center of the lane is desired. Following the general installation process as mentioned previously, the installation process for this specific sensor takes approximately four hours per lane, including cure time for the grout. Specifications for this type of sensors (Class I WIM) include output uniformity of ±7%, operating temperature range from -40°C to 70°C, and signal to noise ratio of 10:1. The sensors are designed to detect the presence of an axle and to measure the axle's weight [IRD 2001].

Figure 3.4: CPATT Piezoelectric Sensors and Roadside Cabinet

The cabinet houses the data acquisition and storage unit (the TCC 540 Traffic Counter) that processes and records the traffic data to date. The main part of the unit is a data logger that records WIM data. It is equipped with a microprocessor, a modem, and a battery charged by the solar panels. On site communication with TCC 540 Traffic Counter is through the built in keypad, or through a serial port to an IBM compatible computer. In addition to on site data collection, data can also be transmitted wirelessly by the modem over a phone line.

3.3 Site Rehabilitation and Sensor Replacement

A detailed field survey in the spring of 2006 found that the sensors on the southbound lane were damaged. It was also discovered that there was a longitudinal crack crossing the sensors in the pavement surface (Figure 3.5). The crack extended for a length of approximately 1.5 m, and was approximately 5 mm thick and 10 mm deep. In order to return the site to being a functional WIM site, the road had to be rehabilited before replacing the damaged sensors. A pavement hot asphalt mixture patching was conducted to recover the pavement to a stable structure and to the ASTM standards in May 2006. The damaged sensors were replaced in June 2006. Furthermore, excavations along the pavement side bank were carefully backfilled to prevent further site deterioriation.

Figure 3.5: A Longitudinal Crack Crossing the Sensors

3.4 Roughness Measurement

After the site rehabilitation, it is desired that the site condition satisfies the ASTM standards, particularly, the roughness measurement for the paved road. The common methods to measure roughness include Dipstick profiler, profilographs, and laser equipments. The principle of Dipstick is directly differentiating the measurements. To take the measurements, an operator walks the dipstick along the two wheel paths on a lane and pivots the instrument about each leg (Figure 3.6 [WSDOT 2000]). The Dipstick is limited for the purpose of calibration of other complex instruments. It is mainly used to collect a relatively small quantity of pavement profile measurements. Cold weather, wet base, and non stable pavement conditions are not ideal for the measurements. Dipstick measurements were carried out on the CPATT site. Raw data and analysis graphs were presented in Appendix A. The linearity of the results renders then suspect, and another roughness analysis will be conducted in the near future.

Figure 3.6: Dipstick 2000 and the Operation

3.5 WIM Data Acquisition Process

WIM electronics capture the digital signal outputs from sensors and then interface with the traffic counter where data are processed to a readable format by using Trafman 6.0 (software of IRD). The data acquisition process involves several steps, as shown in Figure 3.7. WIM data downloaded from the WIM electronics are converted from binary strings to ASCII files using Trafman, and further be converted to Excel files. The Excel files contain data of lane codes, recording time, vehicle speeds, axle numbers, vehicle lengths, axle spacings, GVWs, and axle weights. The data still need to be filtered out nuisance and be manipulated before any data analysis can be carried out. To view waveforms as vehicles pass, an oscilloscope is required to hook up to the sensors.

3.6 Data Collection and Analysis

Data were downloaded from the data logger on site. The data population covers from September 2006 (immediately after a recalibration) to January 2007. Static scale data measured by the Waste Management facility are treated as the reference values of weights and are compared with WIM data in order to evaluate accuracy. Appendix B presents an example of raw data collected by the piezoeletric sensor system.

Since most vehicles crossing the WIM site are two axles currently, the sampling is among vehicles with two axles. Since not all the vehicles recorded by the static scale travel to the WIM site, the sampling process among these two databases (WIM database vs. Static database) is to first match the presenting time of vehicles recorded, and then the axle numbers. Weekdays are randomly selected from the survey period. 55 samples are selected for each lane to represent the population. Appendix C shows an example of the extracting and matching between the two database for GVWs, which are collected from the northbound lane on November 2, 2006. These matched vehicles had the same axle number, and the present time of a vehicle differs within three minutes from the static scales to the WIM site, which is estimated based on the distance between the two locations. The data indicate that most the installed WIM measurements are consistently less than the reference values, as illustrated in Figure 3.8. Table 3.1 shows the statistical comparison between the

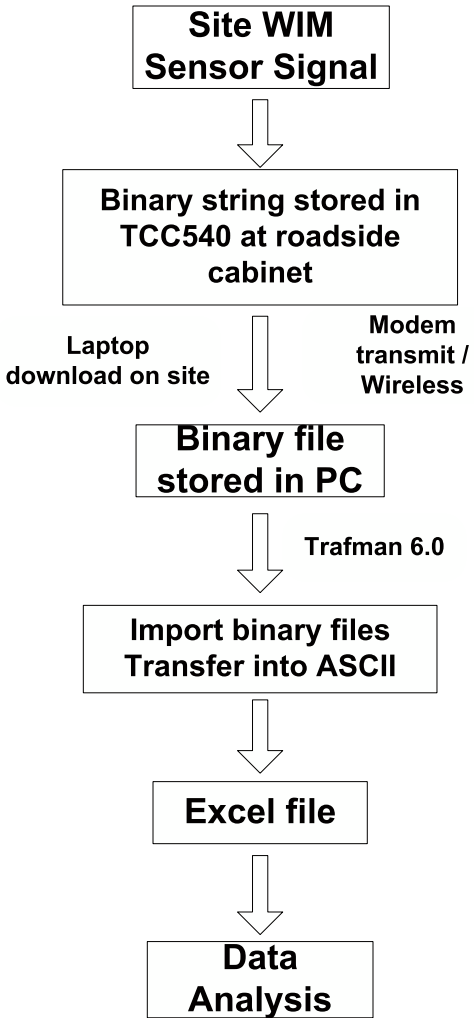


Figure 3.7: WIM Data Acquisition Process at CPATT WIM Site

weights recorded by the static scales and the WIM scales. The relative error on average for Lane 1 is −23.5%, for Lane 2 is −26.7%. It is out of the specified accuracy for the WIM of ±15%. Considering the additional uncertainty introduced by the data matching process between the two databases, these results are essentially inconclusive. Additional sources of error are described below.

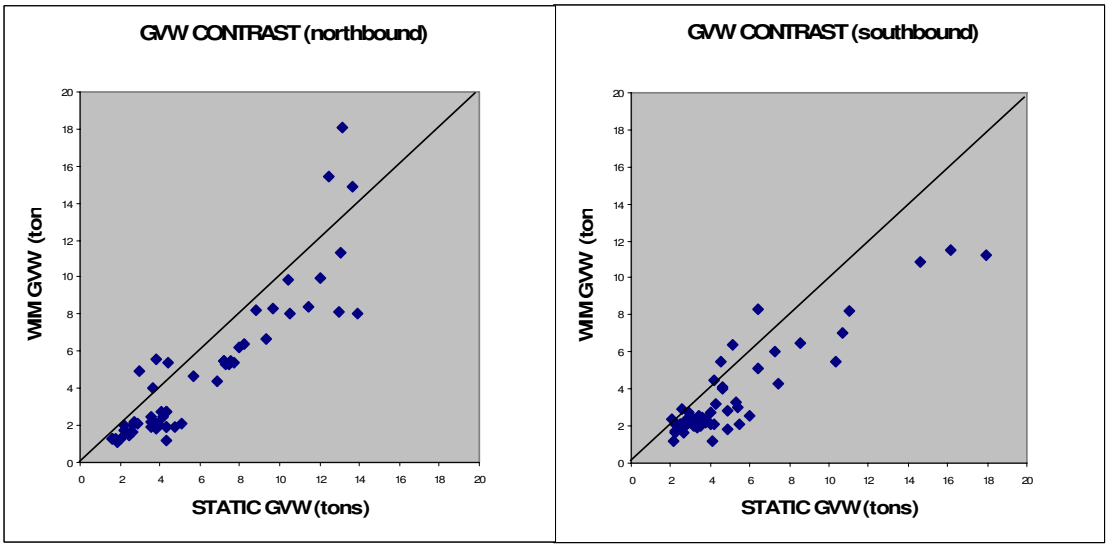


Figure 3.8: Static Scale vs. WIM GVWs

The out of performance could due to the following reasons. Firstly, since sampling was conducted over five months that the weather changed from warm to cold, the temperature impact is unavoidable and significant. Secondly, during the study period, the traffic condition changed such that the initial calibration is set up for a large number of FHWA (Federal Highway Administration) Class 9 vehicles, while the vehicle classes on the site changed since then. It could lead to the initial calibration being inadequate for the experienced traffic condition. Thirdly, there could be subjective error during the sampling to have a comparative data set. Fourthly, imprecision of the static scale could cause the measurement error of the reference values. Based on current condition of the WIM site and the data result, following strategies are suggested to improve the performance:

1. Recalibrate and test

Table 3.1: Gross Vehicle Weights Analysis Result for CPATT WIM

	Lane 1 (North Bound)				**Lane 2 (South Bound)**			
Descriptive Statistics	*WIM* (a)	*Static Scale* (b)	*Difference* $(a-b)$	*Relative Error* $[(a-b)/b]$	*WIM* (a)	*Static Scale* (b)	*Difference* $(a-b)$	*Relative Error* $[(a-b)/b]$
Mean	4.785455	5.9933	−1.207818	−0.235125	3.56	4.979091	−1.419091	−0.266566
Standard Error	0.520712	0.498369	0.2313449	0.035082	0.340069	0.466972	0.2090716	0.02902
Median	2.7	4.33	−1.41	−0.274406	2.4	3.76	−1.14	−0.276018
Mode	2.1	1.65	−0.35	−0.212121	2.1	2.21	−1.52	#N/A
Standard Deviation	3.861703	3.696005	1.7156995	0.260172	2.522022	3.463154	1.5505164	0.215217
Sample Variance	14.91275	13.66046	2.9436248	0.067689	6.360593	11.99343	2.404101	0.046318
Kurtosis	2.486566	−0.613751	3.3251752	2.588794	2.872231	4.994522	1.874662	0.683656
Skewness	1.561824	0.787889	0.7916743	1.322069	1.85166	2.228144	−0.942991	0.713501
Range	17	12.22	10.83	1.385788	10.3	15.92	8.61	1.001573
Minimum	1.1	1.65	−5.87	−0.724771	1.2	2.01	−6.73	−0.708738
Maximum	18.1	13.87	4.96	0.661017	11.5	17.93	1.88	0.292835
Sum	263.2	329.63	−66.43	−12.93186	195.8	273.85	−78.05	−14.66111
Count	55	55	55	55	55	55	55	55
Confidence Level (95%)	1.043964	0.99917	0.4638185	0.070334	0.681798	0.936222	0.4191633	0.058181

Random traffic sample from September 2006 to January 2007

2. Update hardware (data logger) and software (data retrieving system) if budget allows
3. Streamline the data acquisition process (for example, change to wireless communication) to reduce human error and to be efficient
4. Invest in a digital field oscilloscope and view raw data/waveforms to avoid the "black box" of the data logger
5. Install passing lane cameras at the WIM site to capture images and other information of passing vehicles
6. Quantify pavement temperature impact on readings
7. Install a new WIM system, which promises higher accuracy and better stability, such as a quartz piezoelectric sensor system

3.7 Lessons Learned

From the field experience of the CPATT piezoelectric sensor system, there are several lessons learned regarding installation, calibration, and testing of a (piezoelectric) WIM

system to assure accuracy.

3.7.1 Installation

An installation site should be carefully chosen. First, in general, the sites with slow-moving traffic and low traffic volume should be avoided, and the pavement conditions around the sensors should conform to certain standards. For example, roughness shall meet the requirements of LTPP long range and short range roughness index. Second, the width of each installation lane should be wide enough to accommodate the width of wheel of a particular site vehicle. Third, the installation process should strictly follow the installation procedure provided by the product vendors or manufacturers. Finally, before opening the lane to the public after installation, any grout material used to fill slots that is above the pavement surface should be ground down, since it could cause uneven pressure distribution on the sensors and result in measurement errors.

3.7.2 Calibration

Appropriate calibration is critical to achieve required performance of a WIM system. To obtain the best result for a given class of vehicle on a site, it is best to calibrate with either that type of vehicle or one closely representative. For instance, it was ideal to use a dump truck to carry out the calibration at the CPATT test track. For the best calibration, it is also very important that the vehicle for calibration is well maintained (suspension system and tire pressure); the driver must keep a consistent speed while passing over the sensors (minimum 50 km/hour in the case of piezoelectric sensors); and the vehicle path to be taken is lane centered as close as possible. When calibrating in Trafman, it is advised to enable the "Dual" mode to monitor individual sensor readings. Rather than giving an averaged axle weight, this mode breaks down the result to display the data measured by each sensor. Since each sensor has it own calibration factor, it is very important to view each data specific to each sensor and calibrate the sensors separately instead of calibrating the lane as a whole. In addition, since WIM sensors are sensitive to temperature that could result in false axle readings and inconsistent weights, it is imperative to calibrate within a set period time of a day and record pavement temperatures during that time. Appendix

D is the raw data of the first calibration conducted on August 22, 2006. It shows a large variation and unpredictable patten of GVWs, due to varied factors including temperature.

ASTM E1308-02 recommended a WIM calibration process in six steps. First, adjust all WIM system settings to the vendor's recommendations or to the best estimation of the proper setting based on previous experience. Second, have test vehicles for calibration weighed at static scales at the site or a nearby facility to obtain static weight data. Third, run test vehicles (ideally two vehicles) several times with two speeds as passing over the sensors. The two speeds should differ by at least 30 km/h and are above and below the average speed of vehicles operating at the site. Use a calibrated radar speed meter to measure the speed of each test vehicle every time as it passes over the WIM sensors. Fourth, calculate the difference percentage between the WIM system estimates and the reference values for the speed, axle spacing, axle load and GVWs measurements; calculate the mean value for the difference for each set of value. Fifth, obtain the new calibration factor and enter into the WIM system. Adjust WIM settings such that the mean values of the respective difference for each value equal zero approximately. Sixth, determine weather or not the calibrated system can perform at the necessary tolerances as expected. Otherwise, if a large number of differences in the data occurs and does not meet the tolerances level required by ASTM for the specified system, then the system will most likely not perform to a beneficial level [Katz and Rakha 2002].

3.7.3 Future Investigation Strategies

To fully study the accuracy, stability, durability, and other technical characteristics of different WIM sensor systems, it would be a valuable investment if different types of WIM sensor systems, such as piezoelectric, quartz piezoelectric, bending plate, and load-cell based, are instrumented parallel on a test track. With this site layout, it would provide enormous advantages to collect large WIM database, compare diverse features among these sensing systems, and make much information available for various research purposes. Currently, there is no vehicle classification information available. It would be ideal to configure Automatic Vehicle Classification (AVC) systems or other available technologies to obtain information of vehicle classes.

Chapter 4

Economic Model

The use of WIM is to help capture weight violating vehicles, decrease travel time for commercial carriers, reduce congestion, reduce traffic crash risk, exchange traffic information, and eventually help achieve the goal of preserving highway infrastructure at a network level. The purpose of an economic analysis is to determine whether the investment of an ITS component or subsystem is economically beneficial in order to achieve the goal, and to rate the return on the investment compared to that of alternatives (WIM system vs. static weigh station). It focuses on quantifying the specific monetary values of all impacts on regional and national economies, the users, the agencies, and also the environment. An economic analysis attempts to reduce everything to a single benefit-cost ratio [Zavergiu et al. 1996, Novak and McDonald 1998, Lee and Klein 1997, Lee 1999]. However, a comprehensive economic analysis could be very complicated because of several issues: lack of information for a new technology; lack of data and proper assumptions; no adequate evaluation approaches or methods; double counting and improper valuation of benefits; complex interaction and uncertainty. However, if an economic analysis is used to compare alternatives rather than to develop absolute values of benefits or costs, many of the difficult assumptions tend to cancel out and the analysis can provide useful results [Peng et al. 2000].

The purposes of developing an economic model for WIM values are to

- Quantify the benefits and costs of WIM technology ;

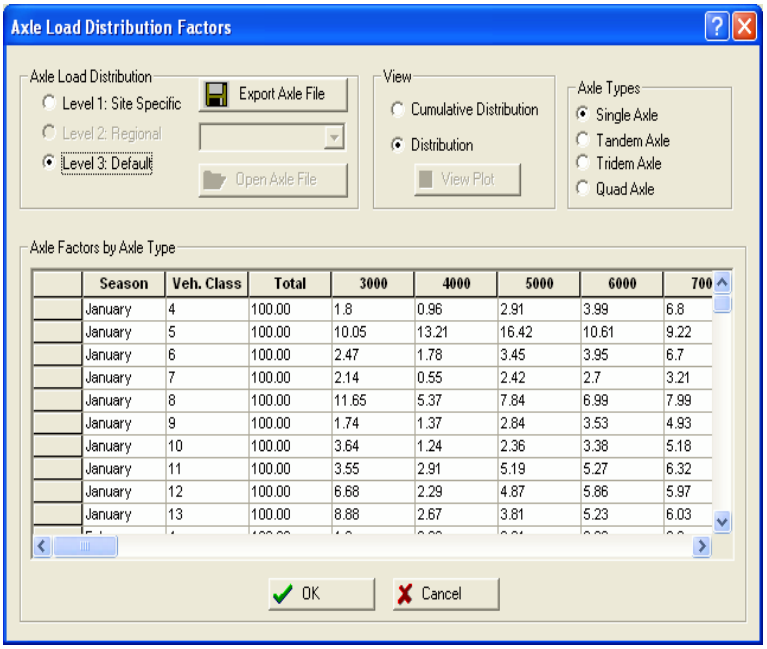
- Understand the impacts of WIM on the economy, society, and the environment;
- Optimize the deployment of a WIM system.

Firstly, this chapter assesses and compares the economic impacts of loads on pavement management, under four scenarios of excess axle loads that obey or violate FHWA legal weight regulations. The scenarios are based on typical real life situations. MEPDG is applied for the study and significant results are presented. Secondly, it discusses the various benefits and costs of WIM systems. In addition, it describes a few of current economic analysis tools for ITS applications. Finally, economic models for WIM values with scenarios are developed with respect to the benefits and costs by using one of the tools. Variables that alter the magnitudes of the benefits and costs are carefully chosen. An sensitivity analysis and an break-even analysis are performed.

4.1 Economic Impact of Excess Axle Load on Pavement Management

According to a study by the International Road Dynamics Inc. [Kishore and Klashinski 2000], 10 percent increase in weight can accelerate pavement damage by over 40 percent. Therefore, if there are excess loads on a pavement, the economic consequence is an immense concern, as well as the service life and the expected level of service of the pavement. Fortunately, WIM data can provide specific and detailed axle load spectra, which can be used to evaluate current loads, predict future loads, and predict pavement performance.

Traffic load, climate, structure, and material are the four primary inputs for the new MEPDG. Axle Load Distribution is one of the key traffic input parameters. Monthly site specific axle loads are divided into different axle load ranges according to vehicle classes. This data can be calculated from WIM data. Figure 4.1 shows the default axle load spectrum interface in the MEPDG. The axle loads are divided into different ranges for each vehicle class in each month. Each axle factor is the percentage of total axle loads that falls in one of the load ranges, and the total percentage is 100 in one month. For example, in January, for vehicles in Class 4, 1.8% of axle loads falls in the range of less than $3,000$ lbs (1,360 kg), 0.96% fall in the range of 3,000-4,000 lbs (1,360-1,814 kg), etc.



	Season	Veh. Class	Total	3000	4000	5000	6000	700
	January	4	100.00	1.8	0.96	2.91	3.99	6.8
	January	5	100.00	10.05	13.21	16.42	10.61	9.22
	January	6	100.00	2.47	1.78	3.45	3.95	6.7
	January	7	100.00	2.14	0.55	2.42	2.7	3.21
	January	8	100.00	11.65	5.37	7.84	6.99	7.99
	January	9	100.00	1.74	1.37	2.84	3.53	4.93
	January	10	100.00	3.64	1.24	2.36	3.38	5.18
	January	11	100.00	3.55	2.91	5.19	5.27	6.32
	January	12	100.00	6.68	2.29	4.87	5.86	5.97
	January	13	100.00	8.88	2.67	3.81	5.23	6.03

Figure 4.1: Default Axle Load Distribution Inputs for MEPDG

The axle load distribution is modeled to follow a Log Normal distribution [Prozzi and Hong 2007], as shown in Figure 4.2.

For the purpose of assessing load-pavement impact, a new Hot Mix Asphalt (HMA) pavement project was designed using the MEPDG Version 0.900 [MEPDG 2006]. A benchmark pavement design is run with the following assumptions:

1. Design life is chosen to be 20 years for observing predicted performance variation in an ample period;

2. Traffic Growth Factor is chosen to be a compound growth of 4% (growth rate) per year. This will generate traffic load conditions representing the future of the HMA pavement;

3. Climate data is taken from Toronto International Airport, Environment Canada, from year 1990 to year 2006;

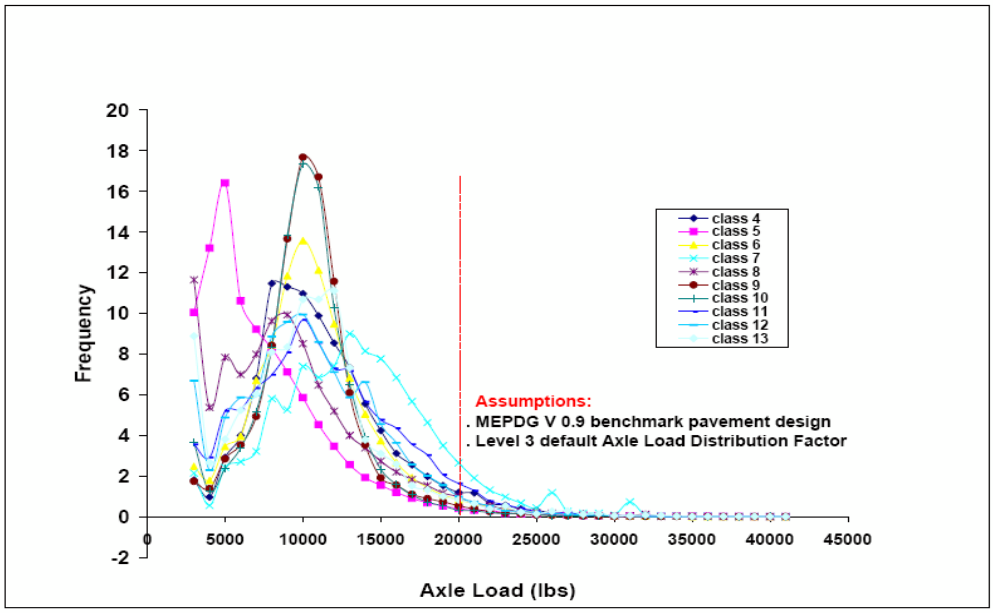


Figure 4.2: A Representative of Single Axle Load Spectrum by Vehicle Class

4. Pavement layer thickness design is based on calculated Structure Number (SN) close to the required Structure Number by using AASHTO design estimation, as shown in Figure 4.3. The 18-kip ESAL are calculated from the original traffic data of the project.

The design ESALs of 30,000,000 requires the SN to be 3.5, and the calculated SN is 3.7 based on the specified layer thickness [MFPDS 2001]. The design SN is close to and less than the required SN. Thus, the specified layer thickness design is not very conservative and the performance prediction will be apparent. According to [AASHTO 1993], the SN of a flexible pavement is generally in the range of 1 to 6. Based on the data calculated in this study, the SNs are in the range for a pavement with medium axle load traffic.

FHWA regulated that truck weight limits are 80,000 lbs (36,287 kg) for GVW, 20,000 lbs (9,071 kg) for Single Axle, and 34,000 lbs (15,422 kg) for Tandem Axle. To examine the load-pavement impact, axle load distribution is designed to four scenarios and FHWA's 20,000 lbs limitation of single axle load is used. Based on the default single axle load, the

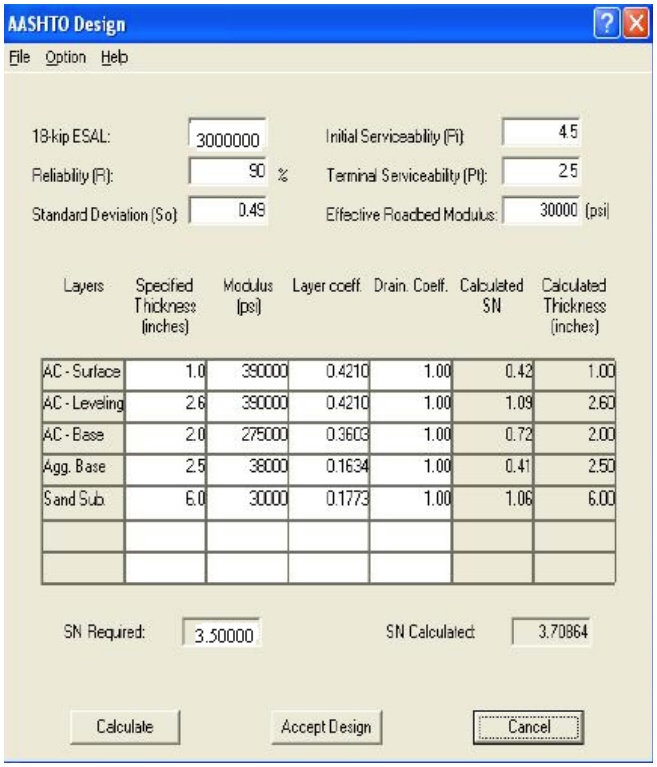


Figure 4.3: Designed Layer Thickness with Comparable Structure Numbers

weighted average method is applied to distribute axle loads in load ranges of greater than 20,000 lbs, such that the sum of percentage of normal load ($\leq 20,000$ lbs) and excess load ($> 20,000$ lbs) is 100. For example, in the scenario of up to 10% overload, each row of data in Figure 4.1 is adjusted, such that the sum of axle load factors within the range of 20,000 lbs is 90%, the sum of factors greater than 20,000 lbs is 10%. Table 4.1 describes different scenarios (four pavements with the same characteristics except different axle load distribution) examined in the study. According to [TRB 1990], these ranges of overload percentage are typical.

The MEPDG was run for each scenario to predict pavement performance in terms of rutting, International Roughness Index (IRI), and other distress indices. There are four runs corresponding to the four scenarios. Each run has the same inputs except that the

Table 4.1: Four Scenarios of Overload-Pavement Impact Study

Scenario	**Load Distribution**	**Explanation**
I	Overload is 0% (Without overload)	Initially, all axle load factors set to within 20,000 lbs (9071 kg), sum up to 100.
II	Overload is up to 10% (10/90 set)	Initially, axle load factors set to 90% within 20,000lbs (9071 kg), 10% is greater than 20,000 lbs (9071 kg).
III	Overload is up to 20% (20/80 set)	Initially, axle load factors set to 80% within 20,000lbs (9071 kg), 20% is greater than 20,000 lbs (9071 kg).
IV	Overload is up to 30% (30/70 set)	Initially, axle load factors set to 70% within 20,000lbs (9071 kg), 30% is greater than 20,000 lbs (9071 kg).

axle load distribution is adjusted to 0% (without overload), 10%, 20%, and 30% overload, to compare overload-pavement performance impact and economic impact. From this study, the role of WIM will be assessed.

Figure 4.4 shows that the total rutting increases over the pavement life and follows a logarithmic function. Scenario I (without overload) has the lowest rutting deterioration all the time. Comparatively, Scenario IV (up to 30% overload) exhibits the worst rutting: rutting depth is 152% of that of Scenario I, correspondingly, Scenario III is 143%, and Scenario II is 130%.

Figure 4.5 illustrates the IRI difference among the scenarios, which follows an exponential trend over time. Scenario I shows the best condition of IRI, while Scenario IV shows the worst. The differences of IRI among the four scenarios are becoming larger over time. The deterioration rates of overloading rapidly increase that result in early rehabilitation and reconstruction. In order to mitigate the fast deterioration rates, it would be advised to decrease the axle loads. For example, if the excess axle load distribution is reduced from 30% to 10% at year 7.5, even with compound 4% traffic volume growth rate in the following years, the IRI performance will be improved as noted by the dash line to the solid line (Figure 4.5). From pavement management perspective, controlling overloads is essential to protect highways from aggravated damages and thus eliminate costs.

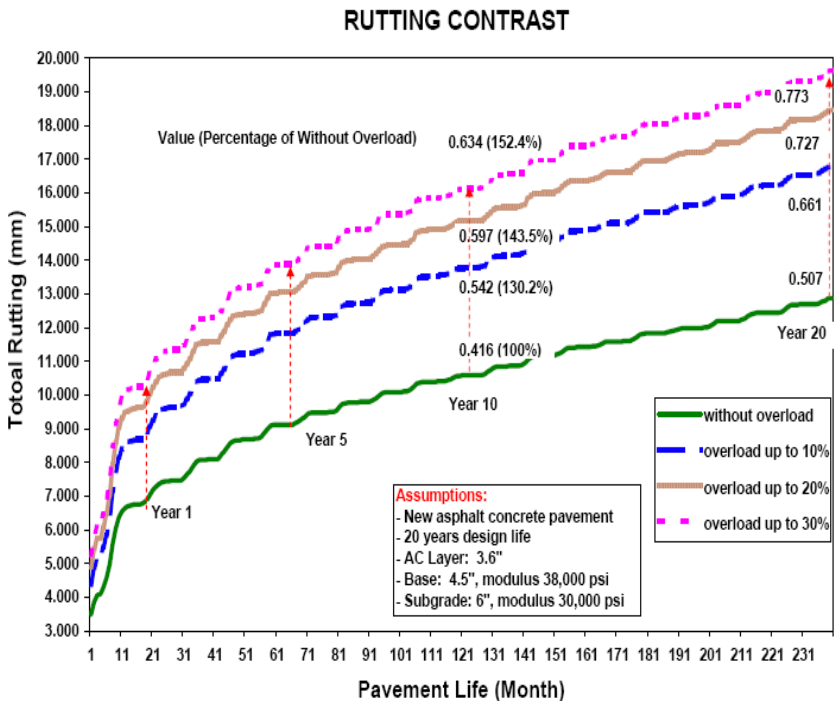


Figure 4.4: Predicted Accumulated Rutting Over 20 Years

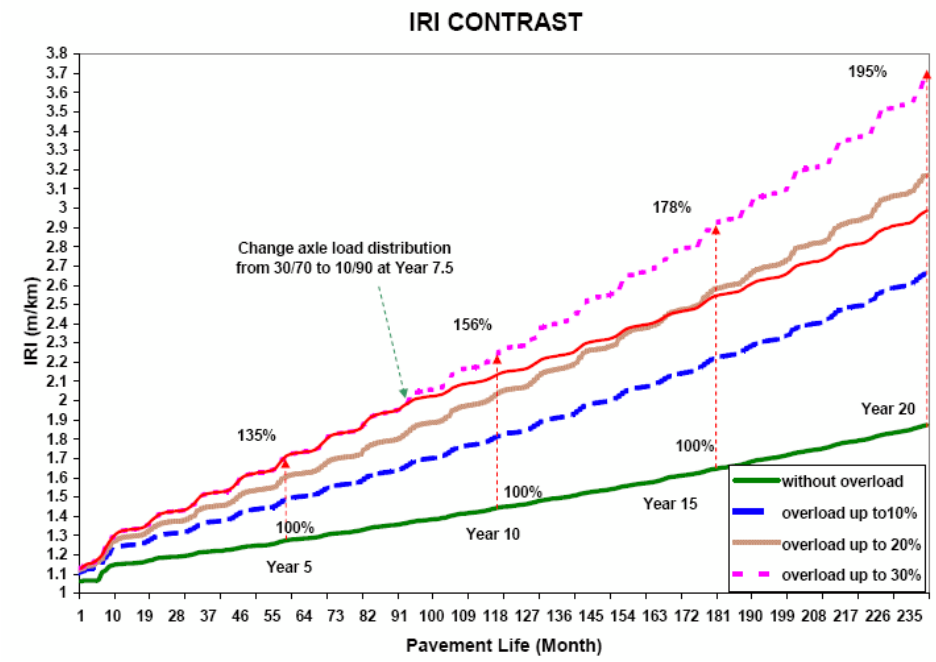


Figure 4.5: Predicted Accumulated IRI Over 20 Years

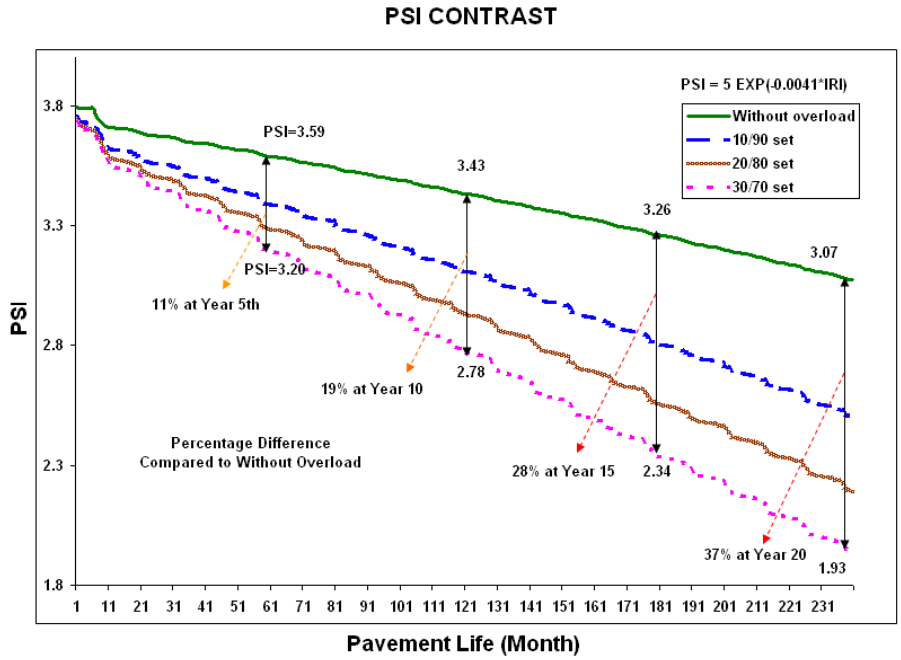


Figure 4.6: Predicted Pavement Serviceability Index Over 20 Years

To compare the overall performance of the pavement under these four scenarios, Pavement Serviceability Index ($\text{PSI} = 5 \times \exp(-0.0041 \times \text{IRI})$) is calculated and compared, as presented in Figure 4.6. It can be seen that PSI of each scenario decreases over time. The decreasing rates of PSI increase as overload percentage increases. As a pavement condition reaches the terminal serviceability over the pavement life, rehabilitation is required to renew the surface (as illustrated in Figure 4.7). From a network life cycle cost perspective, the following assumptions were made:

- PSI of 3.0 results in rehabilitation,
- Following rehabilitation, the pavement PSI is restored to 97% of the initial / new condition.

Figure 4.8 can be used to estimate the time for rehabilitations as indicated by terminal serviceability and the pavement performance indicators after rehabilitations, thus the next

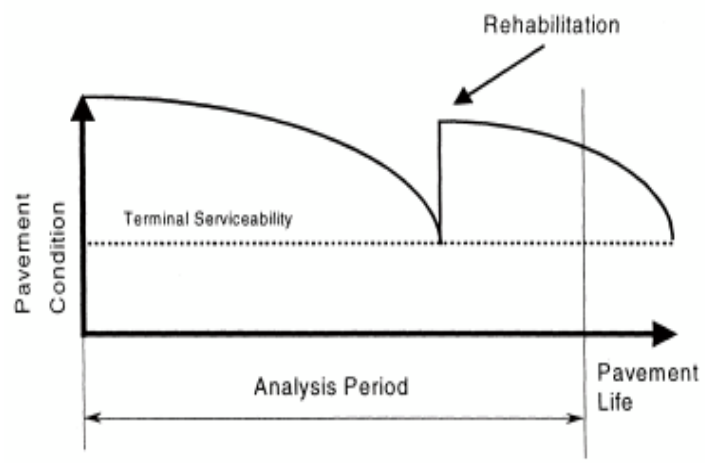


Figure 4.7: Pavement Rehabilitation Model

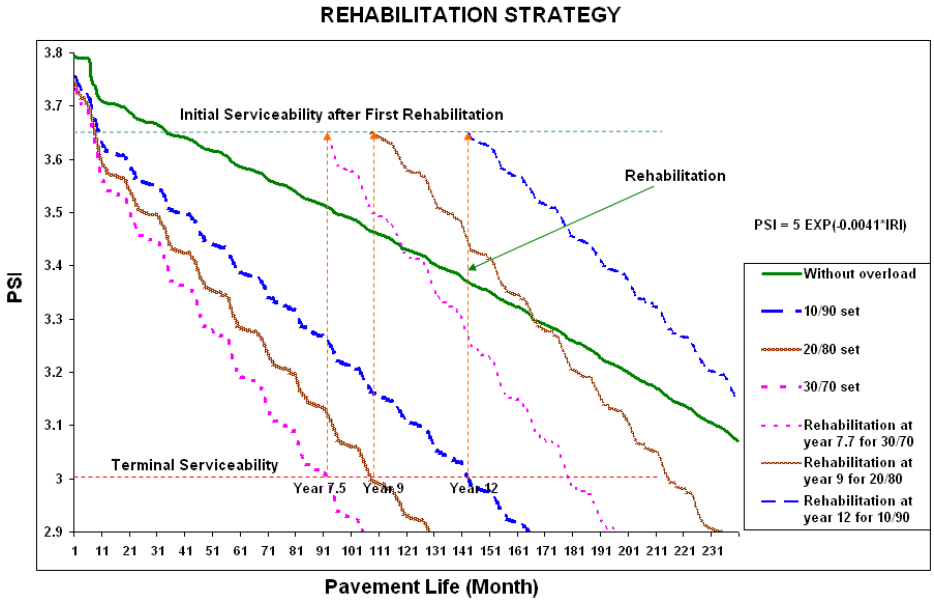


Figure 4.8: Predicted Pavement Rehabilitation Strategy Over 20 Years

rehabilitation year. Figure 4.8 shows that the pavement exposed to 30% overload experiences rehabilitation first, which happens at year 7.5 as the PSI reaches 3.0. Rehabilitation is required at year 9 for the pavement subjected to 20% overload. For the pavement subjected to an excess load of 10%, it happens at year 12. Similarly, the next rehabilitation is estimated at year 15 for the 30% overload, and at year 18 for the 20% overload. After the first rehabilitation, no rehabilitation is required for 10% overload during the pavement life. Comparison of PSI and the resulting rehabilitation years demonstrates that the lower the excess loads, the better pavement performance and the longer service life. The rehabilitation frequencies diverge drastically among the four scenarios. This study demonstrates the importance of weight enforcement of commercial vehicles and WIM systems for effective and efficient site specific traffic load collection.

To evaluate the rehabilitation cost of the four pavements, rutting depth is used as the performance indicator to estimate the cost, which is not for accurate calculations but for comparison purposes.

$$Cr = Cp \times As \times Hr \tag{4.1}$$

where,

Cr = Rehabilitation cost (\$)
As = Section area (m^2)
Hr = Rutting depth (m)
Cp = Unit cost for repaving to recover rutting per m^3 (including lane closure cost)(\$/m^3)

The section area (As) is assumed to be 10,000m^2, unit cost (Cp) of \$100 per m^3, and discount rate of 5%. The selected analysis period is 20 years. The initial section construction cost is \$100,000. Service life is defined as the time period from construction to the first rehabilitation. Table 4.2 summarizes the comparison among these four scenarios, with respect to rutting, IRI, PSI, rehabilitation year, present worth of cost, and service life. There are more than six percent of the cost might be saved per kilometer of a typical road by controlling overloads through WIM. More specific comparisons are listed with respect

to:

Table 4.2: Present Worth Analysis for Alternative Axle Overloads Per Kilometre of a Typical Two-lane Roadway

Year	**Without Overload Rehabi.**	**10% Overload Rehabi.**	**20% Overload Rehabi.**	**30% Overload Rehabi.**
0	$100,000	$100,000	$100,000	$100,000
7.5				$9,754
9			$9,982	
12		$10,160		
15				$12,776
18			$12,929	
20	$9,398			
Net Present Worth Cost ($)	$103,537	$109,272	$112,927	$116,235
Relative Difference in Cost	0%	6%	9%	12%
First Rehabi. Year	≥ 20	12	9	7.5
Second Rehabi. Year			18	15
Service Life (years)	20	12	9	7.5

1. Rutting: at year 20, total rutting of 30/70, 20/80, 10/90 scenarios is respectively 150%, 140%, and 130% of that without overload

2. IRI: at year 20, IRI of 30/70, 20/80, 10/90 scenarios is respectively 195%, 170%, and 140% of that without overload

3. PSI: at year 20, the relative difference of 30/70, 20/80, 10/90 scenarios is respectively 37%, 29%, and 19% of that without overload

4. First rehabilitation time: 30/70, 20/80, 10/90 scenarios is respectively 12, 11, and 7.5 years earlier than that without overload

5. Present worth cost: for 20 years, 30/70, 20/80, 10/90 scenarios is respectively 12%, 9%, and 6% higher than that of without overload, as counting the relative difference

6. The service life is respectively to be 7.5, 9, 12, and 20 years from 30/70 scenario to without overload

In the Table 4.2, the Net Present Worth Costs are calculated as follows:

$$
\begin{aligned}
NPWC_{\text{Without}} &= \$100,000 + \$9,398 \times (A/F, 5\%, 20) \times (P/A, 5\%, 20) \\
NPWC_{10\%} &= \$100,000 + \$10,160 \times (P/F, 5\%, 12) \\
&\quad +\$16,000 \times (A/F, 5\%, 12) \times (P/A, 5\%, 8) \times (P/F, 5\%, 12) \\
NPWC_{20\%} &= \$100,000 + \$9,982 \times (P/F, 5\%, 9) \\
&\quad +\$12,929 \times (P/F, 5\%, 18) \\
&\quad +\$16,000 \times (A/F, 5\%, 9) \times (P/A, 5\%, 2) \times (P/F, 5\%, 18) \\
NPWC_{30\%} &= \$100,000 + \$9,754 \times (P/F, 5\%, 8) \\
&\quad +\$12,776 \times (P/F, 5\%, 15) \\
&\quad +\$16,000 \times (A/F, 5\%, 8) \times (P/A, 5\%, 5) \times (P/F, 5\%, 15)
\end{aligned}
$$

where

$$
\begin{aligned}
NPWC &= \text{Net present worth cost} \\
(A/F, i, n) &= \text{The annual value, given the future value at the} \\
&\quad \text{discount rate (i) and number of years (n)} \\
(P/A, i, n) &= \text{The present value, given the annual value at the} \\
&\quad \text{discount rate (i) and number of years (n)} \\
(P/F, i, n) &= \text{The present value, given the future value at the} \\
&\quad \text{discount rate (i) and number of years (n)} \\
i &= \text{Discount rate} \\
n &= \text{Number of years}
\end{aligned}
$$

According to Figure 4.4 and Figure 4.8, it is estimated that $16,000 of rehabilitation cost would occur at year of 24, 27, and 23 for the Scenario 10% Overload to 30% Overload accordingly. This rehabilitation cost is used to approximately estimate the present worth costs occured between the last rehabilitation years and the year 20th for each scenario.

In summary, to illustrate the overload-pavement impact, four scenarios are modeled with different overload percentages from 0% excess axle load to 30% excess axle load. The MEPDG analysis was carried out for a typical new HMA road section. Significant reductions in pavement performance due to overloads were assessed. The analysis results emphasized the need to measure and properly control overloads and the potential value of a WIM system deployment. Although this is a simple case, it does demonstrate the need to control overloads. It is important to have WIM not only efficiently and effectively monitor traffic load and volume, but also be used for weight enforcement in a cost-effective way.

4.2 Benefits and Costs of WIM Values

Current weigh station technology and resources can not accommodate the dramatic increases of traffic volume on highway systems. WIM has a high processing rate to improve

the operational efficiency of weigh stations and reduce congestion. A typical WIM system can process over 15,000 trucks a day and collect at least 30 days of continuous raw data for a four lane installation [CTRE 1997]. WIM provides critical traffic inputs for pavement design, management, maintenance and new construction. On the other hand, a WIM system is comprised of not only expensive and delicate sensors and other supporting instruments, but also expensive operating software. In brief, the WIM costs include initial equipment cost, installation cost, maintenance cost and other hardware and software costs.

4.2.1 WIM Benefits

The benefits of a WIM system implementation include the followings:

1. Provide a traffic database and clarify the needs of a provincial or state's weight enforcement program,
2. Provide traffic data for research programs, such as the LTPP program,
3. Increase efficiency of prescreening overweight/illegal trucks and thus less travel time and less delay cost,
4. Improve data for Pavement Management System,
5. Improve safety by efficiently reducing overweight trucks on highways.

Figure 4.9 shows the benefits of WIM for the various key stakeholders. The following is a brief discussion of various benefits of WIM with respect to weight enforcement, delay reduction, and safety.

Commercial Vehicle Weight Enforcement

Commercial trucks are a major source of road damage. In Canada, cold weather conditions aggravate the damage. For example, the weight of a five-axle truck is about the same as 20 cars' weight, but the caused road damage of 9600 cars is the same as that of the single truck [Kansas 2004]. The purpose of weight enforcement is to effectively keep overweight commercial trucks off the highway system and thus to protect the highway from premature

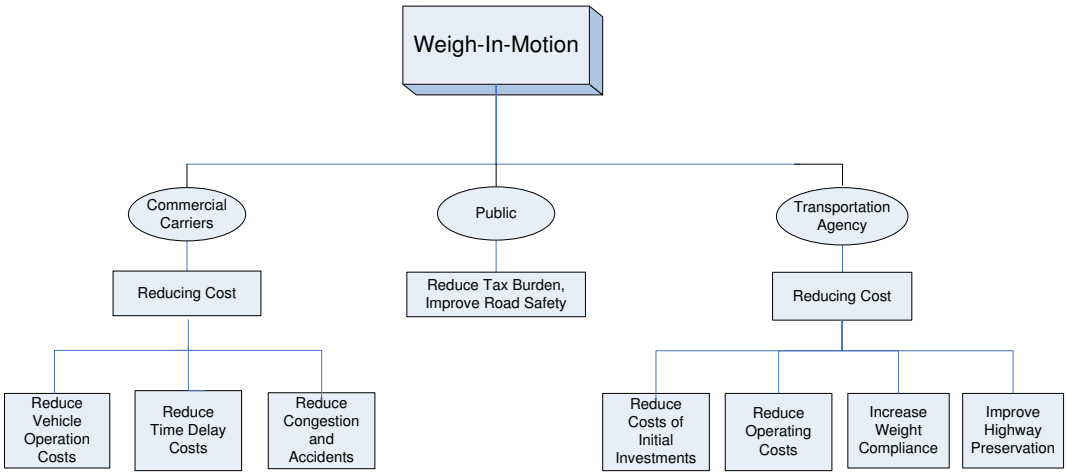


Figure 4.9: A Benefit Tree of WIM on Stakeholders

deterioration. During peak travel time, weigh stations are often closed temporarily until the waiting queues at stations diminish, in order to avoid traffic backups onto the highways. Traffic backup can cause unsafe road conditions. Under this circumstance, many overweight trucks are allowed to bypass stations without being weighed and inspected, resulting in a large cost. It is no surprise that the recorded number of overweight trucks increases dramatically just after WIM systems are used on a highway main lane. Without efficient detection and further strict enforcement, such as penalties to deter violation, weight limit laws are meaningless in a state or province. Enforcement intensity is a function of GVW [Edward et al. 1995], which can be reliably estimated from WIM data. In addition, the processing rate of WIM is quicker.

Depends on WIM data from 1984 to 1986, FHWA estimated that about 25 percent of all combinations were overweight, and 10 to 20 percent of which were operating illegally [TRB 1990]. Given traffic volume of over 5 millions trucks, it means that over 1.25 million trucks would be overweight. In 1985, a study of FHWA identified that illegal overloaded trucks cost taxpayers $160 - $670 million per year for pavement costs at the national level [TRB 1990]. In terms of pavement costs resulting from pavement loading, the saving resulting from tight enforcement is very attractive [Edward et al. 1995].

Delay Reduction

WIM automatically take measurements as vehicles pass over the sensors, without interrupting the traffic flow. Only targeted potential violators are required for further inspections at static weigh stations. Therefore, it entirely removes unnecessary delay incurred by a static weigh station. Assuming five millions trucks on a highway system and average three minutes delay time at a weigh station, then, weighing each truck once would require 15 million minutes, or 28 years. In addition, for an average of eight hours per day of travel, each truck could be easily involved in at least 3 stops at weigh stations. For instance, in Tennessee, about 500,000 trucks are checked four times each day on the state's highways. The cost to the consumers is estimated to be over $15 million daily due to these mandated truck stops [ORNL 2000]. WIM is an economical strategy to minimize unnecessary delays for commercial carriers and can also fulfill enforcement objectives. In addition, as delay is reduced, traffic congestion, gas emission and fuel consumption are also reduced.

Safety Benefit

Commercial vehicle safety has been an important focus of commercial vehicle enforcement agencies for some time[Davis 2003]. Truck handling and stability is affected by a truck's weight and configuration. Overload could cause the main part of a vehicle to be damaged and malfunctioning. Furthermore, an overweight truck can be susceptible to roll overs and is slow to accelerate or decelerate. Therefore, overweight trucks are more likely to be involved in traffic accidents that tend to be fatal. WIM systems have high processing rate, thus more trucks can be weighed over the same period of time, and more illegal overweight trucks would be identified and pulled off the highway system. This would result in a potential decreasing accident rate and considerable savings to the industry and public [ITSOAM 2005].

Improving Traffic Data Collection for Pavement Management System

WIM makes actual load condition available for pavement design. With accurate and detailed real time traffic information, pavement design is becoming more reliable and adequate, which decreases the cost due to either underestimated or overestimated design

capacities. In practice, pavement thickness was designed conservatively because of lack of accurate and detailed traffic load information. The consequence of this type of design is larger thickness than required accordingly.

WIM data can be used to predict future traffic volume for planning of maintenance activities. Some pavement design software, such as the MEPDG, can be used to evaluate pavement performance in terms of rutting, roughness, cracking, and other distress indices. These indices are indictors of timing for certain maintenance before costly rehabilitation or reconstruction. It ensures that maintenance is timed correctly, rather than after pavement structure integrity has already been breached [Bergan et al. 1998], therefore, lower maintenance cost.

4.2.2 WIM Cost

The costs of WIM are distributed into equipment cost, installation cost, maintenance cost, and calibration and testing costs.

Equipment Cost (hardware and software)

The cost of WIM equipments varies according to their performance, service life, and other technical advancement. The equipment cost includes not only the cost of sensors and supplement devices, but also the cost of operating and communicating software. Detailed costs are listed in Figure 4.10.

Installation Cost (excluding traffic control cost) and Maintenance Cost

The equipment installation requires cut of the pavements, placement of sensors and loops in the cutting slots, and the setting of the WIM cabinets, where the sensors and loops are connected to the data logger by electric wires. Necessary site selection, inspection, and preparation are required prior to installation, that may involve pavement resurfacing and rehabilitation costs. The maintenance/replacement cost for a WIM system could be subdivided into three parts: WIM system itself, pavement and sensor frames, and the associated data acquisition system.

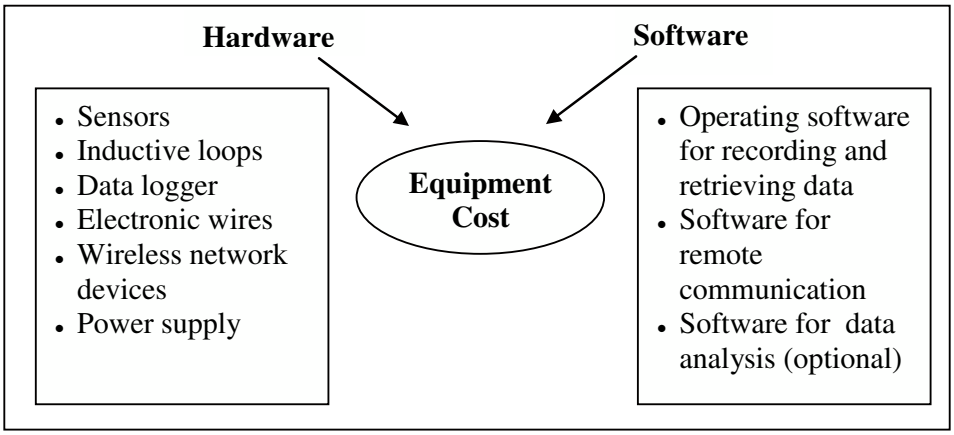


Figure 4.10: WIM Equipment Costs

Table 4.3: WIM Sensor Comparison

WIM Sensor Types	Piezoelectric	Bending Plate	Single Load Cell
Accuracy (95% Confidence)	±15%	±10%	±6%
Expected Life	4 years	6 years	12 years
Initial Installation Cost	$9,000	$21,500	$48,700
Annual Life Cycle Cost	$4,750	$6,400	$8,300
Total cost	$13,750	$27,900	$57,000

Installation cost is directly related to the life cycle cost of the WIM sensor. A life cycle cost is the cost of a WIM system over its entire service life, including costs for installation, maintenance, and salvage. Table 4.3 [Bushman and Pratt 1998] shows for each type of WIM sensor, as the initial installation cost increases, so does the annual life cycle cost, and the expected life and the accuracy. It provides transportation engineers with information for selecting an appropriate WIM system to best fit their needs.

Calibration and Testing Cost

As a special maintenance activity, WIM calibration should be carried out immediately following the initial installation and any considerable maintenance. The calibration costs involve specific heavy trucks usage, road closure, road user delay cost, and workforce.

ASTM E2-1802 recommended two loaded, pre-weighted and measured test vehicles for WIM calibration, for example, Figure 4.11 [Obrien 2005] presents a specific instrumented truck for the purpose of calibration. In general, calibration of a WIM system on two traffic lanes takes about half a day.

Figure 4.11: Instrumented Calibration Truck

4.2.3 WIM Values vs. Static Scale Values

In practice, WIM systems and static weigh stations are used to complement each other, because a citation for a weight violation to a trucking company can not be legally issued unless the truck weight measurement is better than 99 percent accurate[ORNL 2000], which is usually done by weight stations. High-speed scale systems of WIM are installed on main road sections, where trucks are prescreened to be overweight or not, then those pre-identified overweight trucks shall be pulled over to the weigh stations for precise weighing. In order to accommodate the increasing traffic volume, rather than expanding the weigh station facilities, adding new WIM systems to the existing systems is a more cost-effective solution. WIM systems protect weigh stations from unnecessary wear. In addition, the cost of a WIM station is generally less than the cost of a standard weigh station.

Although WIM systems and traditional static weigh stations are practically used together for enforcement management, in order to evaluate the benefits and costs of WIM systems, static weigh stations and WIM systems are treated as a pair of significant alternatives. The economic analysis will weigh the differences between the two alternatives in

the following situations:

- Increased percentage of trucks that can bypass weigh stations after deployment
- Increased percentage of overweight trucks detected after deployment of WIM
- Saved travel time after deployment
- Reduced overweight truck accidents after deployment
- Reduced load damage and pavement cost after deployment

4.3 Economic Analysis Tools for ITS

4.3.1 SCReening for ITS (SCRITS)

To quantify benefits and costs of ITS applications, several tools have been developed. The major analysis tools include Screening for ITS (SCRITS) and ITS Deployment Analysis System (IDAS) developed by FHWA.

SCRITS is an Excel based screening level tool to obtain an initial indication of benefits of various ITS applications. There are 16 applications identified in a spreadsheet, including WIM, traffic signal systems, and bus priority systems. It produces the estimates of user benefits on a daily basis. To start the tool, users need to provide the baseline data including travel statistics and other specific parameters used in a study. Currently, the primary applications of SCRITS are the following: approximation of user benefits for evaluating transportation alternatives, approximation of users benefits for ITS strategic planning, and sensitivity analysis of the benefits to certain input assumptions [SAIC 1999]. Among these applications, sensitivity analysis is one of the best applications since it can be used to identify serial assumed variables that can have a significant influence on the benefits and the overall structuring of an analysis. Sensitivity analysis provides "great flexibility to allow decision-makers to formulate a range of possible results customized to a specific set of conditions" [SAIC 1999].

4.3.2 ITS Deployment Analysis System (IDAS)

The IDAS analysis tool is designed for detailed, comparative benefit-cost analysis for ITS applications. It is used to analyze alternatives, not for optimization [Stockton et. al 2003]. The capacities of the IDAS include comparison and screening of ITS alternatives, estimation of life cycle costs, sensitivity and risk analysis [IDAS 2000]. IDAS comprises five modules including an Input/Output Interface Module (I/O), an Alternatives Generator Module (AGM), a Benefit Module, a Cost Module, and an Alternatives Comparison Module (ACM). It is capable of analyzing more than 60 types of ITS investments, such as WIM systems, transit vehicle signal priority, and safety readiness. Required input data include node coordinate information in a roadway network, information of facility type, capacity, traffic volume, and traffic speed between nodes. In practice, this analysis tool is complicated and expensive to perform.

4.4 Economic Model

To assess the benefit values of WIM systems compared to static weigh stations, it is necessary to understand how WIM functions in highways. A typical WIM system is used with other Commercial Vehicle Operation (CVO) technologies, such as Automatic Vehicle Identification (AVI), visual cameras, and importantly the static weigh scales to confirm overweight. WIM systems are usually located close to a static weigh station near the main lanes of a highway. As a truck approaches a WIM system at the highway speed, the WIM system measures the truck's weight, axle load and configuration, as well as vehicle type if capable. Data is processed by transportation management software, which compares the measured data with the preset axle loads and GVWs to decide whether the truck is overweight or not. If a truck is detected to be possibly overweight, a message is displayed on a roadside sign, directing the truck to a nearby static weigh station for further inspection. Otherwise, no message will appear and the truck can continue without stopping. Image information of a truck can also be monitored through a camera mounted at the road side. Figure 4.12 is a diagram of how a WIM system works on a highway main lane.

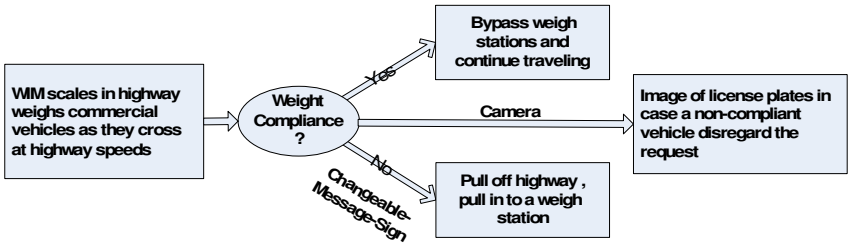


Figure 4.12: Operating Diagram of a WIM System at Highway System

4.4.1 Weight Enforcement - Delay Time Benefit Model

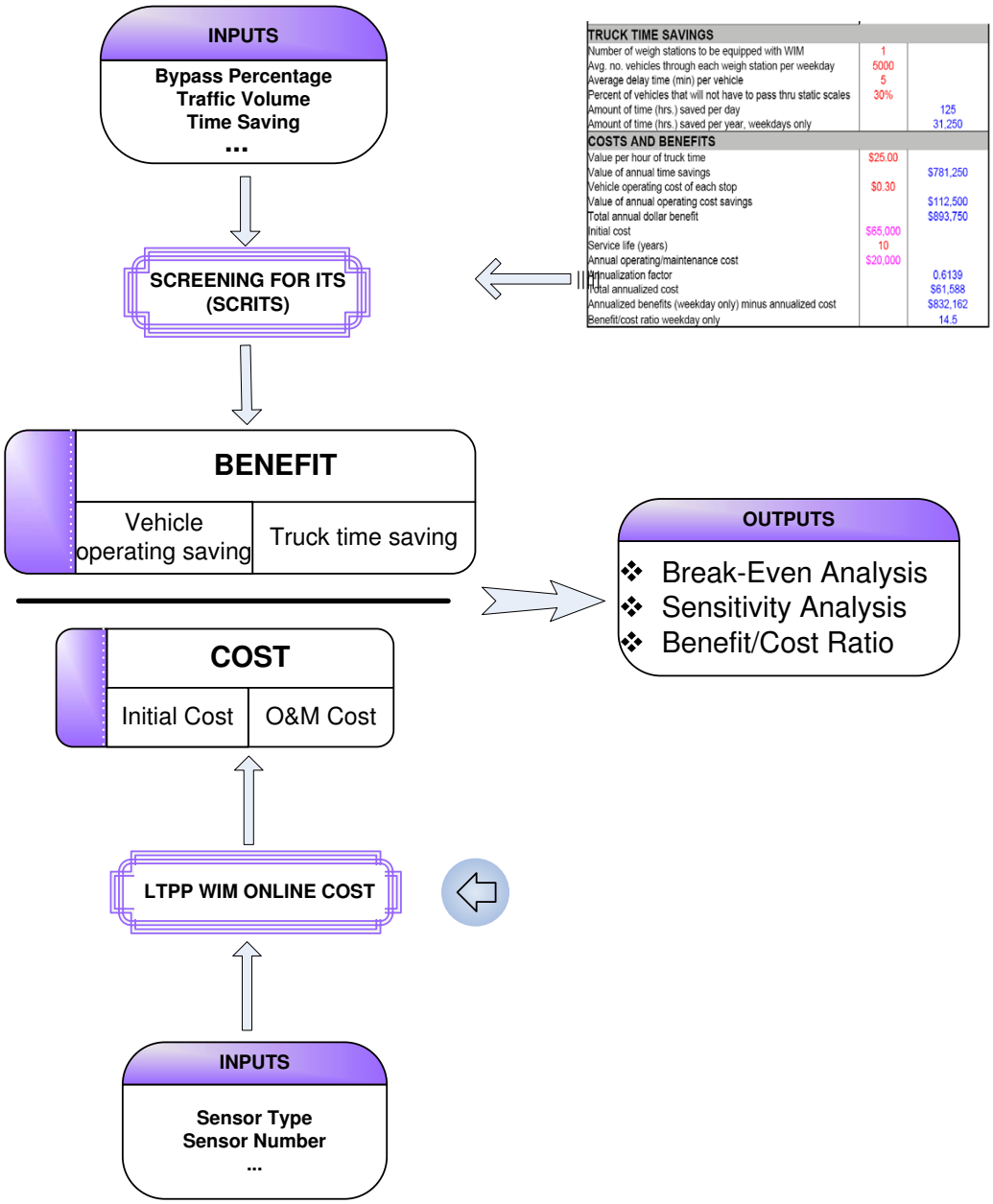
Enforcement of vehicle weight is measured by the number trucks weighed, the number of violations, and the amount of fines. In real effect, it should be feasible to achieve improved weight law compliance, extended pavement life and improved service level. WIM allows for all trucks passing WIM to be weighed, and only possible overloaded vehicles are requested to enter the static scales, and unnecessary delays at the scales are eliminated. It creates increased time for enforcement by personnel. To evaluate the delay benefit, the tool of SCRITS is used to develop the model in terms of saved delay time, Figure 4.13 is the diagram to evaluate delay benefit-cost ratio after evaluating the costs and benefits, which are estimated using LTPP online spreadsheet and SCRITS accordingly.

From a user's perspective, the delay benefit comprises two components: the annual "truck time cost" saving that results from reduced delay time after WIM deployment; the other component is the annual "vehicle operating cost per stop" saving that results from less travel distance for bypass vehicles. Critical components include:

- Truck time cost ($Va_{\text{TruckTime}}$): a combined number that captures the wage and benefits of drivers, time value for inventory, and vehicle depreciation cost per hour;

- Vehicle operating cost (C_{Stop}): a separate factor for truck costs, in addition to time cost, including the cost of fuel, tire. It is expressed as the cost per vehicle mile traveled.

The initial cost (costs of hardware, software, and installation) and annual operating and maintenance costs are estimated from LTPP online resource, "LTPP WIM Cost Online"



TRUCK TIME SAVINGS		
Number of weigh stations to be equipped with WIM	1	
Avg. no. vehicles through each weigh station per weekday	5000	
Average delay time (min) per vehicle	5	
Percent of vehicles that will not have to pass thru static scales	30%	
Amount of time (hrs.) saved per day		125
Amount of time (hrs.) saved per year, weekdays only		31,250
COSTS AND BENEFITS		
Value per hour of truck time	$25.00	
Value of annual time savings		$781,250
Vehicle operating cost of each stop	$0.30	
Value of annual operating cost savings		$112,500
Total annual dollar benefit		$893,750
Initial cost	$65,000	
Service life (years)	10	
Annual operating/maintenance cost	$20,000	
Annualization factor		0.6139
Total annualized cost		$61,588
Annualized benefits (weekday only) minus annualized cost		$832,162
Benefit/cost ratio weekday only		14.5

Figure 4.13: Diagram of Delay Benefit-Cost Ratio Evaluation

[LTPP 2007]. It works as a spreadsheet and allows users to estimate the cost of a new WIM system. It is based on the inclusion of the following: the initial hardware cost, sensor failure rate, calibration cost, and other parameters. The required basic inputs are the number of WIM scales to be purchased and the type of WIM sensors. The spreadsheet then calculates rough estimates of the cost to keep the site operating at the level expected by LTPP. Therefore, it is important that the analyst shall make realistic assumptions and update major inputs used in the cost estimation process to reflect specific conditions. The total cost is expressed as the Equivalent Uniform Annualized Cost (EUAC), which is obtained by multiplying the present value of cost by an annualization factor.

To determine the delay benefit model, the following variables are included. In addition, a break-even and a sensitivity analysis are conducted to study the impact of input assumptions in the model.

$$
\begin{aligned}
WS_N &= \text{Number of weigh stations (static scales) to be equipped with WIM} \\
Veh_N &= \text{Average Number of Vehicles through each WIM} \\
T_{\text{Delay}} &= \text{Average Delay Time per vehicle (minutes)} \\
ByPa &= \text{Percentage of vehicles that will not have to pass through static scales,} \\
&\quad\ \text{i.e. BYPass static scales} \\
C_{\text{Stop}} &= \text{Vehicle operating Cost of each stop (\$)} \\
C_{\text{Initial}} &= \text{Cost of WIM installation (\$)} \\
C_{\text{O\&M}} &= \text{Cost of annual operating/maintenance of WIM (\$)} \\
Va_{\text{TruckTime}} &= \text{Value of Truck Time per hour (\$)} \\
SL &= \text{Service Life of a WIM system (years)} \\
T_{\text{Workday}} &= \text{work days per year} \\
TD_{\text{Saved}} &= \text{Amount of time saved per day (hours)} \\
TY_{\text{Saved}} &= \text{Amount of time saved per year (hours)} \\
Va_{\text{Oper}} &= \text{Value of annual operating cost savings (\$)} \\
Va_{\text{TimeSaved}} &= \text{Value of time saving annually (\$)} \\
B_{\text{Delay}} &= \text{Total annual monetary delay benefit (\$)} \\
C_{\text{Annual}} &= \text{Total annualized cost (\$)} \\
f &= \text{Annualized factor}
\end{aligned}
$$

$$
\begin{aligned}
TD_{\text{Saved}} &= T_{\text{Delay}} \times Veh_N \times ByPa \times WS_N/60 \\
TY_{\text{Saved}} &= TD_{\text{Saved}} \times T_{\text{Workday}} \\
Va_{\text{TimeSaved}} &= Va_{\text{TruckTime}} \times TY_{\text{Saved}} \\
&= Va_{\text{TruckTime}} \times \frac{T_{\text{Delay}}}{60} \times Veh_N \times ByPa \times WS_N \times T_{\text{Workday}} \\
Va_{\text{Oper}} &= C_{\text{Stop}} \times Veh_N \times BaPa \times T_{\text{Workday}} \\
B_{\text{Delay}} &= Va_{\text{Oper}} + Va_{\text{TimeSaved}} \\
C_{\text{Annual}} &= C_{\text{Initial}} \times f + C_{\text{O\&M}} \\
\frac{B}{C} &= \frac{B_{\text{Delay}}}{C_{\text{Annual}}}
\end{aligned}
\tag{4.2}
$$

i.e.

$$
\frac{B}{C} = \frac{C_{\text{Stop}} \times Veh_N \times ByPa \times T_{\text{Workday}} + Va_{\text{TruckTime}} \times \frac{T_{\text{Delay}}}{60} \times Veh_N \times ByPa \times WS_N \times T_{\text{Workday}}}{C_{\text{Initial}} \times f + C_{\text{O\&M}}}
$$

To demonstrate the delay benefit model 4.1, Scenario I is designed as follows: a single static weigh station is with 500 vehicles per day usage, and an average delay time is 5 minutes per vehicle. The initial cost of a two lane single load-cell based WIM system was estimated to be $122,000 with a 10-year service life, and annual operating and maintenance cost of $31,920. Appendix E lists the cost estimation procedure using "LTPP WIM Cost Online" [LTPP 2007]. Vehicle operating cost at each stop was assumed to be 30 cents, and the value per hour of truck time is $25 according to the America Highway Economic Requirement Model and the study of Peng et al. [Peng et al. 2000].

The result shows that the annual benefit is $159,298 and the annual cost is $49,244. The benefit/cost ratio (the equivalent uniform annual benefit to the equivalent uniform annual cost) would be 4.2. It indicates a high benefit.

Break-even analysis

The purpose of break-even analysis is to examine the tradeoff between the potential benefits of an ITS project and its costs, by estimating the minimum level of performance required to have an equivalent cost and benefit. It can be used to identify and quantify critical variables (performance measures) to achieve an acceptable benefit-cost ratio. The approach of break-even analysis is first to set the benefit-cost ratio to be 1, that is, the annual benefits

Table 4.4: Scenario I - Delay Benefit [FHWA 1999]

ANALYSIS OF WIM DELAY BENEFIT			
		User Input	**Calculated Value**
Date of analysis		Feb/07/2007	
Scenario		I	
Analyst		Alanna	
Description : A single load-cell WIM system at a typical highway main lane		Less travel time	
TRUCK TIME SAVINGS			
Number of weigh stations to be equipped with WIM	WS_N	1	
Avg. no. vehicles through each weigh station per weekday	Veh_N	500	
Average delay time (min) saved per vehicle	T_{Delay}	5	
Percent of vehicles that dot not have to report to static scales	$ByPa$	70%	
Workday per year	T_{Workday}	250	
Amount of time (hrs.) saved per day	TD_{Saved}		29
Amount of time (hrs.) saved per year, weekdays only	TY_{Saved}		7,292
COSTS AND BENEFITS			
Value per hour of truck time	$Va_{\text{TruckTime}}$	\$25.00	
Value of annual time savings	Va_{TimeSave}		\$182,292
Vehicle operating cost of each stop	C_{Stop}	\$0.30	
Value of annual operating cost savings	Va_{Oper}		\$26,250
Total annual dollar benefit	B_{Annual}		\$208,542
Initial cost (2 lanes)	C_{Initial}	\$122,000	
Service life (years)	SL	10	
Annual operating/maintenance cost	$C_{\text{O\&M}}$	\$31,920	
Annualization factor	f		0.142
Total annualized cost	C_{Annual}		\$49,244
Annualized benefits (weekday only) minus annualized cost			\$159,298
Benefit-cost ratio weekday only	B/C		4.235

equals to the annual costs. Then, the result solved from the benefit-cost equation shall be in terms of performance measures, such as time saving and increased bypass rate. The critical performance measures identified here can be further used in sensitivity analysis.

Apply Scenario I to demonstrate the break-even analysis: submit the values of $WS_N = 1$, $C_{\text{Stop}} = \$0.30$, $Va_{\text{TruckTime}} = \$25.00$, and other inputs from Table 4.4, along with the initial cost and O&M cost from "LTPP WIM Cost Online"; change bypass rate from 10% to 30%, static scale usage rate (traffic volume) from 100 to 2500 vehicles per weekday. The required time saving to have an equivalent cost and benefit is presented as formula (4.3) and as Figure 4.14.

Let $B/C = 1$, i.e.,

$$\frac{C_{\text{Stop}} \times Veh_N \times Bypa \times T_{\text{Workday}} + Va_{\text{TruckTime}} \times \frac{T_{\text{Delay}}}{60} \times Veh_N \times ByPa \times WS_N \times T_{\text{Workday}}}{C_{\text{Initial}} \times f + C_{\text{O\&M}}} = 1$$

then

$$C_{\text{Initial}} \times f + C_{\text{O\&M}} =$$
$$C_{\text{Stop}} \times Veh_N \times Bypa \times T_{\text{Workday}} + Va_{\text{TruckTime}} \times \frac{T_{\text{Delay}}}{60} \times Veh_N \times ByPa \times WS_N \times T_{\text{Workday}}$$

Hence,

$$\begin{aligned} T_{\text{Delay}} &= \frac{(C_{\text{Initial}} \times f + C_{\text{O\&M}} - C_{\text{Stop}} \times Veh_N \times ByPa \times T_{\text{Workday}}) \times 60}{Va_{\text{TruckTime}} \times Veh_N \times ByPa \times WS_N \times T_{\text{Workday}}} \\ &= \frac{(C_{\text{Initial}} \times f + C_{\text{O\&M}}) \times 60}{Va_{\text{TruckTime}} \times Veh_N \times ByPa \times T_{\text{Workday}}} - \frac{C_{\text{Stop}} \times 60}{Va_{\text{TruckTime}}} \end{aligned} \tag{4.3}$$

Substitute values from Scenario I,

$$\begin{aligned} T_{\text{Delay}} &= \frac{29230 \times 60}{25 \times 250 \times Veh_N \times ByPa} - \frac{0.3 \times 60}{25} \\ &= \frac{280.608}{Veh_N \times ByPa} - 0.72 \end{aligned}$$

It shows that as the bypass percent ($ByPa$) increases, the required time saving (T_{Delay}) for break-even points decreases. The same trend shows between traffic volume and required time saving. In order to be beneficial, for example, 5 minutes time saving requires about 250, 350, and 550 of traffic volume with respect to bypass rate of 30%, 20%, 10% correspondingly. That is, larger traffic volume will require less time saving such that the created benefits easily covers the annual costs for the WIM system. The curve indicates the break-even points are relatively low number in all cases as the traffic volume is greater than a certain amount. WIM deployment that eliminates unnecessary travel time is a valuable investment in nearly all cases except when the traffic volume is very low.

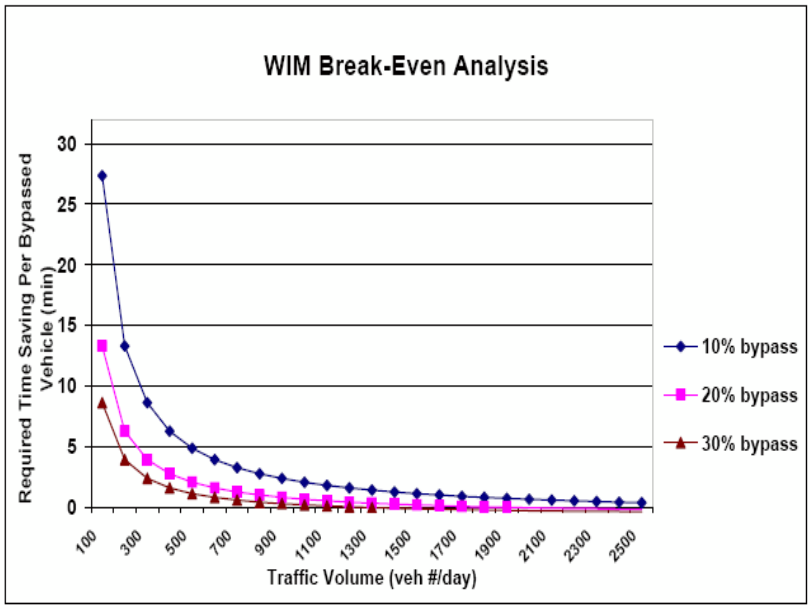


Figure 4.14: Break-Even Analysis of Delay Benefit

Sensitivity Analysis

Given the uncertainty of variables/assumptions in a model, a sensitivity analysis is the process of varying the variables/assumptions over a reasonable range and observing the relative changes in the model response, to demonstrate the impact of inputs on the model output. In this study, the key variables and their varying ranges follow:

1. Traffic volume per weekday (100 -1000)
2. Percentage of vehicles bypassing static scales (10% - 90%): bypass rate after applying WIM
3. Delay time saved per vehicle (2 -10 minutes)
4. Value of truck time ($10 - $30): capture drivers' wage and benefit, time value of inventory, and vehicle depreciation cost

5. Vehicle operating cost (VOC) of each stop ($0.30 - $1.00): cost per vehicle mile traveled

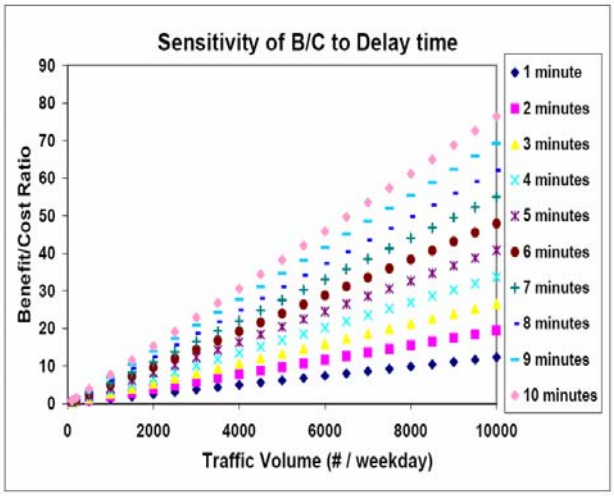


Figure 4.15: Sensitivity of Benefit-Cost Ratio to Delay Time

Model 4.1 indicates a linear positive trend between each of these variables and the benefit-cost ratio. Certain relationships also exist among some of these inputs, such as delay time at a weigh station could increases as traffic volume increases. Figure 4.15 present the sensitivity of B/C ratio to the delay time. The slope of each line (the change rate of B/C) increases as the delay time increases. Figure 4.16 presents the sensitivity of B/C ratio to traffic volume. It shows that the slope of each trend (the change rate of B/C) increases as the traffic volume increases. There is a linear relationship between delay time and B/C ratio. Similarly, the model response to other inputs follow the same trend.

In summary, the sensitivity analysis indicates that as the value of a key variable changes in the range, the value of B/C adjusts in the same direction. Some variables affect the behavior of the model to a larger extent than others. For example, improving percentage of bypass is very attractive since with the 100 percent of bypass, there would be no need for static scales. The break-even analysis indicated that WIM are beneficial except under very low traffic volume and delay time conditions.

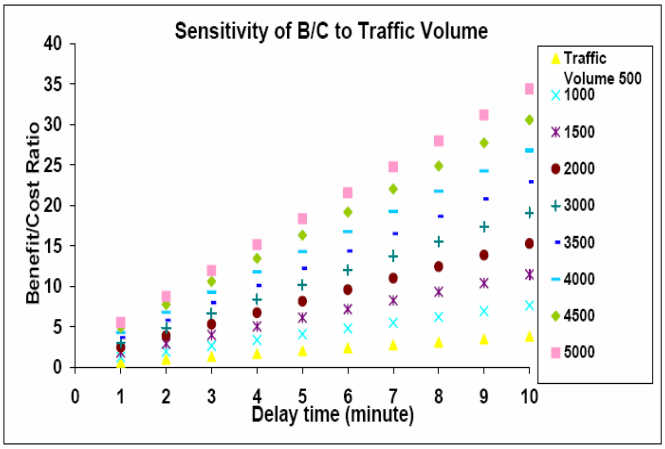


Figure 4.16: Sensitivity of Benefit-Cost Ratio to Traffic Volume

4.4.2 Weight Enforcement - Capability Enhancement Benefit Model

There are two aspects of weight enforcement benefits: one is that the delay time reduced for commercial travelers since fewer vehicles are required to report to scales after WIM deployment, which has been assessed antecedently. The other benefit is that the number of trucks with unauthorized bypass is decreased since weigh stations do not have to be closed during peak hours to avoid congestion. The capability enhancement benefit is evaluated in terms of the amount of fines.

Define the variables and follow with Scenario II to demonstrate the benefit:

$LE(w)$ = Increased Level of Enforcement: inspection rate, the number of trucks out of compliance inspected as a percentage of all trucks using WIM, a function of w

Veh_N = Average Number of Vehicles through each WIM, ie. traffic volume per day

$ESAL_{\text{ow}}$ = ESAL-km, average ESAL traveled in total distance by overweight vehicles per day; an indicator of the total load repetitions imposed, depending on the level of enforcement[Edward et al. 1995]

T_{Workday} = Work days per year

$Pe_{\text{ow}}(w)$ = Penalty per ESAL-km, a function of w

w = GVW limit, in USA = 36.3 tons, in Canada = 39.5 tons [Edward et al. 1995]

B_{ce} = Total annual monetary capacity enhancement benefit

Then

$$B_{\text{ce}} = Pe_{\text{ow}}(w) \times (ESAL_{\text{ow}} \times LE(w) \times Veh_N) \times T_{\text{Workday}}. \tag{4.4}$$

The calculated benefit is \$150,000 from enhanced capacity. The benefit-cost ratio is 3.046, lower than 4.235 of delay benefit in this case. It indicates the system is beneficial to the enforcement agencies. The magnitude of the ratio depends on the level of enforcement, traffic volume, ESAL-km, and the penalty intensity. The cost attached to ESAL-km counts on various factors such as pavement type and truck type [Edward et al. 1995]. According to Model (4.4), the sensitivity analysis results for this model would be similar to that of delay benefit model. The break-even analysis of delay benefit model illustrates that WIM benefits can easily cover the costs as long as the traffic volume is not very low; therefore, it is not necessary to carry out the break-even analysis for this and the following model. The annual cost is calculated using the LTPP WIM Cost Online.

Table 4.5: Scenario II - Weight Enforcement-Capacity Enhancement Benefit

ANALYSIS OF WIM CAPACITY ENFORCEMENT BENEFIT			
		User Input	**Calculated Value**
Date of analysis		Mar/03/2007	
Scenario		II	
Analyst		Alanna	
Description: A single load cell WIM system at a typical highway mainlane		Higher level of enforcement	
WEIGHT ENFORCEMENT LEVEL ANALYSIS			
Avg. no. vehicles through each weigh station per weekday	Veh_N	500	
% Increased level of enforcement after deploying WIM	$LE(w)$	20%	
Weekdays per year	T_{Workday}	250	
Avg. no. overweight vehicles reduced per year due to higher level enforcement			25,000
Average ESAL-km of overload per day	$ESAL_{\text{ow}}$	100	
COSTS AND BENEFITS			
Penalty per ESAL-km	$Pe_{\text{ow}}(w)$	\$0.06	
Annual pavement cost saving due to higher level of enforcement			\$150,000
Installation cost		\$122,000	
Service life (years)		10	
Annual operating/maintenance cost		\$31,920	
Annualization factor			0.142
Total annualized cost			\$49,244
Annualized benefits minus annualized costs			\$100,756
Benefit-cost ratio			3.046

4.4.3 Safety Benefit Model

Overweight vehicles and safety concerns are closely related. Many studies ([Jacob 2002a, Compbell et al. 1988, Fancher 1998]) have concluded that vehicle weight is an aggravating factor in traffic accident rate. WIM can effectively and efficiently detect overweight trucks and decrease traffic congestion. The safety benefit is evaluated in terms of reduced number of accidents.

Define the variables and follow with Scenario III to demonstrate the model:

$$
\begin{aligned}
OW_{\text{Re}} &= \text{Percentage reduction of overweight trucks after deploying WIM} \\
AcR_{\text{ow}} &= \text{Accident rate of overweight trucks in total number of trucks per year} \\
C_{\text{owAc}} &= \text{Accident-related costs per occurrence for overweight accidents} \\
Veh_N &= \text{Average number of vehicles through each WIM, traffic volume} \\
T_{\text{Workday}} &= \text{Work days per year} \\
B_{\text{safety}} &= \text{Total annual monetary safety benefit}
\end{aligned}
$$

Then,

$$B_{\text{safety}} = C_{\text{owAc}} \times AcR_{\text{ow}} \times (Veh_N \times OW_{\text{Re}} \times T_{\text{Workday}}) \tag{4.5}$$

Table 4.6: Scenario III - Safety Benefit

ANALYSIS OF WIM SAFETY BENEFIT			
		User Input	**Calculated Value**
Date of analysis		Mar/03/2007	
Scenario		III	
Analyst		Alanna	
Description: A single load cell WIM system at a typical highway mainlanes		Deduction of accident rate	
ACCIDENT ANALYSIS			
Avg. no. vehicles through each weigh station per weekday	Veh_N	500	
% reduction of overweight trucks after deploying WIM	OW_{Re}	20%	
Weekdays per year	T_{Workday}	250	
Avg. no. overweight vehicles reduced per year			25,000
Accident rate of overweight trucks per year	AcR_{ow}	0.002	
Annual accident reduction of overweight trucks			50
COSTS AND BENEFITS			
Accident-related costs per occurrence for overweight accidents	C_{owAc}	\$5,000	
Value of annual savings in accident-related costs			\$250,000
Installation cost (2 lanes)		\$122,000	
Service life (years)		10	
Annual operating/maintenance cost		\$31,920	
Annualization factor			0.142
Total annualized cost			\$49,244
Annualized benefits minus annualized costs			\$200,756
Benefit-cost ratio			5.077

The estimated benefit value from less accidents is $250,000. The benefit-cost ratio is 5.077, which is significant high and shows that the system is beneficial to reduce congestion and have the road safer. Assumptions shall be carefully re-examined in the table of Scenario III, such as a reasonable value or range for percentage reduction of overweight trucks after deploying WIM, accident rate of overweight trucks, and related cost of overweight accidents. Model (4.5) indicates that the B/C ratio is sensitive to these variables, with the similar relationship as that of the delay benefit model.

Weight enforcement, delay time, and road safety improvement are the main components of WIM benefits as discussed formerly. To express the economic value of WIM as a benefit-cost ratio, these components are integrated with Model (4.2), (4.4) and (4.5). Table 4.7 combines the estimated benefits of the three scenarios. Figure 4.18 integrates the benefit models of weight enforcement and traffic data collection. Since highway wear is not immediately quantifiable, the benefit of traffic data collection was evaluated through the study of overloaded pavement MEPDG simulation, instead of a quantified model. Figure 4.17 illustrates the cost model.

Table 4.7: Integrated Benefits of a Typical Single Load-Cell WIM System

Estimation of WIM values	**Annual Monetary value**
Estimated annual delay benefit	$208,542
Estimated annual enforcement capacity benefit	$150,000
Estimated annual safety benefit	$250,000
Total	$608,542
Estimated annual cost	$ 49,242
Benefit/cost (B/C) ratio	$ 12.358

In summary, the economic benefits of WIM outweigh the costs. Commercial industry experiences more efficient services in a new way, which leads to less delay time, less number of stops, and reduced incidents. The enforcement staff experience better effectiveness and efficiencies of weight enforcement by targeting suspected vehicles only. The transportation engineers have access to specific valuable traffic data for transport planning, highway design, construction, and maintenance strategies. The taxpayers enjoy lower costs for roads and transportation. Highway infrastructure benefits from less overloading damage, longer service life, and better service level. WIM systems are economically feasible for road networks in northern environments.

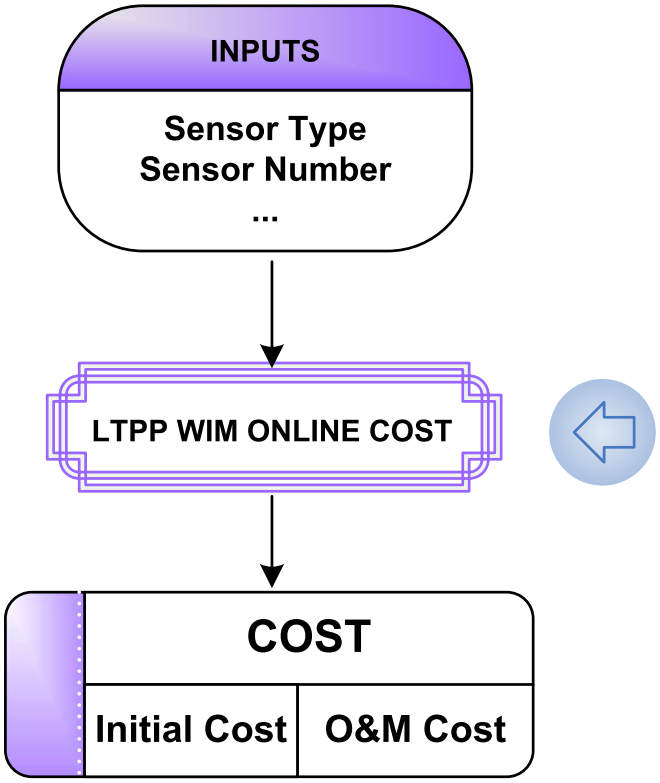


Figure 4.17: Cost Model of WIM Value

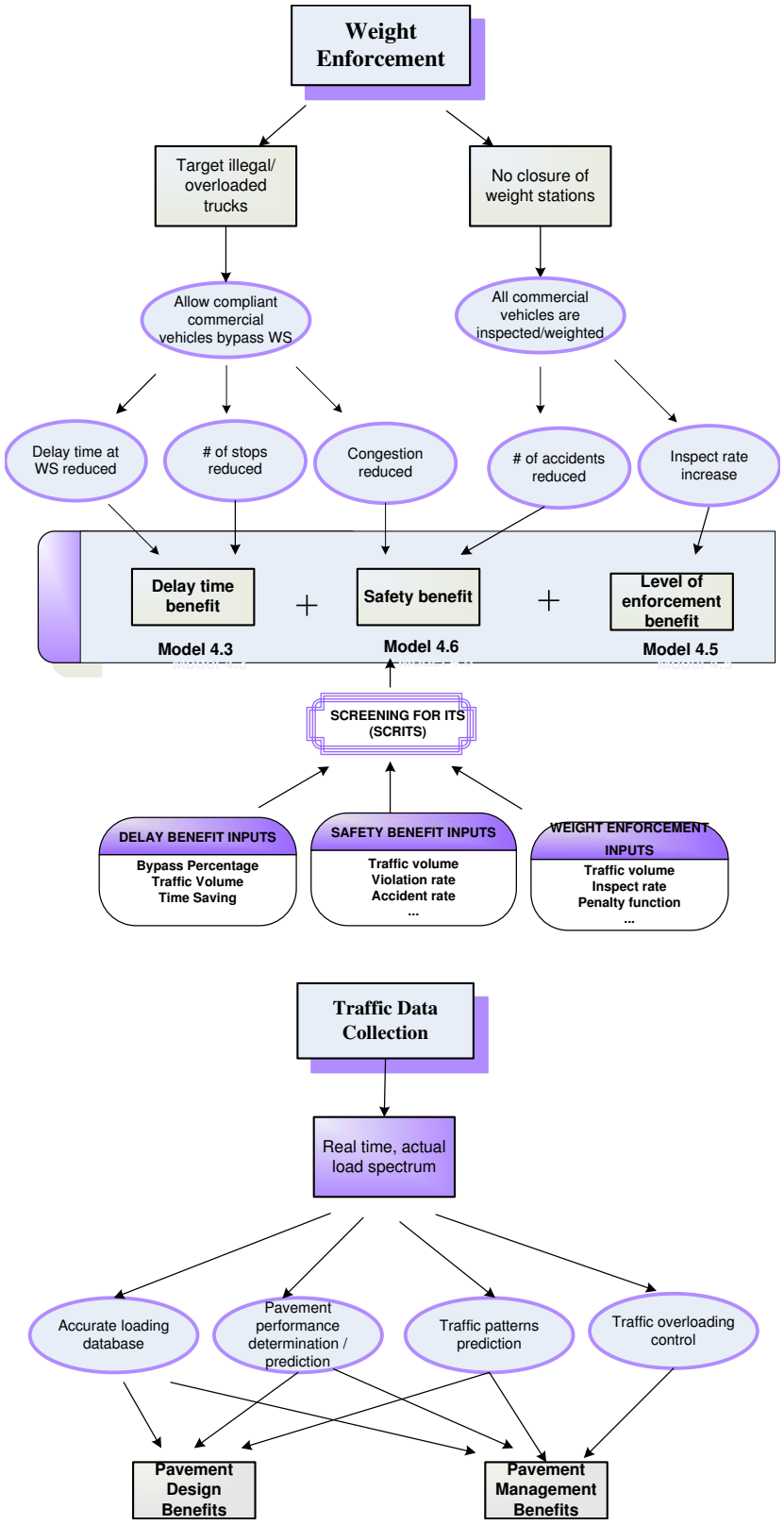


Figure 4.18: Benefits Diagram of WIM

Chapter 5

Economic Data and Tradeoff Analysis: A Case Study

5.1 The Longs Creek WIM System in New Brunswick

To evaluate the effectiveness of WIM, a New Brunswick Department of Transportation (NBDoT)'s WIM system near Longs Creek in New Brunswick was studied. The Longs Creek weigh station had been experiencing congestion due to time-consuming weighing procedures. Vehicles are either allowed to bypass the scales or selected to report to the static scales during peak hours. This compromised the effective enforcement of overweight commercial vehicles.

A WIM system (Figure 5.1 [Davis 2003] and Figure 5.2 [Nash 2006]) was designed for the purpose of pre-screening vehicles and reducing the number of commercial vehicles reporting to the scales. It was installed in the eastbound (two lanes) of Route 2 on the Trans-Canada Highway, and opened on October 2002. The system is comprised of two single load cells, two piezoelectric sensors, 11 inductive loops, two changeable message signs, and two freeze-frame cameras [Davis 2003]. A fixed message sign, about 500m upstream of the WIM scales, directs all trucks to travel on the right hand lane. As a truck enters the system, it passes over an inductive loop (L1), single load cell scales, a piezoelectric sensor, and another loop (L2), where all required data are collected. The license plate image of the truck is also taken by Camera 1 at this point. The truck then continues over three more

inductive loops. The first loop (L5) checks the vehicle presence (here the WIM system has determined whether the vehicle should report to the weigh stations or not). If the truck is found to be possibly overweight, the first Changeable Message Sign (CMS 1) is activated. The driver receives the message of "TRUCK MUST REPORT TO WEIGHT SCALE". L6 triggers Camera 2 to take the image of the truck. If applicable, the CMS 1 is turned off and the CMS 2 is activated . L7 simply turns off the second sign as the truck passes over, as well as signalling the system to transfer the vehicle image to the weight station. Loops 8 and 9 (in the main lane) and 10 and 11 (in the ramp to weigh station) tell the scale operators whether the truck obeyed the message signs and is reporting to the scales (if overweight) or they ignored the message and continuing past the station. In the left hand lane adjacent to the single load cells, there is a loop-piezoelectric-loop configuration to detect any vehicles that did not follow the fixed message sign and traveled in the left hand lane.

5.2 Data Collection Results

Accuracy of the system was evaluated by NBDoT during the first four months of operations and April 2003. The accuracy results are within the specified accuracy by ASTM E2-1308. To examine the operational benefits of the WIM system, a 24 hour traffic survey was conducted between September 18, 2003 and September 30, 2003. These field data include [Davis 2003]:

- Total truck volume, subdivided into Tractor Trailers, Trains, and Straight Trucks
- Number of trucks signalled to report to static scales in a 24 hour period
- The average time for trucks to exit from main lanes, to report to static scale, and return to the main lanes
- The average distance traveled for trucks to exit from main lanes, report to static scale, and to return to main lanes
- The average time for trucks to bypass the static scales

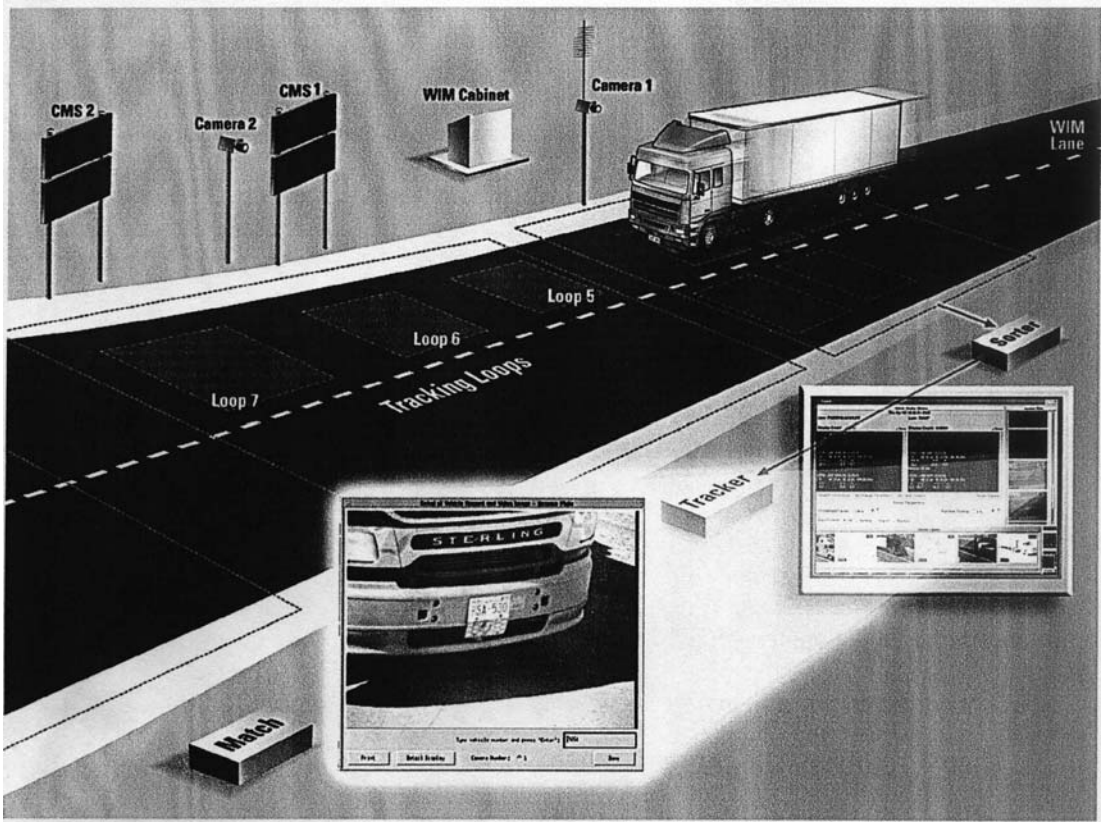


Figure 5.1: Illustration of A Commercial Vehicle Passing Through WIM System in New Brunswick

- The average distance traveled for trucks to bypass the static scales

Given traffic volume and delay time, the average operating costs for each class of truck can be determined. "Operational Costs of Trucks in Canada - 2000" prepared by Trimac Logistics Ltd. was used for the operating cost calculation. All costs and benefits were adjusted for inflation to 2001 dollars with inflation rate of 1.7% (The Consumer Price Index, 2002). The costs and benefits were compared over a five year period from 2002 to 2006, 5% discount rate was used for the analysis.

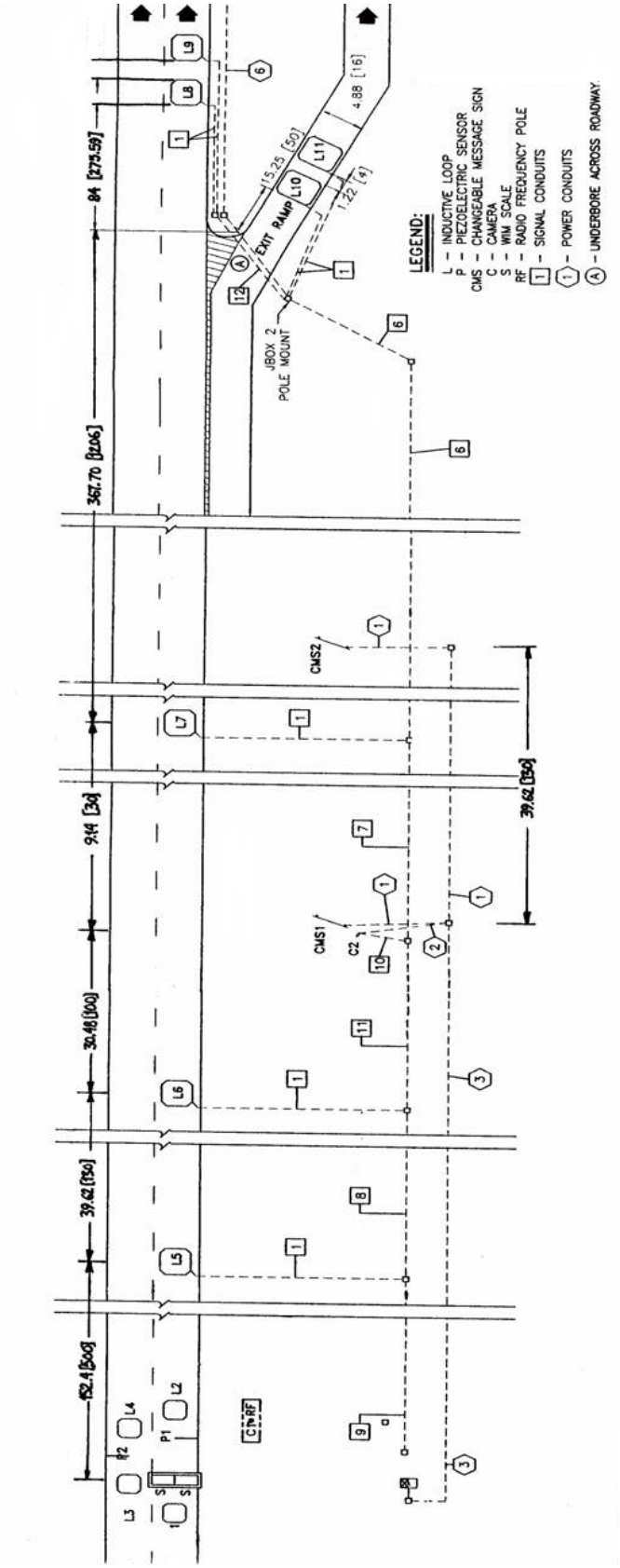


Figure 5.2: Layout of the Longs Creek WIM System in New Brunswick

5.2.1 Traffic Volume Data

The traffic volume data of commercial vehicles observed on the eastbound lanes of Route 2 during the 24 hour survey are included:

$$\begin{aligned} \text{Observed total volume} &= 916 \text{ trucks/day, or 856 converted to AADTT} = 916/1.07 \\ &\quad (1.07 \text{ is the MAF (monthly adjustment factor)}) \\ \text{Signaled to report} &= 215 \text{ trucks/day, or 201 converted with MAF} = 215/1.07 \\ \text{Bypassing} &= 701 \text{ trucks/day, or 655 converted with MAF} = 701/1.07 \end{aligned}$$

That is, an average of 655 trucks per day or 76.5% of the AADTT benefit from the Longs Creek WIM system. Table 5.1 [Davis 2003] shows the bypassing rate and benefiting number of trucks in terms of each truck class at the site. Trucks reporting to the station are considered as overweight if one axle or axle group exceeds the specified limits [Davis 2003].

Table 5.1: Benefit Proportion of Tractor Trailers, Trains, and Straight Trucks

Truck Type	**% of AADTT**	**% Bypassing**	**Number of trucks benefiting from WIM**
Tractor Trailer	84.7	76.8	557
Train	6.3	72.2	39
Straight Trucks	9.0	76.6	59
Total	100	N/A	655 (= 856-201)

5.2.2 Delay Time Data

During the survey period, the average time for a truck to bypass was calculated to be 32 seconds. The average delay time for commercial vehicles required to report to static stations was computed by summing the ramp time and the time to report(4 minutes and 44 second), subtracting bypass time (32 seconds). The resulted average delay time (time saved by WIM) was 4 minutes and 12 seconds for trucks report to static scale and return to main lanes.

5.2.3 Additional Travel Distance Data

A test car survey was conducted to measure the distances. For commercial vehicles that are required to report, the total distance traveled is usually 2.35 km. For vehicles allowed to bypass, the total distance traveled is 0.75 km. Therefore, the extra distance (in other words, distance saved by WIM) incurred by trucks required to report is 2.35 - 0.75 = 1.60 km.

5.2.4 Average Cost to Report

To assess the benefits due to the deployment of the Longs Creek WIM system, an average Cost to Report for the three classes of trucks are computed based on the above delay time, extra distance data, and the "Operational Costs of Trucks in Canada - 2000", which consider varied factors including truck type, unit cost of driver, fuel, repairs, and tires. The Cost to Report is a combination cost of the Truck Time Cost and Vehicle Operating Cost, which were defined in Model 4.1 in the thesis. Table 5.2 [Davis 2003] indicates the estimated average Cost to Report.

Table 5.2: Average Cost to Report at Long Creek Scale Station

Truck Type	**Proportion of AADTT**	**Average Delay (min)**	**Extra Distance (km)**	**Cost to Report**
Tractor Trailer	85%	4.20	1.6	$2.32
Train	6%	4.20	1.6	$2.55
Straight Trucks	9%	4.20	1.6	$2.09

5.3 Benefit-Cost Analysis

Approximately 655 commercial trucks per day or 76.5% AADTT benefit from the WIM system. This value (655) was multiplied by the percentage of AADTT for each type of trucks, to obtain the number of each truck types permitted to bypass per day, for example of Table 5.1. Each of these number is multiplied by its Cost to Report (Table 5.2). These savings then multiply by 365 days and summed to be the total estimated benefit for a year. This computation was over five years, start from year 2002 until 2006. The benefit

value varied for each year according to the amount of bypass vehicles. All the estimations (benefits and costs) were discounted to 2001 dollar. The AADTT growth rate during the five years was estimated to be 4.3% per annum. The proportion of each type of trucks is assumed to be the same for the five year period.

Estimation of the WIM system cost is divided into [Davis 2003],[Nash 2006],

- System supply and installation including 1st year of system supply and service - $443,800
- Changes made to fixed and changeable message signs - $29,900
- Annual maintance costs per site, including regular maintenance (twice a year), service calls, software upgrades - $20,000
- Extra freeze frame camera - $15,600
- Extra options purchased by NBDoT, including left lane sensors- $6,500

The total estimated cost of the Longs Creek WIM system is $610,567 over the five yeas, and the total estimate benefit is $2,253,598. Therefore, the benefit-cost (B/C) ratio is 3.69 for the five year period. This illustrates that appropriate WIM deployment are very beneficial to the commercial industry. In addition, the construction cost only of a static weight station in NB is estimated to be more than $1,200,000.00, including the acceleration lanes, the deceleration lanes, and the ramps [Nash 2006]. It is much more than the cost of the WIM system.

Increased safety of traffic traveling are recognized from the WIM system, since only 23.5% AADTT are required to report which means less backup on the highway. It follows that the enforcement efficiency are also improved by re-allocating resources. Data for quantifying these benefits are not available at the moment. This study [Davis 2003] also brought up that the beneficial result is site specific. There exists tradeoff to the attractive benefits. Careful consideration of the site selection, the anticipated road usage, the required accuracy, and the acceptable costs governs each site specific WIM values. Particularly, proper maintenance and calibration are critical because the local seasonal and climatic changes can seriously affect the system accuracy [Davis 2003].

Chapter 6

Future Study of WIM

6.1 New Materials and Technologies for WIM Sensors

WIM systems play a critical role in gathering traffic information and enhancing weight enforcement. On the other hand, many traditional WIM sensors such as piezoelectric sensors and load-cell based sensors have disadvantages. They are either inaccurate, expensive, or unstable. Efforts have been directed to develop new sensors in order to reduce cost and improve accuracy, to provide better WIM data used for pavement design and weight enforcement. Examples are quartz piezoelectric sensors and optical fiber sensors. Quartz piezoelectric sensors apply the same principle as piezoelectric based sensors, but the design and materials are different, as illustrated in Figure 6.1 [McDonell 1998]. This type of sensor is made up of quartz sensing elements, positioned in an aluminum housing, and constructed with elastic material around it. Quartz piezoelectric sensors have proved to meet or exceed the weight accuracy specified by ASTM for Type I [White et al. 2006], and the cost is competitive with that of load cells. They do not fatigue as quickly and very importantly, the impact of temperature is negligible [Klein 2001], but they are highly sensitive to pavement roughness. Optical fibers adopted as a WIM sensor technology offer accurate measurement capabilities at a reasonable cost [Caussignac 1998, Caussignac et al. 1999]. They have high bandwidth and are lightweight. In addition, optical fiber WIM sensors can be embedded up to 76 mm (three inches) below the surface such that there is highly protective environment to lengthen their service lives [Kunzler et al. 2003].

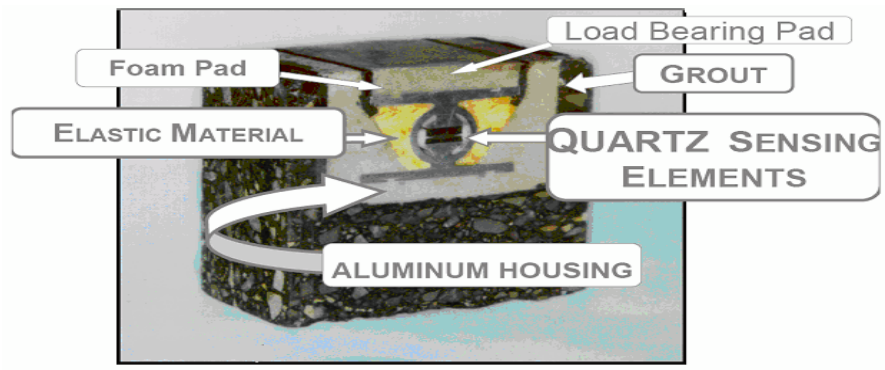


Figure 6.1: Quartz Piezoelectric Sensor

Multiple-Sensor WIM (MS-WIM) is considered as a way to accurately estimate static axle loads at traffic speed. Figure 6.2 [Obrien 2005] is a picture of MS-WIM in the Netherlands, where the WIM sensor array is composed of multiple sensors. The accuracy of estimated weights mainly depends on three aspects: sensors' intrinsic accuracy, static weight estimation algorithm, and array design optimization. There have been research studies on methods to optimize MS-WIM array design with respect to number of sensors, sensor spacings, and sensor locations [Labry et al. 2005]. New algorithms for processing outputs from MS-WIM, such as functional network equations [Gonzalez and Obrien 2005] and neural networks have been developed.

The other significant technology is the new "Integrated Matrix" WIM (IM WIM) sensor concept based on strain gauge technology [Opitz and Kuhne 2005]. In contrast to a conventional bending plate, the sensor strip consists of 16 individual shear deformation elements (Figure 6.3). The new sensors are made of stainless steel material, which is good for durability. A modular system is proposed to facilitate easy maintenance and replacement. This system technology may allow future fully automatic enforcement systems for truck overload.

Figure 6.2: Multiple-sensor WIM in the Netherlands

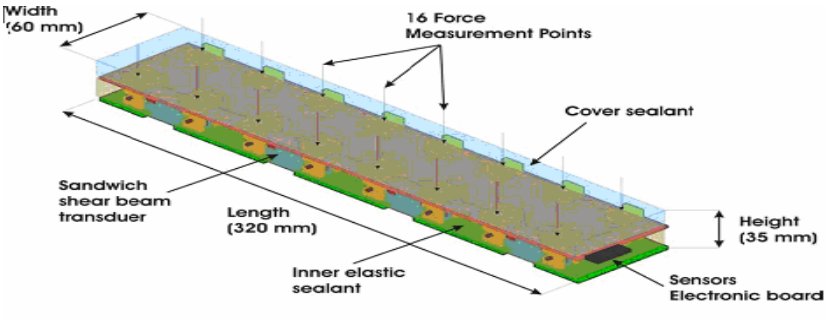


Figure 6.3: IM WIM Module 32 cm Mechanical Design

6.2 New Applications

Besides pavements, WIM technologies have been used in bridges and railways. For example, Bridge WIM (B-WIM) systems use strain sensors located underneath bridges to detect axles. Figure 6.4 [Brozovic et al. 2005] shows a B-WIM site in Poland. In Slovenia, bridge WIM systems use strain gauges to measure the deflection of structures and in combination with speed and axle spacing to calculate axle loads and GVWs. This type of system has high accuracy, is non intrusive to pavements and traffic, and can easily be installed and moved. The measured WIM data is converted to ESALs, which are used for traffic planning

and bridge assessment in Slovenia [Brozovic et al. 2005]. In practice, the number of types of bridges that are suitable for B-WIM is increasing.

Compared to the WIM sensors' performance used for weighing road vehicles, the performance of WIM sensors used for railways is enhanced because dynamic effects are limited: a rail locomotive always passes on the same and a qualitative track (no lateral variation of vehicles). Problems may occur for railway WIM, such as the velocity difference of different wagon of the same train can be large, thus the speed and acceleration of a train have to be taken into account for axle load computation [Zag and Dolcemascolo 2005]. For instance, in Sweden, a monitoring project [Karoumi et al. 2005] was carried out to increase the knowledge of actual traffic loads and their effects on railway bridges. Figure 6.5 is a photo of a train over a newly-installed WIM scale bridge in Alaska. This system is designed to automatically sense train speeds, detect engines, and record railcar weights [ARRC 2007].

Another application is to use and integrate WIM with electronic toll collections on a highway, especially, for toll stations (in Taiwan for example) where charging is based on the types of vehicle instead of vehicle weights.

Figure 6.4: Strain Transducers on A Bridge in Poland

6.3 Virtual WIM

The enforcement through current WIM technologies is not always effective. It is unfeasible to continuously target bypass routes and secondary roads that could be used by truckers to avoid fixed weigh scales. A visual WIM station applies WIM sensors and video tech-

Figure 6.5: A WIM Scale Bridge in Anchorage Rail Yard, Alaska

nology to captures images of passing trucks. Through the use of cameras, WIM data are linked to truck license plates/registration numbers [Santero et al. 2005]. This information is transferred through wireless technology to a central facility. Virtual WIM is a flexible solution to catch violation of vehicles. It also helps traffic predictions be more accurate. In practice, this technology has not been widely applied.

6.4 Calibration

As accuracy is critical for a WIM system to be effective, calibration is very important in order to insure the accuracy. There are two methods to execute the calibration: manual calibration and auto calibration. Manual calibration is time consuming. It is subjected to human errors and can lead to personal roadway hazards. Auto calibration utilizes software calculation and applies an adjustment to the raw estimated weights. It is based on the comparison of the average of a number of measurements of some specific variables (such as average vehicle weight) with the expected values. Although auto calibration has considerable value, it is only useful while the conditions monitored at the study site have been confirmed. In fact, FHWA LTPP (Federal Highway Administration Long-Term Pavement Performance) has confirmed several cases in which auto calibration settings forced scales to estimate biased calibration factors simply because the auto calibration setting was incorrect for a particular site [Hallenbeck and Weinblatt 2004]. Establishing

an effective and efficient calibration methodology is therefore important for insuring WIM accuracy.

6.5 Data Acquisition System (DAS)

The accuracy of a WIM system depends not only on a sensor itself, but also its Data Acquisition System (DAS). The DAS is an important component for proper functions of the whole system. It is comprised of two parts: the communication link to collect data and the software to review and format data.

Communication efficiency with a WIM site is a critical consideration for researchers and vendors. Retrieving data on site is time consuming and costly. Expectedly, data shall be transferred to a remote location in a rapid and efficient manner. Currently, wireless networks are a convenient way. It can be used to transmit data between the on site DAS and a remote host computer. A cellular modem that has a phone number is powered and connected to the DAS. Dialing the number of the modem, the remote computer (also equipped with a modem) can wirelessly retrieve data from the DAS. This direct dial-up data connection can provide data transfer rates of up to 14.4 kbps (one thousand bits per second) [IRD 2001]. The other way is to connect a data logger to a series of wireless network devices (Nport, D-Link, and Antenna), which convert the serial signals to a local area network (Ethernet), then by typing an IP address with the remote computer, real-time data can be downloaded remotely. By wireless connection, researchers can collect raw data flexibly and efficiently, and monitor the performance of a WIM system from a remote location. It also eliminates complicated wiring.

A better, readable and manageable data format is always preferred. Portable WIM system, such as IRD'S DAW 300PC, can be set up in a short time, and the operation system of the portable WIM has user friendly interface that shows only the data wanted. LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) is software that can be used for data acquisition much faster and more efficiently. It can synthesize, analyze, and display waveforms from sensors and develop a virtual interface with required data. However, these technologies for WIM DAS have not been fully investigated and widely applied in practice.

Chapter 7

Conclusions and Recommendations

Weigh-In-Motion has been adapted since the 1980s in Canada. The reasons it is becoming a state-of-the-practice tool for highway preservation are its high processing rate without interrupting traffic flow, and the capability of collecting site specific and real time traffic data for highway system management.

This thesis is to answer the question whether this technology is economically and technically feasible in Northern America not only presently but also in the future. This thesis investigated all significant potential benefits of a typical WIM system compared to conventional static weigh stations, with respect to weight enforcement benefit and traffic data collection benefit. Traffic characteristics, unit cost, and other critical variables were carefully chosen to evaluate these benefits, and models were constructed to compute these benefits. The demonstrated scenario of a typical single load-cell WIM shows the advantages of much less travel time and thus less delay cost to commercial carriers by allowing weight compliant commercial vehicles bypass weight stations; improved enforcement level due to high processing rate to increase inspect rate; decreased number and severity of accidents by reducing congestion on highway and diminishing overweight vehicles. An integrated benefit-cost ratio of this scenario could be 12, that means the benefit far outweighs the cost. The Longs Creek WIM system project in New Brunswick well quantified the significant benefits of the WIM system in reducing travel time and improving enforcement level. It also well illustrated the potential benefit of increased road safety. Only by this single delay benefit,the benefit-cost ratio is 3.8, which is very attractive to commercial

industry and a highway agency. This thesis also conducted an overload-pavement impact study and illustrated the importance of WIM data in pavement design and management, the importance of overload control in preserving highway system and cost saving.

On the other hand, this thesis also raised several issues related to accuracy. Accuracy has been the main technical issue of a WIM system. The material and technology of the sensors, the data acquisition system, the accuracy to cost ratio, the site selection and installation specification, the maintenance strategy and calibration technology all must be carefully considered for a WIM system in the real world. The field experience of piezoelectric WIM at CPATT, University of Waterloo further addressed this concern. Furthermore, the sensor sensitivity to temperature, roughness, and vehicle dynamics add more challenges for researchers and practitioners. However, as a whole, WIM's benefits have been recognized and will be further proved in the future. They are now used not only in pavements, but also bridges, railways and other applications.

It would be recommended to develop new technologies and materials to enhance the sensor stability, durability, and performance, develop mature software for data acquisition, improve algorithms for signal processing and calibration, establish consistent accuracy measurement methods, set up mature and consistent standards for system calibration and acceptance testing, and many other aspects of WIM. With more designation of money, engineers, and other resource, WIM would be more advanced technology and more cost-effective tool to preserve highway systems.

Appendix A

Roughness Raw Data

Data Listing (Page 1)	Job Name: **Run Name:** Date:	Dipstick Roughness Measurement **CPATT WIM SITE** November, 2006	
Step	Dist (meters)	Reading	Elevation (mm)
0			100.0
1	0.30	6.8	106.8
2	0.60	7.6	114.4
3	0.90	7.4	121.8
4	1.20	7.5	129.3
5	1.50	6.8	136.1
6	1.80	7.1	143.2
7	2.10	7.0	150.2
8	2.40	9.4	159.6
9	2.70	7.1	166.7
10	3.00	7.3	174.0
11	3.30	7.1	181.1
12	3.60	7.8	188.9
13	3.90	8.1	197.0
14	4.20	7.8	204.8
15	4.50	6.9	211.7
16	4.80	7.3	219.0
17	5.10	8.4	227.4
18	5.40	8.1	235.5
19	5.70	7.4	242.9
20	6.00	7.6	250.5
21	6.30	7.6	258.1
22	6.60	7.8	265.9
23	6.90	7.2	273.1
24	7.20	7.5	280.6
25	7.50	7.7	288.3
26	7.80	7.5	295.8
27	8.10	7.6	303.4
28	8.40	7.8	311.2
29	8.70	9.4	320.6
30	9.00	8.3	328.9
31	9.30	7.9	336.8
32	9.60	7.7	344.5
33	9.90	8.5	353.0
34	10.20	7.0	360.0
35	10.50	7.3	367.3
36	10.80	7.4	374.7
37	11.10	8.2	382.9
38	11.40	7.8	390.7
39	11.70	8.3	399.0
40	12.00	7.7	406.7
41	12.30	6.3	413.0
42	12.60	6.9	419.9
43	12.90	6.4	426.3
44	13.20	6.8	433.1
45	13.50	7.4	440.5
46	13.80	8.0	448.5
47	14.10	7.6	456.1
48	14.40	7.1	463.2
49	14.70	7.3	470.5
50	15.00	6.2	476.7
51	15.30	6.9	483.6

Data Listing (Page 2)

Job Name: Dipstick Roughness Measurement
Run Name: CPATT WIM SITE
Date: November, 2006

Step	Dist (meters)	Reading	Elevation (mm)
52	15.60	7.6	491.2
53	15.90	7.0	498.2
54	16.20	7.8	506.0
55	16.50	6.1	512.1
56	16.80	7.5	519.6
57	17.10	7.5	527.1
58	17.40	6.8	533.9
59	17.70	5.7	539.6
60	18.00	7.4	547.0
61	18.30	8.4	555.4
62	18.60	3.1	558.5
63	18.90	-7.6	550.9
64	19.20	-7.2	543.7
65	19.50	-6.2	537.5
66	19.80	-6.6	530.9
67	20.10	-6.5	524.4
68	20.40	-6.6	517.8
69	20.70	-6.9	510.9
70	21.00	-6.0	504.9
71	21.30	-6.5	498.4
72	21.60	-6.3	492.1
73	21.90	-7.2	484.9
74	22.20	-6.9	478.0
75	22.50	-5.6	472.4
76	22.80	-6.0	466.4
77	23.10	-6.5	459.9
78	23.40	-29.8	430.1
79	23.70	7.4	437.5
80	24.00	5.9	443.4
81	24.30	5.3	448.7
82	24.60	6.6	455.3
83	24.90	6.2	461.5
84	25.20	6.6	468.1
85	25.50	5.8	473.9
86	25.80	5.3	479.2
87	26.10	5.6	484.8
88	26.40	5.4	490.2
89	26.70	6.8	497.0
90	27.00	6.3	503.3
91	27.30	6.3	509.6
92	27.60	6.4	516.0
93	27.90	5.7	521.7
94	28.20	6.7	528.4
95	28.50	6.2	534.6
96	28.80	6.9	541.5
97	29.10	7.1	548.6
98	29.40	7.5	556.1
99	29.70	7.7	563.8
100	30.00	7.2	571.0
101	30.30	6.2	577.2
102	30.60	6.7	583.9

Data Listing (Page 3)

Job Name: Dipstick Roughness Measurement
Run Name: CPATT WIM SITE
Date: November, 2006

Step	Dist (meters)	Reading	Elevation (mm)
103	30.90	5.4	589.3
104	31.20	6.4	595.7
105	31.50	6.8	602.5
106	31.80	6.8	609.3
107	32.10	7.0	616.3
108	32.40	7.6	623.9
109	32.70	8.0	631.9
110	33.00	7.0	638.9
111	33.30	6.3	645.2
112	33.60	4.3	649.5
113	33.90	6.7	656.2
114	34.20	5.7	661.9
115	34.50	6.2	668.1
116	34.80	6.8	674.9
117	35.10	2.1	677.0
118	35.40	3.3	680.3
119	35.70	4.2	684.5
120	36.00	3.1	687.6
121	36.30	3.3	690.9
122	36.60	5.3	696.2
123	36.90	5.2	701.4
124	37.20	3.0	704.4
125	37.50	2.4	706.8
126	37.80	3.3	710.1
127	38.10	-3.2	706.9
128	38.40	6.2	713.1
129	38.70	6.8	719.9
130	39.00	5.1	725.0
131	39.30	6.0	731.0
132	39.60	6.1	737.1
133	39.90	6.2	743.3
134	40.20	6.2	749.5
135	40.50	5.6	755.1
136	40.80	5.4	760.5
137	41.10	5.8	766.3
138	41.40	5.1	771.4
139	41.70	6.7	778.1
140	42.00	6.0	784.1
141	42.30	5.5	789.6
142	42.60	6.3	795.9
143	42.90	6.4	802.3
144	43.20	6.1	808.4
145	43.50	5.9	814.3
146	43.80	5.9	820.2
147	44.10	6.2	826.4
148	44.40	6.1	832.5
149	44.70	6.9	839.4
150	45.00	6.1	845.5
151	45.30	7.2	852.7
152	45.60	6.3	859.0
153	45.90	6.6	865.6

Data Listing (Page 4)

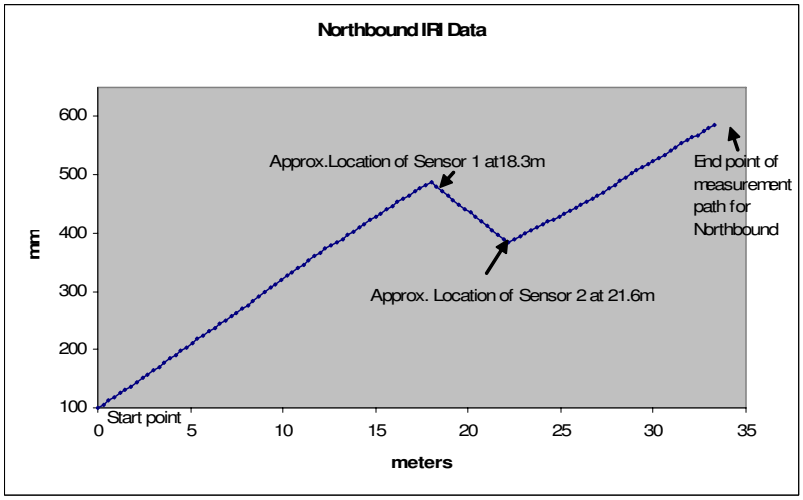
Job Name: Dipstick Roughness Measurement
Run Name: CPATT WIM SITE
Date: November, 2006

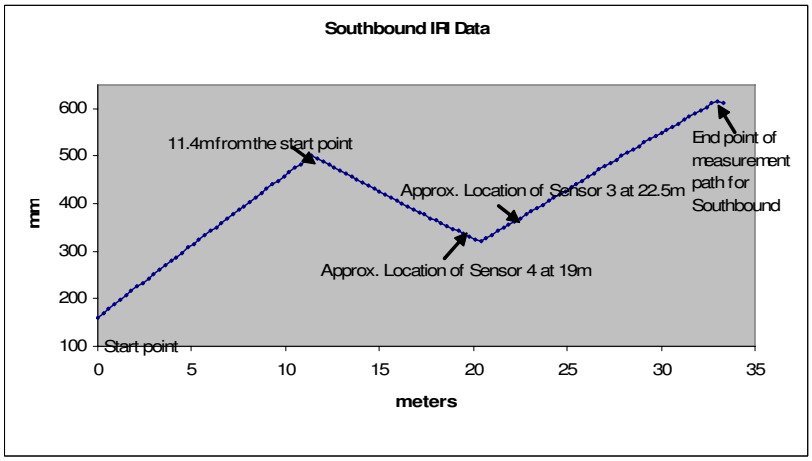
Step	Dist (meters)	Reading	Elevation (mm)
154	46.20	7.0	872.6
155	46.50	5.8	878.4
156	46.80	6.0	884.4
157	47.10	6.2	890.6
158	47.40	6.1	896.7
159	47.70	5.8	902.5
160	48.00	6.2	908.7
161	48.30	5.0	913.7
162	48.60	7.7	921.4
163	48.90	5.2	926.6
164	49.20	6.0	932.6
165	49.50	6.3	938.9
166	49.80	5.8	944.7
167	50.10	6.5	951.2
168	50.40	5.8	957.0
169	50.70	6.4	963.4
170	51.00	-6.5	956.9
171	51.30	-6.1	950.8
172	51.60	-6.3	944.5
173	51.90	-7.9	936.6
174	52.20	-5.8	930.8
175	52.50	-6.7	924.1
176	52.80	-6.1	918.0
177	53.10	-6.5	911.5
178	53.40	-6.8	904.7
179	53.70	-7.8	896.9
180	54.00	-6.1	890.8
181	54.30	-7.1	883.7
182	54.60	-7.4	876.3
183	54.90	-7.4	868.9
184	55.20	-7.8	861.1
185	55.50	-7.3	853.8
186	55.80	-6.9	846.9
187	56.10	-7.4	839.5
188	56.40	-7.6	831.9
189	56.70	-6.8	825.1
190	57.00	-7.6	817.5
191	57.30	-6.8	810.7
192	57.60	-7.2	803.5
193	57.90	-6.7	796.8
194	58.20	-7.7	789.1
195	58.50	-7.4	781.7
196	58.80	-7.6	774.1
197	59.10	-6.6	767.5
198	59.40	-6.9	760.6
199	59.70	-7.3	753.3
200	60.00	7.5	760.8
201	60.30	7.6	768.4
202	60.60	7.8	776.2
203	60.90	7.9	784.1
204	61.20	7.2	791.3

Data Listing (Page 5)

Job Name: Dipstick Roughness Measurement
Run Name: CPATT WIM SITE
Date: November, 2006

Step	Dist (meters)	Reading	Elevation (mm)
205	61.50	8.3	799.6
206	61.80	7.6	807.2
207	62.10	8.0	815.2
208	62.40	7.8	823.0
209	62.70	8.2	831.2
210	63.00	8.2	839.4
211	63.30	8.1	847.5
212	63.60	7.1	854.6
213	63.90	8.2	862.8
214	64.20	6.9	869.7
215	64.50	8.6	878.3
216	64.80	8.4	886.7
217	65.10	7.5	894.2
218	65.40	7.7	901.9
219	65.70	8.0	909.9
220	66.00	8.0	917.9
221	66.30	7.3	925.2
222	66.60	9.2	934.4
223	66.90	8.4	942.8
224	67.20	7.9	950.7
225	67.50	7.8	958.5
226	67.80	9.1	967.6
227	68.10	7.7	975.3
228	68.40	8.1	983.4
229	68.70	7.7	991.1
230	69.00	7.2	998.3
231	69.30	8.4	1006.7
232	69.60	8.9	1015.6
233	69.90	8.2	1023.8
234	70.20	7.9	1031.7
235	70.50	8.1	1039.8
236	70.80	7.6	1047.4
237	71.10	8.3	1055.7
238	71.40	7.7	1063.4
239	71.70	8.5	1071.9
240	72.00	0.9	1072.8
241	72.30	1.6	1074.4
242	72.60	3.0	1077.4
243	72.90	4.9	1082.3
244	73.20	6.0	1088.3
245	73.50	5.1	1093.4
246	73.80	3.5	1096.9
247	74.10	4.0	1100.9
248	74.40	4.8	1105.7


Northbound IRI Data
600
500
400
300
200
100
mm
0
5
10
15
20
25
30
35
meters
Approx.Location of Sensor 1 at18.3m
Approx. Location of Sensor 2 at 21.6m
End point of measurement path for Northbound
Start point


Southbound IRI Data
600
500
400
300
200
100
mm
0
5
10
15
20
25
30
35
meters
11.4m from the start point
Approx. Location of Sensor 3 at 22.5m
Approx. Location of Sensor 4 at 19m
End point of measurement path for Southbound
Start point

Appendix B

WIM Data Collectd by the Piezoelectric WIM System in a Day

```
Data For Site: CPATT
    Info 1: 925 ERB St. W.
    Info 2: Waterloo
Storage Mode : WIM
Start Time   : 11/02/06 at 00:00
Stop Time    : 11/03/06 at 00:00
Data collected by a TCC-540 (ver 2.86)

1:  Info: CPATT                    Store: ALL    Sensors: Pr-Wim-Wim-Pr   Sensor Spacing:  350cm  Loop Length:  183cm  Extra Info:
2:  Info: SOUTH BOUND              Store: ALL    Sensors: Pr-Wim-Wim-Pr   Sensor Spacing:  365cm  Loop Length:  183cm  Extra Info:
WIM Channel #1: 40,8,5,0,1.502  Auto Setup=1st+Gain,4082,5443,255,9-9,1.000
WIM Channel #2: 40,8,5,0,3.370  Auto Setup=1st+Gain,4082,5443,255,9-9,1.000
WIM Channel #3: 40,6,5,0,4.548  Auto Setup=1st+Gain,4082,5443,255,9-9,1.000
WIM Channel #4: 40,6,5,0,4.571  Auto Setup=1st+Gain,4082,5443,255,9-9,1.000
2:  06:03:12.87   69.6kph,  2 Axles, Length= 393cm, A#3  S#6  L#3  G#8  H#8 ,  332cm, GVW tonnes=  1.7,  0.6,  1.1
2:  06:31:35.43   62.6kph,  2 Axles, Length= 431cm, A#3  S#5  L#3  G#8  H#8 ,  332cm, GVW tonnes=  2.5,  1.3,  1.2
2:  06:35:03.56  SnMis #2      Info:
1:  06:35:03.52   67.5kph,  2 Axles, Length= 279cm, A#3  S#6  L#2  G#8  H#8 ,  329cm, GVW tonnes=  0.9,  0.4,  0.5
2:  06:44:29.60  SnMis #2      Info:
1:  06:46:21.75   50.8kph,  2 Axles, Length= 515cm, A#3  S#4  L#4  G#8  H#8 ,  348cm, GVW tonnes=  1.9,  1.0,  0.9
2:  06:49:43.62   37.9kph,  2 Axles, Length= 507cm, A#3  S#2  L#4  G#8  H#8 ,  345cm, GVW tonnes=  1.2,  0.6,  0.6
1:  06:58:29.77   68.6kph,  2 Axles, Length= 502cm, A#3  S#6  L#4  G#8  H#8 ,  363cm, GVW tonnes=  1.9,  1.0,  0.9
2:  07:01:28.86   51.5kph,  6 Axles, Length=1927cm, A#10 S#4  L#10 G#8  H#8 ,  420cm  130cm  846cm  182cm  179cm, GVW tonnes= 42.8,  4.9,  6.9,  6.5,  8.6,  8.1,  7.8
2:  07:02:02.29   50.4kph,  3 Axles, Length= 896cm, A#6  S#4  L#6  G#6  H#6 ,  574cm  135cm, GVW tonnes= 16.1,  4.9,  5.8,  5.4
2:  07:06:35.04   34.3kph,  3 Axles, Length= 937cm, A#6  S#2  L#7  G#8  H#8 ,  562cm  154cm, GVW tonnes= 16.0,  2.6,  7.3,  6.1
2:  07:08:34.67   32.3kph,  3 Axles, Length= 988cm, A#6  S#2  L#7  G#7  H#7 ,  608cm  152cm, GVW tonnes= 15.2,  4.7,  5.6,  4.9
2:  07:09:10.70   72.1kph,  2 Axles, Length= 459cm, A#2  S#6  L#4  G#6  H#6 ,  296cm, GVW tonnes=  1.9,  1.0,  0.9
1:  07:10:29.90   57.4kph,  3 Axles, Length= 917cm, A#6  S#5  L#7  G#8  H#8 ,  576cm  136cm, GVW tonnes= 12.1,  4.4,  4.2,  3.5
2:  07:12:14.08   49.8kph,  6 Axles, Length=1920cm, A#10 S#4  L#10 G#8  H#8 ,  433cm  131cm  843cm  178cm  182cm, GVW tonnes= 38.4,  5.2,  6.6,  7.2,  6.3,  6.7,  6.4
2:  07:12:43.61   38.8kph,  2 Axles, Length= 583cm, A#13 S#2  L#4  G#5  H#5 ,  312cm, GVW tonnes= 12.6,  5.2,  7.4
1:  07:14:47.93   31.6kph,  2 Axles, Length= 563cm, A#13 S#1  L#4  G#8  H#8 ,  312cm, GVW tonnes=  9.1,  3.9,  5.2
2:  07:14:53.27   34.6kph,  3 Axles, Length= 847cm, A#6  S#2  L#6  G#8  H#8 ,  388cm  164cm, GVW tonnes=  9.0,  2.8,  4.6,  1.6
2:  07:15:41.71   46.3kph,  2 Axles, Length= 571cm, A#3  S#3  L#4  G#6  H#6 ,  374cm, GVW tonnes=  1.2,  0.6,  0.6
2:  07:19:01.20   49.1kph,  4 Axles, Length=1043cm, A#3  S#4  L#7  G#8  H#8 ,  427cm  375cm   85cm, GVW tonnes=  4.2,  1.1,  1.3,  0.9,  0.9
1:  07:19:34.27   39.0kph,  3 Axles, Length= 978cm, A#6  S#2  L#7  G#8  H#8 ,  606cm  152cm, GVW tonnes= 13.4,  4.7,  4.3,  4.4
2:  07:19:52.61   45.1kph,  2 Axles, Length= 599cm, A#3  S#3  L#4  G#6  H#6 ,  427cm, GVW tonnes=  2.1,  1.2,  0.9
1:  07:20:30.45   36.1kph,  3 Axles, Length= 931cm, A#6  S#2  L#7  G#6  H#6 ,  584cm  153cm, GVW tonnes= 12.7,  5.4,  3.8,  3.5
1:  07:21:04.52   68.6kph,  2 Axles, Length= 464cm, A#2  S#6  L#4  G#6  H#6 ,  296cm, GVW tonnes=  1.6,  0.8,  0.8
2:  07:21:20.36   37.6kph,  6 Axles, Length=1888cm, A#10 S#2  L#10 G#7  H#7 ,  361cm  126cm  872cm  179cm  178cm, GVW tonnes= 38.1,  0.9,  7.3,  7.3,  7.4,  7.5,  7.7
2:  07:22:40.53   26.4kph,  2 Axles, Length= 745cm, A#2  S#1  L#5  G#7  H#7 ,  291cm, GVW tonnes=  1.2,  0.6,  0.6
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2:  07:24:59.55   54.7kph,  2 Axles, Length= 572cm, A#3  S#4  L#4  G#8  H#8 ,  396cm, GVW tonnes=  2.1,  1.1,  1.0
2:  07:25:34.31   50.9kph,  4 Axles, Length= 972cm, A#3  S#4  L#7  G#6  H#6 ,  348cm  395cm   87cm, GVW tonnes=  3.2,  0.7,  1.3,  0.8,  0.4
1:  07:25:56.12   55.1kph,  6 Axles, Length=1908cm, A#10 S#4  L#10 G#8  H#8 ,  423cm  130cm  851cm  183cm  182cm, GVW tonnes= 15.9,  3.3,  2.7,  2.6,  2.6,  2.3,  2.4
2:  07:26:24.26   45.3kph,  2 Axles, Length= 614cm, A#5  S#3  L#5  G#6  H#6 ,  517cm, GVW tonnes=  6.1,  2.5,  3.6
2:  07:26:40.43   55.2kph,  3 Axles, Length= 895cm, A#6  S#4  L#6  G#4  H#4 ,  557cm  151cm, GVW tonnes= 13.0,  3.1,  5.1,  4.8
2:  07:28:40.50   31.6kph,  3 Axles, Length=1020cm, A#3  S#1  L#7  G#8  H#7 ,  391cm  399cm, GVW tonnes=  1.8,  0.7,  0.9,  0.2
2:  07:29:14.91   35.3kph,  3 Axles, Length= 866cm, A#6  S#2  L#6  G#6  H#6 ,  464cm  135cm, GVW tonnes= 16.7,  7.1,  5.6,  4.0
1:  07:29:57.86   57.8kph,  2 Axles, Length= 558cm, A#3  S#5  L#4  G#8  H#8 ,  373cm, GVW tonnes=  1.2,  0.6,  0.6
2:  07:30:45.69   45.6kph,  2 Axles, Length= 590cm, A#3  S#3  L#4  G#7  H#7 ,  437cm, GVW tonnes=  2.8,  1.5,  1.3
1:  07:31:57.15   23.3kph,  2 Axles, Length= 824cm, A#2  S#1  L#6  G#7  H#7 ,  265cm, GVW tonnes=  2.1,  1.5,  0.6
1:  07:32:01.18   21.9kph,  4 Axles, Length= 937cm, A#3  S#1  L#7  G#2  H#1 ,  377cm  345cm   75cm, GVW tonnes=  1.8,  0.3,  1.1,  0.2,  0.2
2:  07:32:30.68   41.8kph,  2 Axles, Length= 515cm, A#3  S#3  L#4  G#7  H#7 ,  400cm, GVW tonnes=  1.8,  1.2,  0.6
1:  07:35:48.31   52.7kph,  4 Axles, Length= 963cm, A#3  S#4  L#7  G#8  H#8 ,  349cm  401cm   87cm, GVW tonnes=  3.0,  1.0,  1.3,  0.5,  0.2
1:  07:36:12.60   49.8kph,  2 Axles, Length= 617cm, A#5  S#4  L#5  G#5  H#5 ,  519cm, GVW tonnes=  4.0,  2.1,  1.9
1:  07:36:15.32   51.6kph,  3 Axles, Length= 936cm, A#6  S#4  L#7  G#1  H#1 ,  557cm  151cm, GVW tonnes= 11.5,  3.6,  3.9,  4.0
1:  07:36:44.17   36.8kph,  3 Axles, Length= 882cm, A#6  S#2  L#6  G#5  H#5 ,  464cm  133cm, GVW tonnes= 12.1,  6.5,  2.5,  3.1
1:  07:38:37.82   33.1kph,  4 Axles, Length=1041cm, A#3  S#2  L#7  G#7  H#7 ,  401cm  403cm   79cm, GVW tonnes=  2.6,  1.1,  1.1,  0.1,  0.3
2:  07:38:54.64   37.2kph,  2 Axles, Length= 622cm, A#3  S#2  L#5  G#8  H#8 ,  429cm, GVW tonnes=  1.2,  0.6,  0.6
2:  07:38:56.81   37.7kph,  3 Axles, Length= 977cm, A#3  S#2  L#7  G#1  H#1 ,  332cm  397cm, GVW tonnes=  2.1,  0.8,  0.8,  0.5
2:  07:39:00.21   35.2kph,  2 Axles, Length= 565cm, A#3  S#2  L#4  G#2  H#1 ,  406cm, GVW tonnes=  1.9,  1.3,  0.6
1:  07:43:18.74   44.7kph,  2 Axles, Length= 549cm, A#3  S#3  L#4  G#8  H#8 ,  406cm, GVW tonnes=  2.0,  1.0,  1.0
1:  07:44:01.86   45.2kph,  6 Axles, Length=1921cm, A#10 S#3  L#10 G#6  H#6 ,  437cm  131cm  842cm  178cm  180cm, GVW tonnes= 16.2,  3.6,  2.6,  3.0,  2.5,  2.1,  2.4
2:  07:44:10.53   61.3kph,  2 Axles, Length= 473cm, A#3  S#5  L#4  G#8  H#8 ,  352cm, GVW tonnes=  1.9,  1.0,  0.9
2:  07:45:46.69   63.2kph,  3 Axles, Length= 893cm, A#6  S#5  L#6  G#7  H#7 ,  558cm  151cm, GVW tonnes= 13.3,  3.0,  4.8,  5.5
1:  07:46:30.80   64.4kph,  2 Axles, Length= 523cm, A#3  S#6  L#4  G#8  H#8 ,  353cm, GVW tonnes=  1.4,  0.7,  0.7
2:  07:49:34.48   39.6kph,  3 Axles, Length= 931cm, A#6  S#2  L#7  G#8  H#8 ,  556cm  154cm, GVW tonnes= 19.3,  6.6,  6.5,  6.2
1:  07:50:56.00   42.3kph,  2 Axles, Length= 559cm, A#3  S#3  L#4  G#8  H#8 ,  409cm, GVW tonnes=  2.2,  1.6,  0.6
1:  07:54:23.37   64.3kph,  3 Axles, Length= 919cm, A#6  S#6  L#7  G#8  H#8 ,  555cm  152cm, GVW tonnes= 12.4,  3.9,  4.2,  4.3
1:  07:56:14.69   42.7kph,  2 Axles, Length= 634cm, A#3  S#3  L#5  G#7  H#7 ,  433cm, GVW tonnes=  2.2,  0.6,  1.6
2:  07:58:03.05  SnMis #2      Info:
2:  07:58:04.28  SnMis #1      Info:
1:  07:58:03.01   61.9kph,  6 Axles, Length=1681cm, A#10 S#5  L#9  G#7  H#7 ,  387cm  126cm  874cm  179cm  179cm, GVW tonnes=  7.1,  1.1,  1.4,  1.3,  1.1,  1.1,  1.1
1:  07:59:02.43   29.9kph,  3 Axles, Length= 937cm, A#6  S#1  L#7  G#6  H#6 ,  548cm  154cm, GVW tonnes= 10.0,  2.2,  3.7,  4.1
2:  07:59:41.45   77.8kph,  2 Axles, Length= 436cm, A#2  S#7  L#3  G#8  H#8 ,  296cm, GVW tonnes=  1.7,  0.9,  0.8
1:  08:00:13.91   76.0kph,  4 Axles, Length= 963cm, A#3  S#7  L#7  G#7  H#7 ,  332cm  410cm   85cm, GVW tonnes=  2.5,  0.8,  0.8,  0.5,  0.4
2:  08:04:10.62   52.9kph,  3 Axles, Length= 862cm, A#6  S#4  L#6  G#8  H#8 ,  457cm  150cm, GVW tonnes= 16.2,  5.5,  5.5,  5.2
2:  08:04:30.99   61.0kph,  3 Axles, Length= 928cm, A#6  S#5  L#7  G#5  H#4 ,  557cm  151cm, GVW tonnes= 16.9,  5.7,  5.7,  5.5
1:  08:12:12.85   67.3kph,  3 Axles, Length= 925cm, A#6  S#6  L#7  G#8  H#8 ,  549cm  100cm, GVW tonnes=  9.4,  3.1,  3.8,  2.5
2:  08:12:37.77   45.1kph,  3 Axles, Length= 945cm, A#6  S#3  L#7  G#8  H#8 ,  552cm  153cm, GVW tonnes= 15.6,  4.9,  5.7,  5.0
2:  08:13:44.21   57.8kph,  2 Axles, Length= 655cm, A#5  S#5  L#5  G#7  H#7 ,  528cm, GVW tonnes=  6.3,  3.0,  3.3
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2:  08:18:05.76   50.9kph,  3 Axles, Length= 937cm, A#6  S#4  L#7  G#8  H#8 ,  607cm  154cm, GVW tonnes= 19.6,  5.6,  7.2,  6.8
1:  08:18:18.32   47.9kph,  3 Axles, Length= 873cm, A#6  S#3  L#6  G#8  H#8 ,  460cm  151cm, GVW tonnes= 11.1,  5.1,  3.2,  2.8
1:  08:20:03.70   54.5kph,  3 Axles, Length= 949cm, A#6  S#4  L#7  G#7  H#7 ,  557cm  152cm, GVW tonnes= 11.1,  4.4,  2.8,  3.9
2:  08:20:57.34   65.8kph,  4 Axles, Length=1024cm, A#3  S#6  L#7  G#8  H#8 ,  420cm  407cm   80cm, GVW tonnes=  3.7,  1.4,  1.3,  0.5,  0.5
2:  08:21:51.42   60.1kph,  3 Axles, Length= 907cm, A#6  S#5  L#6  G#6  H#6 ,  555cm  151cm, GVW tonnes= 15.5,  5.5,  5.2,  4.8
2:  08:22:08.94  SnMis #1      Info:
1:  08:22:08.98  SnMis #2      Info:
2:  08:22:47.15   38.7kph,  2 Axles, Length= 808cm, A#3  S#2  L#6  G#6  H#6 ,  314cm, GVW tonnes=  1.2,  0.6,  0.6
2:  08:23:48.32   36.7kph,  3 Axles, Length= 825cm, A#6  S#2  L#6  G#7  H#7 ,  464cm  138cm, GVW tonnes= 13.5,  3.4,  4.8,  5.3
2:  08:26:14.83   55.1kph,  2 Axles, Length= 547cm, A#3  S#4  L#4  G#8  H#8 ,  374cm, GVW tonnes=  1.2,  0.6,  0.6
1:  08:29:08.43   46.8kph,  3 Axles, Length= 925cm, A#6  S#3  L#7  G#8  H#8 ,  609cm  152cm, GVW tonnes= 14.0,  5.1,  4.3,  4.6
1:  08:29:09.91   48.7kph,  2 Axles, Length= 520cm, A#3  S#4  L#4  G#1  H#1 ,  335cm, GVW tonnes=  2.6,  1.3,  1.3
1:  08:29:45.42   68.4kph,  3 Axles, Length= 895cm, A#6  S#6  L#6  G#6  H#6 ,  554cm  154cm, GVW tonnes= 11.9,  3.4,  4.6,  3.9
1:  08:29:57.34   69.2kph,  4 Axles, Length=1033cm, A#3  S#6  L#7  G#3  H#3 ,  421cm  410cm   81cm, GVW tonnes=  3.6,  1.6,  1.5,  0.3,  0.2
1:  08:31:29.04   53.4kph,  2 Axles, Length= 640cm, A#5  S#4  L#5  G#7  H#7 ,  526cm, GVW tonnes=  4.9,  2.3,  2.6
2:  08:31:58.83   41.3kph,  3 Axles, Length= 903cm, A#6  S#3  L#6  G#8  H#8 ,  530cm  156cm, GVW tonnes= 14.2,  5.3,  5.8,  3.1
2:  08:32:26.20   61.0kph,  3 Axles, Length= 816cm, A#6  S#5  L#6  G#5  H#5 ,  562cm  138cm, GVW tonnes= 10.9,  3.8,  3.7,  3.4
2:  08:36:27.35   54.5kph,  4 Axles, Length= 936cm, A#3  S#4  L#7  G#8  H#8 ,  363cm  396cm   80cm, GVW tonnes=  3.2,  0.9,  0.6,  1.0,  0.7
1:  08:38:55.22   42.9kph,  3 Axles, Length= 890cm, A#6  S#3  L#6  G#8  H#8 ,  467cm  139cm, GVW tonnes= 10.7,  4.8,  2.8,  3.1
2:  08:42:09.85   44.0kph,  4 Axles, Length=1058cm, A#3  S#3  L#7  G#8  H#8 ,  335cm  447cm   86cm, GVW tonnes=  4.0,  1.1,  1.4,  0.9,  0.6
2:  08:43:06.40   46.0kph,  2 Axles, Length= 548cm, A#3  S#3  L#4  G#6  H#6 ,  405cm, GVW tonnes=  2.2,  1.6,  0.6
2:  08:44:27.47   58.2kph,  4 Axles, Length= 935cm, A#3  S#5  L#7  G#7  H#7 ,  335cm  397cm   84cm, GVW tonnes=  2.7,  0.7,  1.2,  0.4,  0.4
1:  08:44:48.93   54.6kph,  2 Axles, Length= 571cm, A#3  S#4  L#4  G#8  H#8 ,  376cm, GVW tonnes=  1.2,  0.6,  0.6
1:  08:46:05.82   23.8kph,  3 Axles, Length= 868cm, A#6  S#1  L#6  G#7  H#7 ,  386cm  163cm, GVW tonnes= 10.6,  2.3,  6.5,  1.8
1:  08:47:52.36   40.7kph,  3 Axles, Length= 916cm, A#6  S#3  L#7  G#7  H#7 ,  530cm  153cm, GVW tonnes= 11.3,  4.5,  3.5,  3.3
2:  08:48:19.32   53.6kph,  4 Axles, Length= 977cm, A#3  S#4  L#7  G#8  H#8 ,  391cm  396cm   85cm, GVW tonnes=  4.4,  1.0,  1.5,  1.2,  0.7
1:  08:51:09.37   60.5kph,  3 Axles, Length= 885cm, A#6  S#5  L#6  G#8  H#8 ,  563cm  139cm, GVW tonnes=  8.5,  3.1,  2.7,  2.7
2:  08:53:11.48   36.7kph,  3 Axles, Length= 933cm, A#6  S#2  L#7  G#8  H#8 ,  584cm  152cm, GVW tonnes= 14.5,  5.5,  4.6,  4.4
1:  08:53:26.14   59.7kph,  4 Axles, Length= 919cm, A#3  S#5  L#7  G#8  H#8 ,  361cm  398cm   83cm, GVW tonnes=  3.1,  1.1,  1.5,  0.3,  0.2
1:  08:53:54.48   55.3kph,  4 Axles, Length=1046cm, A#3  S#4  L#7  G#5  H#5 ,  335cm  450cm   86cm, GVW tonnes=  3.2,  1.1,  1.2,  0.5,  0.4
1:  08:54:57.37   66.9kph,  4 Axles, Length= 965cm, A#3  S#6  L#7  G#7  H#7 ,  335cm  400cm   84cm, GVW tonnes=  2.5,  0.7,  1.0,  0.3,  0.5
1:  08:56:27.58   61.4kph,  4 Axles, Length=1006cm, A#3  S#5  L#7  G#7  H#7 ,  394cm  401cm   87cm, GVW tonnes=  3.8,  1.4,  1.6,  0.5,  0.3
1:  08:58:11.04   63.6kph,  2 Axles, Length= 533cm, A#3  S#5  L#4  G#7  H#7 ,  404cm, GVW tonnes=  2.0,  1.4,  0.6
2:  09:01:35.35   44.6kph,  2 Axles, Length= 587cm, A#3  S#3  L#4  G#8  H#8 ,  414cm, GVW tonnes=  1.2,  0.6,  0.6
2:  09:02:54.42   38.2kph,  2 Axles, Length= 752cm, A#3  S#2  L#5  G#7  H#7 ,  447cm, GVW tonnes=  1.9,  1.3,  0.6
2:  09:03:14.29   50.3kph,  2 Axles, Length= 509cm, A#3  S#4  L#4  G#4  H#4 ,  331cm, GVW tonnes=  1.4,  0.8,  0.6
2:  09:04:49.68   40.2kph,  3 Axles, Length= 895cm, A#6  S#3  L#6  G#7  H#7 ,  581cm  149cm, GVW tonnes= 12.1,  4.7,  3.4,  4.0
1:  09:05:52.02   35.2kph,  3 Axles, Length= 918cm, A#6  S#2  L#7  G#8  H#8 ,  585cm  152cm, GVW tonnes= 14.2,  5.9,  4.3,  4.0
2:  09:06:19.30   47.8kph,  2 Axles, Length= 527cm, A#3  S#3  L#4  G#7  H#7 ,  357cm, GVW tonnes=  1.1,  0.5,  0.6
2:  09:07:13.60   54.1kph,  3 Axles, Length= 937cm, A#6  S#4  L#7  G#6  H#6 ,  609cm  153cm, GVW tonnes= 17.6,  6.4,  5.5,  5.7
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1:  09:09:01.48   54.0kph,  2 Axles, Length= 497cm, A#3  S#4  L#4  G#8  H#8 ,  346cm, GVW tonnes=  1.4,  0.7,  0.7
1:  09:09:25.29   35.3kph,  2 Axles, Length= 572cm, A#3  S#2  L#4  G#5  H#5 ,  416cm, GVW tonnes=  1.2,  0.6,  0.6
1:  09:10:37.60   71.6kph,  2 Axles, Length= 493cm, A#3  S#6  L#4  G#7  H#7 ,  333cm, GVW tonnes=  1.8,  1.0,  0.8
1:  09:13:38.84   31.8kph,  2 Axles, Length= 822cm, A#3  S#1  L#6  G#8  H#8 ,  319cm, GVW tonnes=  1.2,  0.6,  0.6
2:  09:14:17.10   66.7kph,  2 Axles, Length= 505cm, A#3  S#6  L#4  G#8  H#8 ,  348cm, GVW tonnes=  1.6,  0.9,  0.7
1:  09:14:29.63   41.3kph,  3 Axles, Length= 869cm, A#6  S#3  L#6  G#6  H#6 ,  579cm  149cm, GVW tonnes= 11.8,  4.2,  3.9,  3.7
1:  09:18:01.05   33.8kph,  2 Axles, Length= 762cm, A#3  S#2  L#6  G#8  H#8 ,  446cm, GVW tonnes=  2.7,  1.2,  1.5
2:  09:18:36.67   44.3kph,  2 Axles, Length= 610cm, A#5  S#3  L#5  G#8  H#8 ,  518cm, GVW tonnes=  5.4,  2.3,  3.1
2:  09:19:26.03   74.4kph,  2 Axles, Length= 504cm, A#3  S#7  L#4  G#6  H#6 ,  352cm, GVW tonnes=  1.6,  0.9,  0.7
1:  09:20:54.91   58.3kph,  3 Axles, Length= 944cm, A#6  S#5  L#7  G#8  H#8 ,  612cm  155cm, GVW tonnes= 13.0,  5.0,  4.3,  3.7
2:  09:21:34.61   57.9kph,  6 Axles, Length=1903cm, A#10 S#5  L#10 G#8  H#8 ,  419cm  129cm  842cm  180cm  178cm, GVW tonnes= 40.9,  5.5,  7.5,  7.5,  7.1,  6.3,  7.0
1:  09:23:22.24   74.2kph,  2 Axles, Length= 515cm, A#3  S#7  L#4  G#8  H#8 ,  349cm, GVW tonnes=  1.6,  0.9,  0.7
1:  09:23:47.67   74.6kph,  2 Axles, Length= 502cm, A#3  S#7  L#4  G#5  H#5 ,  351cm, GVW tonnes=  1.6,  0.9,  0.7
2:  09:27:10.47   49.9kph,  3 Axles, Length= 851cm, A#6  S#4  L#6  G#8  H#8 ,  471cm  139cm, GVW tonnes= 19.5,  5.0,  7.4,  7.1
1:  09:28:47.13   42.7kph,  2 Axles, Length= 622cm, A#5  S#3  L#5  G#8  H#8 ,  515cm, GVW tonnes=  4.3,  2.2,  2.1
2:  09:30:18.78   48.0kph,  4 Axles, Length= 975cm, A#3  S#3  L#7  G#8  H#8 ,  348cm  395cm   78cm, GVW tonnes=  3.5,  0.9,  1.1,  0.8,  0.7
2:  09:32:58.31   48.4kph,  3 Axles, Length= 943cm, A#6  S#4  L#7  G#8  H#8 ,  620cm  149cm, GVW tonnes= 13.4,  5.8,  3.0,  4.6
1:  09:32:59.85   47.5kph,  2 Axles, Length= 561cm, A#3  S#3  L#4  G#8  H#8 ,  399cm, GVW tonnes=  2.8,  1.4,  1.4
2:  09:33:04.00   54.2kph,  3 Axles, Length= 936cm, A#6  S#4  L#7  G#2  H#2 ,  556cm  154cm, GVW tonnes= 15.8,  5.5,  4.9,  5.4
1:  09:33:27.06   57.8kph,  4 Axles, Length= 981cm, A#3  S#5  L#7  G#5  H#5 ,  350cm  398cm   79cm, GVW tonnes=  3.6,  1.1,  1.2,  0.7,  0.6
2:  09:35:51.00   90.8kph,  2 Axles, Length= 495cm, A#3  S#9  L#4  G#8  H#8 ,  334cm, GVW tonnes=  1.3,  0.7,  0.6
1:  09:36:53.67   55.3kph,  3 Axles, Length= 876cm, A#6  S#4  L#6  G#8  H#8 ,  472cm  138cm, GVW tonnes= 10.8,  2.9,  3.9,  4.0
2:  09:37:33.17   56.0kph,  2 Axles, Length= 544cm, A#3  S#4  L#4  G#7  H#7 ,  390cm, GVW tonnes=  1.6,  1.0,  0.6
1:  09:40:08.86   69.5kph,  3 Axles, Length= 960cm, A#6  S#6  L#7  G#8  H#8 ,  556cm  148cm, GVW tonnes= 11.9,  5.1,  4.1,  2.7
1:  09:42:32.46   77.0kph,  2 Axles, Length= 455cm, A#2  S#7  L#3  G#8  H#8 ,  295cm, GVW tonnes=  2.4,  1.2,  1.2
1:  09:42:47.88   52.7kph,  3 Axles, Length= 942cm, A#6  S#4  L#7  G#4  H#4 ,  619cm  148cm, GVW tonnes= 13.7,  6.2,  3.1,  4.4
2:  09:42:50.83   50.6kph,  6 Axles, Length=1918cm, A#10 S#4  L#10 G#8  H#8 ,  433cm  130cm  840cm  178cm  181cm, GVW tonnes= 34.6,  5.0,  6.4,  5.9,  6.1,  5.7,  5.5
1:  09:47:27.80   37.2kph,  2 Axles, Length= 562cm, A#3  S#2  L#4  G#8  H#8 ,  393cm, GVW tonnes=  2.3,  1.0,  1.3
1:  09:47:31.97   41.0kph,  6 Axles, Length=1883cm, A#10 S#3  L#10 G#2  H#2 ,  421cm  129cm  840cm  180cm  178cm, GVW tonnes= 16.6,  3.2,  3.0,  2.8,  2.6,  2.4,  2.6
2:  09:48:13.48   47.2kph,  2 Axles, Length= 566cm, A#3  S#3  L#4  G#8  H#8 ,  387cm, GVW tonnes=  2.1,  0.6,  1.5
2:  09:52:41.62   56.5kph,  3 Axles, Length= 930cm, A#6  S#5  L#7  G#8  H#8 ,  606cm  152cm, GVW tonnes= 23.6,  6.2,  8.9,  8.5
2:  09:55:01.58   56.0kph,  2 Axles, Length= 646cm, A#5  S#4  L#5  G#8  H#8 ,  524cm, GVW tonnes= 10.1,  3.5,  6.6
1:  09:55:27.97   46.8kph,  2 Axles, Length= 572cm, A#3  S#3  L#4  G#8  H#8 ,  386cm, GVW tonnes=  1.2,  0.6,  0.6
2:  09:58:42.21   77.6kph,  2 Axles, Length= 505cm, A#3  S#7  L#4  G#8  H#8 ,  351cm, GVW tonnes=  1.6,  0.9,  0.7
1:  10:00:50.76   70.3kph,  2 Axles, Length= 508cm, A#3  S#6  L#4  G#8  H#8 ,  350cm, GVW tonnes=  1.7,  1.0,  0.7
2:  10:00:57.29   59.2kph,  2 Axles, Length= 556cm, A#3  S#5  L#4  G#8  H#8 ,  374cm, GVW tonnes=  1.2,  0.6,  0.6
2:  10:02:28.95   57.4kph,  6 Axles, Length=1874cm, A#10 S#5  L#10 G#7  H#7 ,  385cm  127cm  873cm  180cm  179cm, GVW tonnes= 38.7,  3.9,  7.7,  6.8,  7.3,  6.6,  6.4
1:  10:03:54.42   57.5kph,  3 Axles, Length= 958cm, A#6  S#5  L#7  G#8  H#8 ,  609cm  153cm, GVW tonnes= 14.1,  5.6,  4.3,  4.2
2:  10:04:17.37   70.3kph,  2 Axles, Length= 480cm, A#3  S#6  L#4  G#7  H#7 ,  350cm, GVW tonnes=  1.6,  0.8,  0.8
1:  10:05:54.85   55.1kph,  6 Axles, Length=1909cm, A#10 S#4  L#10 G#8  H#7 ,  432cm  130cm  836cm  176cm  179cm, GVW tonnes= 18.2,  3.9,  3.5,  3.3,  2.4,  2.6,  2.5
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2:  10:08:15.80   61.5kph,  3 Axles, Length= 871cm, A#6  S#5  L#6  G#8  H#8 ,  471cm  138cm, GVW tonnes= 21.7,  5.6,  7.8,  8.3
2:  10:09:03.76   61.6kph,  2 Axles, Length= 622cm, A#3  S#5  L#5  G#6  H#6 ,  378cm, GVW tonnes=  1.2,  0.6,  0.6
1:  10:09:11.30   48.3kph,  2 Axles, Length= 523cm, A#3  S#4  L#4  G#8  H#8 ,  354cm, GVW tonnes=  2.1,  1.1,  1.0
1:  10:09:57.37   54.9kph,  2 Axles, Length= 637cm, A#5  S#4  L#5  G#6  H#6 ,  525cm, GVW tonnes=  5.1,  2.5,  2.6
1:  10:13:14.67   57.3kph,  2 Axles, Length= 579cm, A#3  S#5  L#4  G#8  H#8 ,  378cm, GVW tonnes=  1.2,  0.6,  0.6
2:  10:13:14.82   54.2kph,  6 Axles, Length=1900cm, A#10 S#4  L#10 G#8  H#8 ,  401cm  152cm  857cm  177cm  179cm, GVW tonnes= 35.7,  4.0,  6.4,  6.9,  6.3,  6.0,  6.1
2:  10:14:53.24   46.4kph,  4 Axles, Length=1111cm, A#3  S#3  L#7  G#7  H#7 ,  347cm  469cm   81cm, GVW tonnes=  3.1,  1.2,  1.2,  0.5,  0.2
2:  10:16:12.23   45.7kph,  3 Axles, Length= 873cm, A#6  S#3  L#6  G#7  H#7 ,  462cm  135cm, GVW tonnes= 24.5,  8.8,  8.0,  7.7
1:  10:16:41.73   49.0kph,  3 Axles, Length= 812cm, A#6  S#4  L#6  G#8  H#8 ,  473cm  138cm, GVW tonnes=  8.4,  2.6,  3.1,  2.7
1:  10:20:55.75   72.4kph,  2 Axles, Length= 630cm, A#3  S#7  L#5  G#8  H#8 ,  370cm, GVW tonnes=  2.1,  0.6,  1.5
2:  10:23:58.79   57.7kph,  4 Axles, Length= 955cm, A#3  S#5  L#7  G#8  H#8 ,  346cm  382cm   85cm, GVW tonnes=  5.3,  1.1,  1.5,  1.5,  1.2
1:  10:25:05.71   49.7kph,  4 Axles, Length=1087cm, A#3  S#4  L#7  G#8  H#8 ,  346cm  468cm   80cm, GVW tonnes=  3.3,  1.4,  1.0,  0.4,  0.5
2:  10:26:12.73   46.3kph,  3 Axles, Length= 985cm, A#6  S#3  L#7  G#8  H#8 ,  493cm  133cm, GVW tonnes= 15.1,  4.6,  5.7,  4.8
2:  10:26:15.43   47.9kph,  2 Axles, Length= 568cm, A#3  S#3  L#4  G#1  H#1 ,  397cm, GVW tonnes=  2.1,  1.1,  1.0
1:  10:26:16.93   56.6kph,  6 Axles, Length=1862cm, A#10 S#5  L#10 G#7  H#7 ,  386cm  126cm  868cm  178cm  176cm, GVW tonnes= 18.2,  3.5,  3.3,  3.4,  2.6,  2.6,  2.8
1:  10:26:50.65   53.7kph,  3 Axles, Length= 885cm, A#6  S#4  L#6  G#6  H#6 ,  469cm  137cm, GVW tonnes= 14.4,  7.3,  3.6,  3.5
1:  10:31:48.57   61.8kph,  4 Axles, Length= 935cm, A#3  S#5  L#7  G#8  H#8 ,  348cm  385cm   87cm, GVW tonnes=  3.6,  1.3,  1.2,  0.7,  0.4
2:  10:33:24.05   35.6kph,  3 Axles, Length= 753cm, A#6  S#2  L#5  G#8  H#8 ,  440cm  153cm, GVW tonnes= 12.3,  4.0,  4.4,  3.9
2:  10:33:31.08   50.5kph,  2 Axles, Length= 585cm, A#3  S#4  L#4  G#2  H#2 ,  411cm, GVW tonnes=  2.2,  0.6,  1.6
2:  10:34:31.51   36.9kph,  3 Axles, Length= 899cm, A#6  S#2  L#6  G#7  H#7 ,  471cm  138cm, GVW tonnes= 19.2,  5.4,  6.7,  7.1
1:  10:35:05.69   50.5kph,  3 Axles, Length= 984cm, A#6  S#4  L#7  G#8  H#8 ,  496cm  132cm, GVW tonnes= 12.7,  4.0,  4.1,  4.6
2:  10:37:19.02   31.0kph,  3 Axles, Length= 805cm, A#6  S#1  L#6  G#8  H#8 ,  420cm  151cm, GVW tonnes= 15.6,  1.4,  7.3,  6.9
2:  10:37:21.75   33.0kph,  3 Axles, Length= 858cm, A#6  S#2  L#6  G#1  H#1 ,  463cm  141cm, GVW tonnes= 19.6,  5.0,  8.2,  6.4
2:  10:38:12.83   58.4kph,  3 Axles, Length= 890cm, A#6  S#5  L#6  G#6  H#6 ,  472cm  138cm, GVW tonnes= 21.6,  5.4,  8.5,  7.7
2:  10:39:06.36   38.4kph,  2 Axles, Length= 571cm, A#3  S#2  L#4  G#6  H#6 ,  425cm, GVW tonnes=  1.9,  1.1,  0.8
2:  10:39:30.13   44.5kph,  2 Axles, Length= 628cm, A#5  S#3  L#5  G#5  H#5 ,  517cm, GVW tonnes= 10.3,  3.2,  7.1
1:  10:40:47.17   46.2kph,  3 Axles, Length= 729cm, A#6  S#3  L#5  G#8  H#8 ,  439cm  153cm, GVW tonnes= 12.8,  4.8,  3.8,  4.2
1:  10:40:59.09   60.1kph,  6 Axles, Length=1862cm, A#10 S#5  L#10 G#3  H#3 ,  401cm  150cm  852cm  176cm  178cm, GVW tonnes= 17.9,  3.4,  3.4,  3.0,  2.6,  2.6,  2.9
1:  10:41:10.86   64.6kph,  2 Axles, Length= 551cm, A#3  S#6  L#4  G#3  H#3 ,  425cm, GVW tonnes=  2.3,  1.3,  1.0
1:  10:42:31.64   39.8kph,  3 Axles, Length= 883cm, A#6  S#2  L#6  G#7  H#7 ,  472cm  139cm, GVW tonnes= 12.3,  3.7,  4.5,  4.1
2:  10:42:33.34   42.1kph,  2 Axles, Length= 423cm, A#2  S#3  L#3  G#8  H#8 ,  266cm, GVW tonnes=  0.7,  0.6,  0.1
1:  10:43:03.05   58.1kph,  2 Axles, Length= 585cm, A#3  S#5  L#4  G#6  H#6 ,  407cm, GVW tonnes=  2.8,  1.2,  1.6
2:  10:43:14.21   63.9kph,  4 Axles, Length=1103cm, A#3  S#5  L#7  G#6  H#6 ,  336cm  487cm   88cm, GVW tonnes=  3.0,  1.1,  0.8,  0.6,  0.5
2:  10:44:45.16   36.3kph,  3 Axles, Length= 867cm, A#6  S#2  L#6  G#7  H#7 ,  472cm  139cm, GVW tonnes= 19.1,  5.8,  7.0,  6.3
2:  10:44:49.08   38.8kph,  3 Axles, Length= 951cm, A#6  S#2  L#7  G#2  H#2 ,  561cm  154cm, GVW tonnes= 17.5,  5.9,  5.7,  5.9
2:  10:46:05.67   55.0kph,  3 Axles, Length= 935cm, A#6  S#4  L#7  G#7  H#7 ,  610cm  153cm, GVW tonnes= 20.1,  7.3,  6.8,  6.0
1:  10:46:38.04   36.6kph,  3 Axles, Length= 888cm, A#6  S#2  L#6  G#8  H#8 ,  475cm  137cm, GVW tonnes= 11.4,  3.5,  3.4,  4.5
1:  10:49:08.22   60.8kph,  3 Axles, Length= 869cm, A#6  S#5  L#6  G#8  H#8 ,  463cm  138cm, GVW tonnes= 10.7,  3.0,  3.8,  3.9
2:  10:49:58.48   47.9kph,  2 Axles, Length= 794cm, A#5  S#3  L#6  G#8  H#8 ,  601cm, GVW tonnes= 16.3,  5.7, 10.6
1:  10:52:32.83   23.4kph,  3 Axles, Length= 782cm, A#6  S#1  L#6  G#8  H#8 ,  416cm  148cm, GVW tonnes=  7.8,  1.2,  3.4,  3.2
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2:  10:53:05.01   27.6kph,  2 Axles, Length= 609cm, A#3  S#1  L#5  G#8  H#8 ,  429cm, GVW tonnes=  1.2,  0.6,  0.6
1:  10:55:42.24   32.9kph,  2 Axles, Length= 613cm, A#5  S#2  L#5  G#8  H#8 ,  513cm, GVW tonnes=  4.7,  2.1,  2.6
1:  10:55:45.83   36.4kph,  3 Axles, Length= 861cm, A#6  S#2  L#6  G#2  H#1 ,  467cm  138cm, GVW tonnes= 11.4,  3.0,  4.1,  4.3
1:  10:55:48.23   37.7kph,  3 Axles, Length= 932cm, A#6  S#2  L#7  G#1  H#1 ,  555cm  151cm, GVW tonnes= 14.2,  3.9,  5.1,  5.2
2:  10:57:56.53   54.2kph,  4 Axles, Length= 889cm, A#3  S#4  L#6  G#8  H#8 ,  326cm  378cm   76cm, GVW tonnes=  3.8,  0.8,  0.6,  1.0,  1.4
1:  11:00:39.52   57.8kph,  3 Axles, Length= 941cm, A#6  S#5  L#7  G#8  H#8 ,  612cm  153cm, GVW tonnes= 11.8,  4.8,  3.4,  3.6
1:  11:00:43.93   55.8kph,  4 Axles, Length=1085cm, A#3  S#4  L#7  G#2  H#2 ,  336cm  488cm   86cm, GVW tonnes=  2.0,  0.8,  0.7,  0.3,  0.2
2:  11:01:07.96   25.9kph,  2 Axles, Length=1428cm, A#5  S#1  L#8  G#8  H#8 ,  570cm, GVW tonnes=  2.4,  1.2,  1.2
1:  11:01:25.41   16.9kph,  2 Axles, Length= 702cm, A#5  S#1  L#5  G#6  H#6 ,  477cm, GVW tonnes=  2.6,  0.8,  1.8
2:  11:01:44.03   34.8kph,  3 Axles, Length= 899cm, A#6  S#2  L#6  G#6  H#6 ,  471cm  140cm, GVW tonnes= 18.3,  5.0,  7.6,  5.7
2:  11:02:09.85   40.7kph,  3 Axles, Length= 872cm, A#6  S#3  L#6  G#5  H#5 ,  473cm  139cm, GVW tonnes= 22.9,  5.6,  9.0,  8.3
2:  11:05:44.85   47.4kph,  2 Axles, Length= 461cm, A#3  S#3  L#4  G#8  H#8 ,  341cm, GVW tonnes=  2.5,  1.0,  1.5
1:  11:06:34.14   24.7kph,  2 Axles, Length= 622cm, A#3  S#1  L#5  G#8  H#8 ,  430cm, GVW tonnes=  1.2,  0.6,  0.6
2:  11:08:07.85   24.3kph,  3 Axles, Length= 921cm, A#6  S#1  L#7  G#8  H#8 ,  536cm  139cm, GVW tonnes= 13.8,  1.5,  6.5,  5.8
2:  11:08:42.55   29.0kph,  3 Axles, Length= 879cm, A#6  S#1  L#6  G#6  H#6 ,  472cm  138cm, GVW tonnes= 21.1,  4.8,  8.3,  8.0
1:  11:10:26.02   40.3kph,  3 Axles, Length= 894cm, A#6  S#3  L#6  G#8  H#8 ,  474cm  138cm, GVW tonnes= 12.5,  3.5,  4.3,  4.7
1:  11:10:29.86   37.3kph,  3 Axles, Length= 901cm, A#6  S#2  L#6  G#2  H#2 ,  474cm  140cm, GVW tonnes= 11.4,  2.9,  4.1,  4.4
1:  11:10:32.98   39.9kph,  2 Axles, Length= 604cm, A#3  S#2  L#4  G#2  H#1 ,  430cm, GVW tonnes=  2.0,  1.1,  0.9
2:  11:10:54.87   51.1kph,  2 Axles, Length= 546cm, A#3  S#4  L#4  G#8  H#8 ,  375cm, GVW tonnes=  1.2,  0.6,  0.6
1:  11:11:08.25   56.2kph,  4 Axles, Length= 914cm, A#3  S#4  L#7  G#6  H#6 ,  328cm  387cm   79cm, GVW tonnes=  2.5,  1.2,  0.6,  0.4,  0.3
2:  11:11:55.45   33.1kph,  3 Axles, Length= 976cm, A#6  S#2  L#7  G#7  H#7 ,  578cm  138cm, GVW tonnes= 16.5,  4.7,  5.9,  5.9
2:  11:12:14.18   47.8kph,  2 Axles, Length= 412cm, A#2  S#3  L#3  G#4  H#4 ,  285cm, GVW tonnes=  1.7,  0.9,  0.8
1:  11:12:14.01   38.8kph,  2 Axles, Length= 769cm, A#5  S#2  L#6  G#7  H#7 ,  561cm, GVW tonnes=  7.8,  4.3,  3.5
2:  11:13:22.41   52.5kph,  2 Axles, Length= 520cm, A#3  S#4  L#4  G#7  H#7 ,  366cm, GVW tonnes=  2.0,  1.1,  0.9
2:  11:14:54.25   72.3kph,  4 Axles, Length= 943cm, A#3  S#6  L#7  G#7  H#7 ,  366cm  374cm   76cm, GVW tonnes=  3.2,  0.8,  1.2,  0.6,  0.6
2:  11:17:10.04   45.8kph,  4 Axles, Length= 929cm, A#3  S#3  L#7  G#8  H#8 ,  348cm  397cm   78cm, GVW tonnes=  3.9,  0.9,  1.2,  1.0,  0.8
1:  11:19:46.13   18.1kph,  3 Axles, Length= 956cm, A#6  S#1  L#7  G#8  H#8 ,  530cm  140cm, GVW tonnes=  5.7,  0.2,  2.8,  2.7
2:  11:19:56.07   58.8kph,  2 Axles, Length= 511cm, A#3  S#5  L#4  G#8  H#8 ,  350cm, GVW tonnes=  2.0,  1.2,  0.8
2:  11:20:04.36   52.7kph,  2 Axles, Length= 507cm, A#3  S#4  L#4  G#2  H#2 ,  440cm, GVW tonnes=  1.2,  0.6,  0.6
2:  11:21:28.85   31.3kph,  3 Axles, Length= 873cm, A#6  S#1  L#6  G#7  H#7 ,  468cm  140cm, GVW tonnes= 17.6,  4.3,  6.7,  6.6
1:  11:21:51.67   25.7kph,  3 Axles, Length= 881cm, A#6  S#1  L#6  G#8  H#8 ,  473cm  137cm, GVW tonnes= 10.5,  3.1,  3.4,  4.0
2:  11:22:07.06   55.7kph,  2 Axles, Length= 644cm, A#5  S#4  L#5  G#6  H#6 ,  526cm, GVW tonnes=  8.0,  3.5,  4.5
1:  11:22:54.15   43.8kph,  2 Axles, Length= 530cm, A#3  S#3  L#4  G#7  H#7 ,  350cm, GVW tonnes=  1.8,  0.8,  1.0
1:  11:23:08.42   48.4kph,  3 Axles, Length= 969cm, A#6  S#4  L#7  G#3  H#3 ,  576cm  139cm, GVW tonnes= 14.1,  4.4,  5.0,  4.7
1:  11:23:49.11   43.7kph,  2 Axles, Length= 548cm, A#3  S#3  L#4  G#6  H#6 ,  372cm, GVW tonnes=  1.2,  0.6,  0.6
1:  11:24:29.20   33.8kph,  2 Axles, Length= 535cm, A#3  S#2  L#4  G#6  H#6 ,  359cm, GVW tonnes=  0.9,  0.4,  0.5
2:  11:25:51.87   56.4kph,  4 Axles, Length= 953cm, A#3  S#5  L#7  G#8  H#8 ,  334cm  397cm   83cm, GVW tonnes=  3.4,  1.0,  1.3,  0.5,  0.6
1:  11:26:11.84   41.6kph,  2 Axles, Length= 504cm, A#3  S#3  L#4  G#7  H#7 ,  339cm, GVW tonnes=  2.5,  1.2,  1.3
1:  11:27:13.93   51.3kph,  4 Axles, Length= 966cm, A#3  S#4  L#7  G#7  H#7 ,  365cm  375cm   77cm, GVW tonnes=  3.2,  1.3,  1.3,  0.3,  0.3
1:  11:28:07.34   61.5kph,  2 Axles, Length= 413cm, A#2  S#5  L#3  G#6  H#6 ,  266cm, GVW tonnes=  1.2,  0.6,  0.6
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1: 11:28:13.38  44.9kph, 4 Axles, Length= 974cm, A#3 S#3 L#7 G#2 H#2 , 348cm 400cm  80cm, GVW tonnes= 3.2, 1.2, 1.5, 0.3, 0.2
1: 11:30:56.21  32.9kph, 3 Axles, Length= 873cm, A#6 S#2 L#6 G#8 H#8 , 469cm 138cm, GVW tonnes= 10.1, 2.7, 3.7, 3.7
2: 11:31:08.95  67.2kph, 2 Axles, Length= 578cm, A#3 S#6 L#4 G#8 H#8 , 420cm, GVW tonnes= 1.8, 1.2, 0.6
1: 11:32:29.38  42.6kph, 2 Axles, Length= 541cm, A#3 S#3 L#4 G#7 H#7 , 439cm, GVW tonnes= 1.2, 0.6, 0.6
1: 11:32:32.23  43.9kph, 2 Axles, Length= 538cm, A#3 S#3 L#4 G#1 H#1 , 335cm, GVW tonnes= 1.7, 1.0, 0.7
2: 11:32:36.88  38.6kph, 3 Axles, Length=1007cm, A#3 S#2 L#7 G#7 H#7 , 400cm 475cm, GVW tonnes= 2.8, 1.3, 1.0, 0.5
2: 11:33:11.44  40.9kph, 3 Axles, Length=1002cm, A#6 S#3 L#7 G#6 H#6 , 588cm 153cm, GVW tonnes= 24.2, 6.9, 8.6, 8.7
1: 11:34:32.61  53.6kph, 2 Axles, Length= 675cm, A#5 S#4 L#5 G#8 H#7 , 527cm, GVW tonnes= 6.1, 3.3, 2.8
2: 11:34:33.05  58.6kph, 6 Axles, Length=1930cm, A#10 S#5 L#10 G#7 H#7 , 420cm 131cm 848cm 182cm 180cm, GVW tonnes= 40.1, 4.8, 6.6, 6.7, 7.6, 7.3, 7.1
1: 11:34:35.11  54.2kph, 4 Axles, Length= 970cm, A#3 S#4 L#7 G#1 H#1 , 335cm 399cm  84cm, GVW tonnes= 2.7, 0.7, 1.1, 0.5, 0.4
2: 11:35:59.82  43.0kph, 2 Axles, Length= 362cm, A#2 S#3 L#3 G#7 H#7 , 261cm, GVW tonnes= 0.8, 0.5, 0.3
2: 11:36:20.73  41.3kph, 5 Axles, Length=1826cm, A#9 S#3 L#9 G#5 H#5 , 350cm 145cm 907cm 182cm, GVW tonnes= 14.8, 3.9, 1.6, 4.7, 2.6, 2.0
2: 11:37:07.15  48.7kph, 2 Axles, Length= 457cm, A#3 S#4 L#4 G#6 H#6 , 344cm, GVW tonnes= 1.6, 1.0, 0.6
2: 11:37:12.38  46.9kph, 4 Axles, Length= 948cm, A#3 S#3 L#7 G#2 H#2 , 350cm 386cm  75cm, GVW tonnes= 3.1, 1.1, 1.3, 0.5, 0.2
1: 11:39:42.07  56.7kph, 2 Axles, Length= 505cm, A#3 S#5 L#4 G#8 H#8 , 341cm, GVW tonnes= 2.2, 1.4, 0.8
2: 11:40:32.28  64.0kph, 3 Axles, Length= 877cm, A#6 S#5 L#6 G#8 H#8 , 471cm 139cm, GVW tonnes= 20.4, 5.4, 7.4, 7.6
2: 11:40:46.43  63.5kph, 4 Axles, Length= 999cm, A#3 S#5 L#7 G#3 H#3 , 422cm 381cm  78cm, GVW tonnes= 2.9, 0.6, 1.4, 0.5, 0.4
2: 11:41:12.13  61.2kph, 2 Axles, Length= 490cm, A#3 S#5 L#4 G#5 H#5 , 333cm, GVW tonnes= 1.5, 0.9, 0.6
1: 11:41:50.20  36.2kph, 4 Axles, Length=1067cm, A#3 S#2 L#7 G#8 H#8 , 400cm 405cm  79cm, GVW tonnes= 2.8, 1.1, 0.8, 0.3, 0.6
2: 11:41:57.94  49.4kph, 3 Axles, Length= 882cm, A#6 S#4 L#6 G#6 H#6 , 545cm 153cm, GVW tonnes= 12.3, 4.6, 4.0, 3.7
2: 11:42:34.65  50.9kph, 3 Axles, Length= 945cm, A#6 S#4 L#7 G#6 H#6 , 555cm 154cm, GVW tonnes= 16.3, 5.4, 5.7, 5.2
1: 11:43:00.74  48.6kph, 2 Axles, Length= 545cm, A#3 S#4 L#4 G#7 H#7 , 422cm, GVW tonnes= 2.7, 1.3, 1.4
1: 11:43:14.88  60.6kph, 3 Axles, Length=1021cm, A#6 S#5 L#7 G#3 H#3 , 593cm 155cm, GVW tonnes= 16.6, 5.6, 6.1, 4.9
1: 11:47:39.51  74.1kph, 2 Axles, Length= 512cm, A#3 S#7 L#4 G#8 H#8 , 334cm, GVW tonnes= 1.9, 1.0, 0.9
2: 11:48:11.95  49.5kph, 2 Axles, Length= 428cm, A#2 S#4 L#3 G#8 H#8 , 299cm, GVW tonnes= 1.3, 0.8, 0.5
1: 11:48:43.91  50.9kph, 4 Axles, Length= 943cm, A#3 S#4 L#7 G#7 H#7 , 347cm 390cm  77cm, GVW tonnes= 3.1, 1.1, 1.4, 0.3, 0.3
2: 11:49:43.95  44.6kph, 2 Axles, Length= 754cm, A#3 S#3 L#5 G#7 H#7 , 448cm, GVW tonnes= 2.2, 0.6, 1.6
1: 11:51:45.76  56.8kph, 3 Axles, Length= 889cm, A#6 S#5 L#6 G#8 H#8 , 468cm 139cm, GVW tonnes= 12.2, 4.2, 4.2, 3.8
1: 11:55:22.57  62.5kph, 4 Axles, Length=1002cm, A#3 S#5 L#7 G#8 H#8 , 420cm 382cm  79cm, GVW tonnes= 2.7, 1.2, 1.2, 0.2, 0.1
1: 11:55:34.09  42.4kph, 2 Axles, Length= 613cm, A#3 S#3 L#5 G#3 H#3 , 432cm, GVW tonnes= 3.2, 1.6, 1.6
1: 11:56:07.12  69.4kph, 3 Axles, Length= 953cm, A#6 S#6 L#7 G#6 H#6 , 546cm 101cm, GVW tonnes= 11.0, 4.6, 4.1, 2.3
1: 11:57:45.37  48.0kph, 2 Axles, Length= 436cm, A#2 S#3 L#3 G#7 H#7 , 300cm, GVW tonnes= 1.3, 0.8, 0.5
2: 11:59:16.14  31.8kph, 3 Axles, Length= 963cm, A#6 S#1 L#7 G#8 H#8 , 650cm 136cm, GVW tonnes= 16.4, 5.9, 5.3, 5.2
1: 12:03:25.27  55.9kph, 6 Axles, Length=1939cm, A#10 S#4 L#10 G#8 H#8 , 422cm 131cm 849cm 183cm 182cm, GVW tonnes= 18.4, 4.1, 3.2, 3.1, 3.1, 2.4, 2.5
1: 12:04:17.52  44.2kph, 2 Axles, Length= 774cm, A#3 S#3 L#6 G#6 H#6 , 449cm, GVW tonnes= 1.9, 1.3, 0.6
1: 12:05:46.86  42.9kph, 3 Axles, Length= 883cm, A#6 S#3 L#6 G#7 H#7 , 544cm 151cm, GVW tonnes= 13.2, 4.1, 4.2, 4.9
2: 12:05:51.39  69.0kph, 2 Axles, Length= 483cm, A#3 S#6 L#4 G#8 H#8 , 329cm, GVW tonnes= 2.2, 1.0, 1.2
2: 12:08:19.10  48.5kph, 6 Axles, Length=1921cm, A#10 S#4 L#10 G#8 H#8 , 434cm 131cm 843cm 178cm 182cm, GVW tonnes= 37.9, 5.3, 7.1, 6.5, 6.2, 6.6, 6.2
1: 12:11:36.60  55.0kph, 3 Axles, Length= 990cm, A#6 S#4 L#7 G#8 H#8 , 654cm 139cm, GVW tonnes= 12.7, 4.6, 4.0, 4.1
2: 12:11:58.50  23.7kph, 3 Axles, Length= 785cm, A#6 S#1 L#6 G#8 H#8 , 417cm 133cm, GVW tonnes= 3.9, 0.6, 2.0, 1.3
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2:  12:18:03.78   57.3kph,  2 Axles, Length= 565cm, A#3  S#5  L#4  G#8  H#8 ,  373cm, GVW tonnes=  1.2,  0.6,  0.6
2:  12:20:20.87   44.1kph,  2 Axles, Length= 823cm, A#5  S#3  L#6  G#8  H#8 ,  546cm, GVW tonnes=  5.3,  2.8,  2.5
2:  12:20:22.97   42.6kph,  2 Axles, Length= 617cm, A#3  S#3  L#5  G#1  H#1 ,  436cm, GVW tonnes=  2.9,  1.5,  1.4
2:  12:28:05.64   62.9kph,  2 Axles, Length= 604cm, A#3  S#5  L#4  G#8  H#8 ,  377cm, GVW tonnes=  1.2,  0.6,  0.6
1:  12:29:06.57   22.3kph,  3 Axles, Length= 782cm, A#6  S#1  L#6  G#8  H#8 ,  421cm  149cm, GVW tonnes=  6.4,  1.1,  2.5,  2.8
2:  12:31:57.20   32.2kph,  3 Axles, Length= 904cm, A#6  S#2  L#6  G#8  H#8 ,  550cm  151cm, GVW tonnes= 11.7,  3.9,  4.0,  3.8
1:  12:32:33.64   40.1kph,  2 Axles, Length= 837cm, A#5  S#2  L#6  G#8  H#8 ,  544cm, GVW tonnes=  5.5,  3.0,  2.5
1:  12:32:55.05   53.6kph,  2 Axles, Length= 584cm, A#3  S#4  L#4  G#5  H#5 ,  376cm, GVW tonnes=  1.2,  0.6,  0.6
2:  12:34:16.09   59.7kph,  6 Axles, Length=1905cm, A#10 S#5  L#10 G#8  H#8 ,  386cm  127cm  878cm  180cm  180cm, GVW tonnes= 41.1,  4.0,  8.3,  7.5,  7.2,  7.1,  7.0
1:  12:36:16.03   48.3kph,  6 Axles, Length=1932cm, A#10 S#4  L#10 G#8  H#8 ,  435cm  132cm  844cm  179cm  182cm, GVW tonnes= 18.1,  4.0,  3.0,  3.1,  2.8,  2.4,  2.8
1:  12:36:20.02   49.7kph,  2 Axles, Length= 611cm, A#3  S#4  L#5  G#2  H#1 ,  380cm, GVW tonnes=  1.2,  0.6,  0.6
2:  12:37:27.62   46.1kph,  2 Axles, Length= 582cm, A#3  S#3  L#4  G#8  H#8 ,  415cm, GVW tonnes=  1.2,  0.6,  0.6
2:  12:38:23.84   44.5kph,  2 Axles, Length= 467cm, A#3  S#3  L#4  G#6  H#6 ,  333cm, GVW tonnes=  1.6,  1.0,  0.6
2:  12:39:39.14   55.2kph,  4 Axles, Length= 863cm, A#2  S#4  L#6  G#7  H#7 ,  299cm  393cm   80cm, GVW tonnes=  2.5,  0.9,  1.1,  0.3,  0.2
1:  12:43:13.80   64.6kph,  2 Axles, Length= 524cm, A#3  S#6  L#4  G#8  H#8 ,  334cm, GVW tonnes=  1.7,  1.0,  0.7
1:  12:46:00.80   31.3kph,  3 Axles, Length= 912cm, A#6  S#1  L#6  G#8  H#8 ,  550cm  149cm, GVW tonnes= 11.9,  4.6,  3.5,  3.8
2:  12:46:42.67   37.7kph,  3 Axles, Length= 899cm, A#6  S#2  L#6  G#8  H#8 ,  553cm  154cm, GVW tonnes= 14.6,  4.5,  5.2,  4.9
1:  12:47:57.92   58.2kph,  4 Axles, Length= 912cm, A#2  S#5  L#6  G#7  H#7 ,  297cm  393cm   81cm, GVW tonnes=  3.4,  1.3,  1.6,  0.3,  0.2
1:  12:51:23.93   49.6kph,  2 Axles, Length= 610cm, A#3  S#4  L#5  G#8  H#8 ,  419cm, GVW tonnes=  1.2,  0.6,  0.6
1:  12:51:36.06  SnMis #1      Info:
2:  12:51:36.11  SnMis #2      Info:
2:  12:51:37.22  SnMis #1      Info:
1:  12:51:37.27  SnMis #2      Info:
2:  12:52:26.51   27.2kph,  2 Axles, Length= 626cm, A#3  S#1  L#5  G#8  H#8 ,  427cm, GVW tonnes=  1.2,  0.6,  0.6
2:  12:52:29.60   26.6kph,  2 Axles, Length= 567cm, A#3  S#1  L#4  G#2  H#1 ,  388cm, GVW tonnes=  1.1,  0.5,  0.6
2:  12:55:00.81   35.3kph,  3 Axles, Length= 917cm, A#6  S#2  L#7  G#8  H#8 ,  545cm  152cm, GVW tonnes= 13.5,  4.7,  4.4,  4.4
1:  12:56:30.50   17.3kph,  5 Axles, Length=1769cm, A#9  S#1  L#9  G#8  H#8 ,  311cm  124cm  847cm  161cm, GVW tonnes=  1.9,  0.2,  1.2,  0.3,  0.1,  0.1
1:  12:56:39.79   36.8kph,  4 Axles, Length= 993cm, A#8  S#2  L#7  G#2  H#2 ,  560cm  164cm  175cm, GVW tonnes= 14.1,  4.8,  5.0,  3.7,  0.6
1:  12:56:48.92   34.0kph,  2 Axles, Length= 543cm, A#3  S#2  L#4  G#2  H#2 ,  336cm, GVW tonnes=  2.1,  1.0,  1.1
2:  12:59:20.38   42.6kph,  2 Axles, Length= 765cm, A#5  S#3  L#6  G#8  H#8 ,  601cm, GVW tonnes= 11.5,  4.6,  6.9
1:  13:03:34.09   55.6kph,  2 Axles, Length= 445cm, A#2  S#4  L#3  G#8  H#8 ,  287cm, GVW tonnes=  1.6,  0.8,  0.8
2:  13:03:34.42   59.0kph,  2 Axles, Length= 647cm, A#5  S#5  L#5  G#8  H#8 ,  525cm, GVW tonnes=  6.6,  2.6,  4.0
2:  13:04:08.75   58.7kph,  2 Axles, Length= 585cm, A#3  S#5  L#4  G#6  H#6 ,  408cm, GVW tonnes=  1.9,  1.3,  0.6
1:  13:04:34.33   64.3kph,  2 Axles, Length= 381cm, A#2  S#6  L#3  G#7  H#6 ,  261cm, GVW tonnes=  0.9,  0.5,  0.4
1:  13:05:14.21   47.8kph,  3 Axles, Length= 924cm, A#6  S#3  L#7  G#6  H#6 ,  542cm  150cm, GVW tonnes= 11.1,  3.5,  3.7,  3.9
2:  13:07:06.00   48.2kph,  2 Axles, Length= 619cm, A#5  S#4  L#5  G#8  H#8 ,  518cm, GVW tonnes=  5.4,  2.4,  3.0
1:  13:07:33.49   27.2kph,  2 Axles, Length= 643cm, A#3  S#1  L#5  G#8  H#8 ,  427cm, GVW tonnes=  1.2,  0.6,  0.6
1:  13:07:35.87   28.2kph,  2 Axles, Length= 578cm, A#3  S#1  L#4  G#1  H#1 ,  406cm, GVW tonnes=  1.2,  0.6,  0.6
2:  13:07:50.99   47.8kph,  6 Axles, Length=1912cm, A#10 S#3  L#10 G#6  H#6 ,  402cm  152cm  858cm  179cm  180cm, GVW tonnes= 39.8,  4.1,  6.7,  6.8,  7.8,  7.3,  7.1
2:  13:10:02.99   42.7kph,  3 Axles, Length= 943cm, A#6  S#3  L#7  G#8  H#8 ,  552cm  153cm, GVW tonnes= 17.3,  5.5,  5.7,  6.1
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1:  13:10:16.80   45.4kph,  2 Axles, Length= 834cm, A#5  S#3  L#6  G#8  H#8 ,  604cm, GVW tonnes=  8.9,  4.2,  4.7
2:  13:10:28.56   47.6kph,  3 Axles, Length= 892cm, A#6  S#3  L#6  G#5  H#5 ,  462cm  135cm, GVW tonnes= 23.6,  7.1,  8.0,  8.5
2:  13:10:50.90   52.6kph,  3 Axles, Length= 777cm, A#6  S#4  L#6  G#5  H#5 ,  553cm  127cm, GVW tonnes= 11.7,  4.1,  5.0,  2.6
1:  13:10:56.22   56.9kph,  2 Axles, Length= 617cm, A#3  S#5  L#5  G#6  H#6 ,  412cm, GVW tonnes=  2.3,  1.1,  1.2
1:  13:15:04.03   55.5kph,  2 Axles, Length= 582cm, A#3  S#4  L#4  G#8  H#8 ,  396cm, GVW tonnes=  2.1,  1.0,  1.1
2:  13:15:30.18   39.3kph,  2 Axles, Length= 638cm, A#3  S#2  L#5  G#8  H#8 ,  445cm, GVW tonnes=  1.2,  0.6,  0.6
1:  13:16:02.84   55.5kph,  2 Axles, Length= 663cm, A#5  S#4  L#5  G#6  H#6 ,  529cm, GVW tonnes=  5.2,  2.6,  2.6
1:  13:17:00.70   44.8kph,  2 Axles, Length= 647cm, A#5  S#3  L#5  G#6  H#6 ,  521cm, GVW tonnes=  4.1,  2.5,  1.6
2:  13:18:59.45   74.3kph,  2 Axles, Length= 493cm, A#3  S#7  L#4  G#8  H#8 ,  332cm, GVW tonnes=  1.5,  0.8,  0.7
1:  13:19:29.57   41.2kph,  3 Axles, Length= 972cm, A#6  S#3  L#7  G#8  H#8 ,  556cm  154cm, GVW tonnes= 15.3,  5.7,  4.5,  5.1
2:  13:19:43.73   39.7kph,  4 Axles, Length=1284cm, A#3  S#2  L#8  G#6  H#6 ,  341cm  586cm   76cm, GVW tonnes=  2.0,  0.6,  0.6,  0.4,  0.4
2:  13:20:33.46   31.7kph,  3 Axles, Length= 828cm, A#6  S#1  L#6  G#6  H#6 ,  457cm  151cm, GVW tonnes= 13.9,  1.3,  5.5,  7.1
2:  13:20:50.64   35.6kph,  3 Axles, Length= 878cm, A#6  S#2  L#6  G#4  H#4 ,  564cm  129cm, GVW tonnes= 14.0,  3.0,  7.6,  3.4
1:  13:22:59.14   48.1kph,  3 Axles, Length= 913cm, A#6  S#3  L#7  G#8  H#8 ,  466cm  135cm, GVW tonnes= 12.1,  6.1,  2.8,  3.2
1:  13:24:09.50   37.8kph,  3 Axles, Length= 732cm, A#6  S#2  L#5  G#7  H#7 ,  552cm  125cm, GVW tonnes=  5.8,  2.4,  1.7,  1.7
2:  13:24:27.45   48.0kph,  4 Axles, Length= 961cm, A#3  S#3  L#7  G#8  H#8 ,  360cm  403cm   83cm, GVW tonnes=  4.3,  1.3,  0.6,  1.2,  1.2
1:  13:27:14.27   54.9kph,  6 Axles, Length=1978cm, A#10 S#4  L#10 G#8  H#8 ,  408cm  153cm  881cm  186cm  187cm, GVW tonnes= 19.3,  4.1,  3.7,  3.6,  2.6,  2.6,  2.7
1:  13:27:36.19   51.0kph,  2 Axles, Length= 491cm, A#3  S#4  L#4  G#5  H#5 ,  332cm, GVW tonnes=  1.7,  1.0,  0.7
2:  13:28:59.12   55.7kph,  3 Axles, Length= 955cm, A#6  S#4  L#7  G#8  H#8 ,  607cm  146cm, GVW tonnes= 19.3,  6.1,  6.6,  6.6
1:  13:30:25.41   56.7kph,  2 Axles, Length= 612cm, A#3  S#5  L#5  G#8  H#8 ,  426cm, GVW tonnes=  2.1,  1.2,  0.9
2:  13:30:29.83   40.5kph,  3 Axles, Length= 935cm, A#6  S#3  L#7  G#7  H#7 ,  553cm  154cm, GVW tonnes= 17.1,  6.1,  6.3,  4.7
2:  13:31:37.83   56.2kph,  2 Axles, Length= 564cm, A#3  S#4  L#4  G#7  H#7 ,  390cm, GVW tonnes=  1.8,  1.2,  0.6
1:  13:31:39.75   51.4kph,  2 Axles, Length= 645cm, A#3  S#4  L#5  G#7  H#7 ,  446cm, GVW tonnes=  1.2,  0.6,  0.6
1:  13:31:48.46   42.4kph,  3 Axles, Length= 885cm, A#6  S#3  L#6  G#2  H#2 ,  588cm  124cm, GVW tonnes=  9.5,  3.9,  2.7,  2.9
1:  13:34:13.40   43.3kph,  2 Axles, Length= 575cm, A#3  S#3  L#4  G#8  H#8 ,  367cm, GVW tonnes=  1.8,  0.8,  1.0
2:  13:34:46.54   37.3kph,  2 Axles, Length=1078cm, A#5  S#2  L#7  G#8  H#8 ,  696cm, GVW tonnes=  9.0,  3.1,  5.9
2:  13:34:53.61   36.2kph,  2 Axles, Length= 583cm, A#3  S#2  L#4  G#2  H#2 ,  420cm, GVW tonnes=  1.2,  0.6,  0.6
2:  13:35:34.55  SnMis #2      Info:
1:  13:35:53.78   37.8kph,  3 Axles, Length= 816cm, A#6  S#2  L#6  G#7  H#7 ,  475cm  152cm, GVW tonnes= 11.6,  3.5,  4.1,  4.0
2:  13:36:56.63   75.1kph,  2 Axles, Length= 453cm, A#2  S#7  L#3  G#8  H#8 ,  297cm, GVW tonnes=  1.9,  0.9,  1.0
1:  13:37:53.12   36.2kph,  4 Axles, Length=1292cm, A#3  S#2  L#8  G#7  H#7 ,  339cm  584cm   77cm, GVW tonnes=  1.6,  0.6,  0.6,  0.2,  0.2
1:  13:39:39.06   42.1kph,  3 Axles, Length= 968cm, A#6  S#3  L#7  G#7  H#7 ,  607cm  147cm, GVW tonnes=  8.9,  3.9,  2.5,  2.5
1:  13:40:19.38   40.3kph,  3 Axles, Length= 960cm, A#6  S#3  L#7  G#6  H#6 ,  554cm  154cm, GVW tonnes= 14.5,  6.2,  3.7,  4.6
2:  13:40:30.45   50.9kph,  6 Axles, Length=1994cm, A#12 S#4  L#10 G#8  H#8 ,  542cm  147cm  635cm  256cm  266cm, GVW tonnes= 39.0,  5.1,  7.4,  7.6,  0.2,  9.4,  9.3
1:  13:40:57.44   41.6kph,  2 Axles, Length= 563cm, A#3  S#3  L#4  G#6  H#6 ,  391cm, GVW tonnes=  2.7,  1.1,  1.6
1:  13:41:24.64   30.4kph,  2 Axles, Length=1110cm, A#5  S#1  L#7  G#5  H#5 ,  706cm, GVW tonnes=  8.3,  3.0,  5.3
1:  13:41:48.52   61.7kph,  4 Axles, Length= 950cm, A#3  S#5  L#7  G#5  H#5 ,  357cm  403cm   84cm, GVW tonnes=  2.5,  0.6,  0.6,  0.8,  0.5
2:  13:42:41.35   39.6kph,  3 Axles, Length= 982cm, A#6  S#2  L#7  G#8  H#8 ,  494cm  133cm, GVW tonnes= 15.8,  4.6,  5.8,  5.4
2:  13:44:35.67   43.2kph,  2 Axles, Length= 811cm, A#5  S#3  L#6  G#7  H#7 ,  598cm, GVW tonnes= 12.8,  4.6,  8.2
1:  13:45:09.89   41.4kph,  2 Axles, Length= 599cm, A#3  S#3  L#4  G#8  H#8 ,  419cm, GVW tonnes=  1.2,  0.6,  0.6
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2:  13:47:07.23   58.9kph,  3 Axles, Length= 871cm, A#6  S#5  L#6  G#8  H#8 ,  470cm  136cm, GVW tonnes= 20.6,  5.2,  8.2,  7.2
2:  13:48:03.91   48.6kph,  2 Axles, Length= 523cm, A#3  S#4  L#4  G#6  H#6 ,  355cm, GVW tonnes=  1.7,  1.0,  0.7
2:  13:49:51.23   60.0kph,  2 Axles, Length= 783cm, A#5  S#5  L#6  G#7  H#7 ,  563cm, GVW tonnes= 11.4,  4.2,  7.2
2:  13:52:14.63   52.1kph,  6 Axles, Length=1930cm, A#10 S#4  L#10 G#8  H#8 ,  420cm  131cm  846cm  181cm  180cm, GVW tonnes= 34.9,  4.3,  6.4,  6.1,  6.1,  6.1,  5.9
1:  13:52:56.26   40.3kph,  3 Axles, Length=1002cm, A#6  S#3  L#7  G#8  H#8 ,  494cm  134cm, GVW tonnes= 11.2,  3.5,  4.0,  3.7
2:  13:54:12.89   37.2kph,  3 Axles, Length= 929cm, A#6  S#2  L#7  G#7  H#7 ,  585cm  152cm, GVW tonnes= 16.0,  6.2,  5.2,  4.6
1:  13:54:35.69   54.3kph,  3 Axles, Length= 888cm, A#6  S#4  L#6  G#7  H#7 ,  471cm  138cm, GVW tonnes= 11.9,  3.6,  4.4,  3.9
1:  13:56:16.61   52.9kph,  2 Axles, Length= 812cm, A#5  S#4  L#6  G#7  H#7 ,  600cm, GVW tonnes=  8.6,  4.1,  4.5
2:  13:57:16.94   25.0kph,  3 Axles, Length= 815cm, A#6  S#1  L#6  G#8  H#8 ,  415cm  134cm, GVW tonnes=  4.1,  0.9,  2.2,  1.0
2:  13:57:27.05   37.5kph,  3 Axles, Length= 910cm, A#6  S#2  L#6  G#3  H#2 ,  556cm  157cm, GVW tonnes= 18.0,  4.7,  7.0,  6.3
2:  13:58:24.46   66.2kph,  2 Axles, Length= 794cm, A#3  S#6  L#6  G#6  H#6 ,  450cm, GVW tonnes=  1.2,  0.6,  0.6
1:  13:58:59.00   59.0kph,  5 Axles, Length=2028cm, A#9  S#5  L#10 G#8  H#8 ,  545cm  148cm  910cm  272cm, GVW tonnes= 19.6,  3.5,  4.3,  4.2,  3.8,  3.8
1:  13:59:07.63   57.9kph,  2 Axles, Length= 802cm, A#5  S#5  L#6  G#2  H#2 ,  570cm, GVW tonnes=  7.8,  4.1,  3.7
2:  14:00:08.03   85.6kph,  2 Axles, Length= 507cm, A#3  S#8  L#4  G#7  H#7 ,  351cm, GVW tonnes=  1.8,  1.1,  0.7
1:  14:05:13.25   36.7kph,  3 Axles, Length= 915cm, A#6  S#2  L#7  G#8  H#8 ,  576cm  147cm, GVW tonnes= 13.8,  6.5,  3.5,  3.8
2:  14:05:33.25   44.6kph,  4 Axles, Length= 933cm, A#2  S#3  L#7  G#8  H#8 ,  295cm  391cm   72cm, GVW tonnes=  3.7,  0.5,  1.0,  0.9,  1.3
2:  14:05:36.88   43.4kph,  2 Axles, Length= 563cm, A#3  S#3  L#4  G#2  H#1 ,  407cm, GVW tonnes=  1.2,  0.6,  0.6
1:  14:07:21.40   77.9kph,  2 Axles, Length= 760cm, A#3  S#7  L#5  G#8  H#8 ,  451cm, GVW tonnes=  1.2,  0.6,  0.6
1:  14:08:08.48   54.3kph,  3 Axles, Length= 954cm, A#6  S#4  L#7  G#6  H#6 ,  556cm  153cm, GVW tonnes= 13.5,  5.2,  4.1,  4.2
2:  14:08:54.44   56.9kph,  2 Axles, Length= 563cm, A#3  S#5  L#4  G#8  H#8 ,  397cm, GVW tonnes=  2.2,  1.2,  1.0
2:  14:09:56.92   46.9kph,  2 Axles, Length= 596cm, A#3  S#3  L#4  G#7  H#7 ,  426cm, GVW tonnes=  2.6,  1.6,  1.0
1:  14:11:00.13   29.5kph,  3 Axles, Length= 808cm, A#6  S#1  L#6  G#8  H#8 ,  437cm  150cm, GVW tonnes= 10.1,  3.0,  3.6,  3.5
1:  14:13:10.06   54.6kph,  2 Axles, Length= 568cm, A#3  S#4  L#4  G#8  H#8 ,  407cm, GVW tonnes=  1.2,  0.6,  0.6
2:  14:13:24.08   41.5kph,  3 Axles, Length=1037cm, A#6  S#3  L#7  G#8  H#8 ,  620cm  151cm, GVW tonnes= 12.3,  5.5,  3.5,  3.3
1:  14:15:30.82   79.7kph,  2 Axles, Length= 597cm, A#3  S#7  L#4  G#8  H#8 ,  425cm, GVW tonnes=  2.7,  1.4,  1.3
2:  14:16:44.46   52.5kph,  6 Axles, Length=1882cm, A#10 S#4  L#10 G#8  H#8 ,  431cm  131cm  838cm  176cm  181cm, GVW tonnes= 38.8,  5.5,  7.2,  6.4,  6.7,  6.8,  6.2
1:  14:17:57.70   57.1kph,  6 Axles, Length=1920cm, A#10 S#5  L#10 G#8  H#8 ,  422cm  129cm  845cm  181cm  180cm, GVW tonnes= 17.5,  3.4,  3.1,  3.0,  2.8,  2.5,  2.7
2:  14:18:44.36   72.7kph,  2 Axles, Length= 554cm, A#3  S#7  L#4  G#7  H#7 ,  427cm, GVW tonnes=  2.1,  1.1,  1.0
2:  14:21:45.54   40.7kph,  2 Axles, Length= 621cm, A#5  S#3  L#5  G#8  H#8 ,  519cm, GVW tonnes=  5.2,  2.5,  2.7
1:  14:22:12.09   61.4kph,  2 Axles, Length= 595cm, A#3  S#5  L#4  G#8  H#8 ,  425cm, GVW tonnes=  2.2,  1.2,  1.0
1:  14:22:20.14   62.6kph,  2 Axles, Length= 464cm, A#3  S#5  L#4  G#2  H#2 ,  353cm, GVW tonnes=  2.2,  1.2,  1.0
2:  14:22:50.08   51.3kph,  4 Axles, Length=1059cm, A#3  S#4  L#7  G#7  H#7 ,  357cm  444cm   84cm, GVW tonnes=  3.8,  1.4,  0.6,  1.0,  0.8
1:  14:23:26.20   68.0kph,  2 Axles, Length= 470cm, A#2  S#6  L#4  G#7  H#7 ,  295cm, GVW tonnes=  2.0,  1.0,  1.0
2:  14:23:27.14   53.0kph,  3 Axles, Length= 940cm, A#6  S#4  L#7  G#6  H#6 ,  554cm  154cm, GVW tonnes= 17.4,  5.5,  6.4,  5.5
2:  14:25:02.98   37.9kph,  2 Axles, Length= 811cm, A#3  S#2  L#6  G#7  H#7 ,  317cm, GVW tonnes=  1.2,  0.6,  0.6
1:  14:25:40.42   30.6kph,  2 Axles, Length= 442cm, A#2  S#1  L#3  G#8  H#8 ,  231cm, GVW tonnes=  1.1,  1.0,  0.1
1:  14:25:52.52   28.0kph,  3 Axles, Length=1047cm, A#6  S#1  L#7  G#3  H#3 ,  618cm  149cm, GVW tonnes= 10.7,  4.4,  3.0,  3.3
1:  14:27:36.83  SnMis #1      Info:
2:  14:27:36.52   52.4kph,  3 Axles, Length= 879cm, A#6  S#4  L#6  G#8  H#8 ,  555cm  152cm, GVW tonnes= 12.2,  2.3,  4.8,  5.1
2:  14:29:45.91   51.4kph,  6 Axles, Length=1880cm, A#10 S#4  L#10 G#8  H#8 ,  386cm  127cm  875cm  179cm  179cm, GVW tonnes= 39.2,  3.8,  7.9,  7.3,  7.0,  6.9,  6.3
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1:  14:32:25.13   54.5kph,  3 Axles, Length= 961cm, A#6  S#4  L#7  G#8  H#8 ,  555cm  154cm, GVW tonnes= 13.5,  6.1,  3.6,  3.8
1:  14:32:29.21   53.6kph,  4 Axles, Length=1075cm, A#3  S#4  L#7  G#2  H#2 ,  357cm  445cm   84cm, GVW tonnes=  3.6,  1.4,  0.6,  0.8,  0.8
1:  14:33:29.13   43.0kph,  2 Axles, Length= 646cm, A#5  S#3  L#5  G#6  H#6 ,  521cm, GVW tonnes=  4.5,  2.4,  2.1
1:  14:33:47.87   48.9kph,  4 Axles, Length= 868cm, A#2  S#4  L#6  G#4  H#4 ,  295cm  393cm   73cm, GVW tonnes=  3.0,  0.7,  1.0,  0.8,  0.5
1:  14:34:25.97   31.8kph,  2 Axles, Length= 834cm, A#3  S#1  L#6  G#6  H#6 ,  317cm, GVW tonnes=  1.2,  0.6,  0.6
1:  14:35:54.25   64.8kph,  4 Axles, Length= 969cm, A#7  S#6  L#7  G#7  H#7 ,  553cm  159cm   89cm, GVW tonnes= 12.1,  4.1,  4.1,  3.8,  0.1
2:  14:36:58.50   59.8kph,  2 Axles, Length= 368cm, A#3  S#5  L#3  G#8  H#8 ,  333cm, GVW tonnes=  0.8,  0.4,  0.4
2:  14:42:29.71   51.4kph,  3 Axles, Length= 886cm, A#6  S#4  L#6  G#8  H#8 ,  471cm  137cm, GVW tonnes= 17.9,  4.2,  6.9,  6.8
1:  14:42:28.46   34.1kph,  6 Axles, Length=1918cm, A#10 S#2  L#10 G#8  H#8 ,  432cm  130cm  839cm  176cm  180cm, GVW tonnes= 18.3,  4.0,  3.5,  3.6,  2.2,  2.6,  2.4
2:  14:44:50.14   51.5kph,  3 Axles, Length= 884cm, A#6  S#4  L#6  G#8  H#8 ,  484cm  133cm, GVW tonnes= 19.5,  4.1,  7.7,  7.7
1:  14:47:25.28   61.5kph,  2 Axles, Length= 571cm, A#3  S#5  L#4  G#8  H#8 ,  395cm, GVW tonnes=  2.0,  1.1,  0.9
2:  14:48:28.35   45.7kph,  3 Axles, Length= 898cm, A#6  S#3  L#6  G#8  H#8 ,  556cm  138cm, GVW tonnes= 13.2,  4.6,  4.7,  3.9
1:  14:48:51.61   54.5kph,  3 Axles, Length= 902cm, A#6  S#4  L#6  G#7  H#7 ,  472cm  138cm, GVW tonnes= 12.7,  4.3,  4.2,  4.2
2:  14:50:40.10   54.7kph,  2 Axles, Length= 609cm, A#3  S#4  L#5  G#8  H#8 ,  445cm, GVW tonnes=  1.2,  0.6,  0.6
2:  14:55:04.32   51.5kph,  3 Axles, Length= 884cm, A#6  S#4  L#6  G#8  H#8 ,  470cm  139cm, GVW tonnes= 19.1,  4.8,  7.3,  7.0
1:  14:55:25.82   58.5kph,  6 Axles, Length=1918cm, A#10 S#5  L#10 G#8  H#8 ,  387cm  128cm  889cm  185cm  183cm, GVW tonnes= 17.0,  3.2,  3.3,  2.8,  2.6,  2.4,  2.7
1:  14:56:27.99   39.0kph,  3 Axles, Length= 903cm, A#6  S#2  L#6  G#7  H#7 ,  484cm  136cm, GVW tonnes= 10.6,  2.2,  4.3,  4.1
2:  14:57:29.69   69.2kph,  2 Axles, Length= 454cm, A#3  S#6  L#3  G#8  H#8 ,  333cm, GVW tonnes=  1.9,  1.1,  0.8
2:  14:57:32.66   74.7kph,  2 Axles, Length= 440cm, A#2  S#7  L#3  G#1  H#1 ,  295cm, GVW tonnes=  2.3,  1.2,  1.1
1:  15:01:41.10   46.5kph,  3 Axles, Length= 931cm, A#6  S#3  L#7  G#8  H#8 ,  556cm  137cm, GVW tonnes= 10.7,  4.0,  3.2,  3.5
2:  15:03:36.00   56.3kph,  3 Axles, Length= 870cm, A#6  S#5  L#6  G#8  H#8 ,  471cm  139cm, GVW tonnes= 13.9,  3.8,  5.4,  4.7
1:  15:04:08.22   39.2kph,  3 Axles, Length= 852cm, A#6  S#2  L#6  G#8  H#8 ,  469cm  138cm, GVW tonnes= 10.5,  2.8,  3.9,  3.8
1:  15:05:03.79   66.7kph,  3 Axles, Length= 641cm, A#6  S#6  L#5  G#6  H#6 ,  442cm   83cm, GVW tonnes=  5.1,  2.5,  2.5,  0.1
2:  15:08:42.33   44.0kph,  4 Axles, Length= 911cm, A#3  S#3  L#6  G#8  H#8 ,  353cm  383cm   85cm, GVW tonnes=  4.1,  1.3,  1.2,  1.0,  0.6
2:  15:11:08.61   57.0kph,  2 Axles, Length= 835cm, A#5  S#5  L#6  G#8  H#8 ,  595cm, GVW tonnes= 11.8,  4.2,  7.6
1:  15:11:10.33   36.1kph,  3 Axles, Length= 902cm, A#6  S#2  L#6  G#8  H#8 ,  467cm  136cm, GVW tonnes= 11.7,  3.6,  3.9,  4.2
1:  15:11:53.50   47.3kph,  4 Axles, Length= 945cm, A#3  S#3  L#7  G#6  H#6 ,  354cm  388cm   86cm, GVW tonnes=  2.7,  0.6,  0.6,  1.0,  0.5
1:  15:18:35.38   55.8kph,  2 Axles, Length= 834cm, A#5  S#4  L#6  G#8  H#8 ,  601cm, GVW tonnes=  7.3,  3.3,  4.0
1:  15:20:25.74   79.4kph,  2 Axles, Length= 519cm, A#3  S#7  L#4  G#7  H#7 ,  350cm, GVW tonnes=  1.3,  0.7,  0.6
2:  15:22:39.11   43.7kph,  2 Axles, Length= 564cm, A#3  S#3  L#4  G#8  H#8 ,  414cm, GVW tonnes=  1.2,  0.6,  0.6
2:  15:22:58.33   45.0kph,  2 Axles, Length= 561cm, A#3  S#3  L#4  G#4  H#4 ,  407cm, GVW tonnes=  1.2,  0.6,  0.6
2:  15:24:12.71   41.2kph,  3 Axles, Length= 909cm, A#6  S#3  L#6  G#7  H#7 ,  546cm  152cm, GVW tonnes= 21.8,  3.9,  9.0,  8.9
2:  15:30:38.14   32.6kph,  3 Axles, Length= 794cm, A#6  S#2  L#6  G#8  H#8 ,  421cm  152cm, GVW tonnes= 13.0,  1.3,  5.6,  6.1
2:  15:30:40.59   32.0kph,  3 Axles, Length= 901cm, A#6  S#1  L#6  G#1  H#1 ,  474cm  142cm, GVW tonnes= 17.6,  3.9,  7.8,  5.9
1:  15:32:24.61   39.3kph,  2 Axles, Length= 560cm, A#3  S#2  L#4  G#8  H#8 ,  414cm, GVW tonnes=  2.1,  1.5,  0.6
1:  15:33:15.32   54.0kph,  2 Axles, Length= 560cm, A#3  S#4  L#4  G#6  H#6 ,  407cm, GVW tonnes=  1.2,  0.6,  0.6
2:  15:34:12.75   45.4kph,  2 Axles, Length= 611cm, A#5  S#3  L#5  G#8  H#8 ,  516cm, GVW tonnes=  7.0,  3.0,  4.0
2:  15:34:30.70   52.8kph,  3 Axles, Length= 967cm, A#6  S#4  L#7  G#4  H#4 ,  557cm  151cm, GVW tonnes= 17.7,  5.8,  6.2,  5.7
1:  15:36:56.21   30.4kph,  3 Axles, Length= 944cm, A#6  S#1  L#7  G#8  H#8 ,  547cm  150cm, GVW tonnes= 13.3,  4.5,  4.3,  4.5
2:  15:38:10.08   53.5kph,  3 Axles, Length= 899cm, A#6  S#4  L#6  G#8  H#8 ,  470cm  139cm, GVW tonnes= 21.2,  5.3,  8.7,  7.2
```

```
2:  15:38:41.36   51.4kph,  3 Axles, Length= 891cm, A#6  S#4  L#6  G#6  H#6 ,  470cm  138cm, GVW tonnes= 20.1,  5.4,  7.5,  7.2
2:  15:39:13.84   40.7kph,  3 Axles, Length= 904cm, A#6  S#3  L#6  G#6  H#6 ,  474cm  140cm, GVW tonnes= 19.9,  5.1,  8.0,  6.8
1:  15:39:23.49   47.3kph,  2 Axles, Length= 513cm, A#3  S#3  L#4  G#8  H#8 ,  348cm, GVW tonnes=  2.0,  1.1,  0.9
1:  15:41:21.70   46.7kph,  3 Axles, Length= 862cm, A#6  S#3  L#6  G#7  H#7 ,  472cm  138cm, GVW tonnes= 10.3,  3.0,  3.6,  3.7
2:  15:42:34.90   34.3kph,  3 Axles, Length= 937cm, A#6  S#2  L#7  G#8  H#8 ,  554cm  137cm, GVW tonnes= 13.9,  3.7,  4.8,  5.4
1:  15:43:40.61   27.5kph,  3 Axles, Length= 750cm, A#6  S#1  L#5  G#8  H#8 ,  429cm  150cm, GVW tonnes=  8.2,  2.1,  3.0,  3.1
1:  15:43:53.59   58.6kph,  3 Axles, Length= 956cm, A#6  S#5  L#7  G#3  H#3 ,  561cm  153cm, GVW tonnes= 14.4,  5.6,  4.5,  4.3
1:  15:44:58.09   43.9kph,  2 Axles, Length= 625cm, A#5  S#3  L#5  G#7  H#7 ,  519cm, GVW tonnes=  4.2,  2.5,  1.7
2:  15:46:10.05   41.9kph,  3 Axles, Length= 887cm, A#6  S#3  L#6  G#8  H#8 ,  471cm  139cm, GVW tonnes= 16.3,  4.4,  6.1,  5.8
1:  15:47:33.29   43.3kph,  3 Axles, Length= 886cm, A#6  S#3  L#6  G#8  H#8 ,  473cm  137cm, GVW tonnes= 10.8,  3.5,  3.6,  3.7
2:  15:47:55.26   58.3kph,  4 Axles, Length= 928cm, A#3  S#5  L#7  G#7  H#7 ,  339cm  396cm   77cm, GVW tonnes=  4.4,  0.8,  1.3,  1.2,  1.1
1:  15:49:45.94   49.3kph,  3 Axles, Length= 874cm, A#6  S#4  L#6  G#8  H#8 ,  473cm  138cm, GVW tonnes= 11.8,  3.6,  4.2,  4.0
2:  15:52:41.85   43.5kph,  6 Axles, Length=2030cm, A#12 S#3  L#10 G#8  H#8 ,  544cm  149cm  648cm  257cm  272cm, GVW tonnes= 42.3,  5.6,  8.9,  8.4,  0.1,  9.7,  9.6
1:  15:53:02.13   33.6kph,  3 Axles, Length= 936cm, A#6  S#2  L#7  G#8  H#8 ,  556cm  137cm, GVW tonnes= 10.8,  4.4,  2.8,  3.6
1:  15:53:17.66   42.4kph,  3 Axles, Length= 896cm, A#6  S#3  L#6  G#4  H#3 ,  472cm  139cm, GVW tonnes= 12.1,  3.4,  4.4,  4.3
2:  15:56:43.62   34.0kph,  3 Axles, Length= 888cm, A#6  S#2  L#6  G#8  H#8 ,  468cm  136cm, GVW tonnes= 17.3,  4.2,  6.6,  6.5
2:  15:56:46.13   32.1kph,  3 Axles, Length= 871cm, A#6  S#1  L#6  G#1  H#1 ,  474cm  131cm, GVW tonnes= 14.9,  4.0,  5.2,  5.7
2:  15:57:08.88   46.0kph,  3 Axles, Length= 962cm, A#6  S#3  L#7  G#5  H#5 ,  555cm  151cm, GVW tonnes= 16.4,  5.6,  5.5,  5.3
1:  15:57:28.61   29.6kph,  3 Axles, Length= 879cm, A#6  S#1  L#6  G#8  H#8 ,  474cm  139cm, GVW tonnes=  9.9,  3.1,  3.4,  3.4
1:  16:01:04.79   60.3kph,  4 Axles, Length= 935cm, A#3  S#5  L#7  G#8  H#8 ,  340cm  402cm   79cm, GVW tonnes=  2.5,  0.8,  1.0,  0.4,  0.3
2:  16:01:36.80   32.7kph,  3 Axles, Length= 904cm, A#6  S#2  L#6  G#8  H#8 ,  472cm  139cm, GVW tonnes= 17.7,  4.6,  6.5,  6.6
2:  16:01:39.07   33.5kph,  3 Axles, Length= 888cm, A#6  S#2  L#6  G#1  H#1 ,  463cm  139cm, GVW tonnes= 18.4,  5.0,  7.8,  5.6
2:  16:02:52.64   62.0kph,  2 Axles, Length= 547cm, A#3  S#5  L#4  G#7  H#7 ,  407cm, GVW tonnes=  2.1,  1.5,  0.6
1:  16:04:45.99   33.7kph,  3 Axles, Length= 873cm, A#6  S#2  L#6  G#8  H#8 ,  465cm  136cm, GVW tonnes= 10.4,  2.7,  3.7,  4.0
1:  16:05:17.88   47.5kph,  3 Axles, Length= 865cm, A#6  S#3  L#6  G#6  H#6 ,  478cm  133cm, GVW tonnes= 10.5,  2.8,  3.8,  3.9
1:  16:06:21.81   48.1kph,  3 Axles, Length= 946cm, A#6  S#3  L#7  G#7  H#7 ,  557cm  151cm, GVW tonnes= 13.6,  5.0,  4.0,  4.6
1:  16:08:55.39   71.6kph,  2 Axles, Length= 527cm, A#3  S#6  L#4  G#8  H#8 ,  410cm, GVW tonnes=  3.2,  1.6,  1.6
1:  16:10:13.96   37.9kph,  3 Axles, Length= 886cm, A#6  S#2  L#6  G#7  H#7 ,  476cm  141cm, GVW tonnes= 11.2,  3.1,  4.1,  4.0
1:  16:14:11.69   64.9kph,  3 Axles, Length= 859cm, A#6  S#6  L#6  G#8  H#8 ,  465cm  131cm, GVW tonnes=  9.2,  3.4,  4.0,  1.8
1:  16:14:52.28   45.3kph,  5 Axles, Length=2037cm, A#9  S#3  L#10 G#6  H#6 ,  550cm  150cm  921cm  276cm, GVW tonnes= 19.2,  3.4,  3.8,  4.0,  4.1,  3.9
2:  16:25:55.59   54.7kph,  3 Axles, Length= 977cm, A#6  S#4  L#7  G#8  H#8 ,  556cm  151cm, GVW tonnes= 15.3,  5.2,  5.0,  5.1
2:  16:26:46.09   47.3kph,  2 Axles, Length= 565cm, A#3  S#3  L#4  G#6  H#6 ,  408cm, GVW tonnes=  2.7,  1.5,  1.2
1:  16:34:09.10   64.3kph,  4 Axles, Length= 898cm, A#8  S#6  L#6  G#8  H#8 ,   96cm  454cm  141cm, GVW tonnes= 10.0,  3.5,  0.1,  3.6,  2.8
1:  16:36:45.70   63.5kph,  2 Axles, Length= 527cm, A#3  S#5  L#4  G#8  H#8 ,  406cm, GVW tonnes=  2.6,  1.4,  1.2
2:  16:49:15.89   45.4kph,  2 Axles, Length= 550cm, A#3  S#3  L#4  G#8  H#8 ,  371cm, GVW tonnes=  1.2,  0.6,  0.6
2:  16:52:39.13   28.5kph,  3 Axles, Length= 823cm, A#6  S#1  L#6  G#8  H#8 ,  420cm  142cm, GVW tonnes=  8.8,  0.9,  6.1,  1.8
2:  16:52:58.63   34.7kph,  2 Axles, Length= 587cm, A#3  S#2  L#4  G#4  H#4 ,  420cm, GVW tonnes=  1.6,  1.0,  0.6
2:  16:56:24.28   48.6kph,  3 Axles, Length= 803cm, A#3  S#4  L#6  G#8  H#8 ,  338cm  367cm, GVW tonnes=  2.1,  1.0,  0.9,  0.2
1:  16:59:26.69   41.7kph,  2 Axles, Length= 503cm, A#3  S#3  L#4  G#8  H#8 ,  349cm, GVW tonnes=  1.6,  0.9,  0.7
1:  17:02:08.82   29.1kph,  3 Axles, Length= 797cm, A#6  S#1  L#6  G#8  H#8 ,  416cm  149cm, GVW tonnes=  7.4,  1.2,  3.2,  3.0
```

```
1:  17:03:21.29   30.4kph,  2 Axles, Length= 607cm, A#3  S#1  L#4  G#7  H#7 ,  422cm, GVW tonnes=  2.7,  1.3,  1.4
1:  17:05:46.41   53.7kph,  2 Axles, Length= 558cm, A#3  S#4  L#4  G#8  H#8 ,  374cm, GVW tonnes=  1.2,  0.6,  0.6
1:  17:08:52.68   55.1kph,  3 Axles, Length= 766cm, A#3  S#4  L#6  G#8  H#8 ,  338cm  367cm, GVW tonnes=  1.7,  0.9,  0.7,  0.1
1:  17:15:50.05   57.7kph,  2 Axles, Length= 446cm, A#3  S#5  L#3  G#8  H#8 ,  333cm, GVW tonnes=  1.5,  0.8,  0.7
1:  17:19:15.97   57.7kph,  2 Axles, Length= 532cm, A#3  S#5  L#4  G#8  H#8 ,  438cm, GVW tonnes=  1.9,  0.9,  1.0
2:  17:26:41.62   76.9kph,  2 Axles, Length= 475cm, A#3  S#7  L#4  G#8  H#8 ,  330cm, GVW tonnes=  1.5,  0.8,  0.7
2:  17:28:38.35  SnMis #1      Info:
1:  17:28:38.53  SnMis #2      Info:
1:  17:28:40.70  SnMis #1      Info:
1:  17:55:55.89   83.7kph,  2 Axles, Length= 410cm, A#3  S#8  L#3  G#8  H#8 ,  333cm, GVW tonnes=  0.8,  0.4,  0.4
1:  17:56:20.63   17.7kph,  2 Axles, Length=1404cm, A#2  S#1  L#8  G#5  H#5 ,  299cm, GVW tonnes=  0.2,  0.1,  0.1
```

Appendix C

Data Sampling

A Typical Matching Process of WIM GVWs with Static Scale GVWs
Date collected for November 2, 2006

TimeIn	Static weight (kg)	Matching		Northbound Vehicle Present Time	WIM weight (kg)
07:50:06	6890	**07:52:00**	**4400**	06:29:05	2300
08:15:30	9330	**08:16:51**	**6700**	06:42:15	1900
08:21:03	7950			07:13:48	1500
08:52:18	3170			07:32:17	1500
09:18:55	9350			07:32:28	1500
09:31:40	12730			07:34:33	6000
09:32:46	12710	**09:33:52**	**1700**	07:40:56	2100
09:58:48	9680	**09:59:57**	**8300**	07:47:58	1900
10:13:48	12500			**07:52:00**	**4400**
10:16:27	12880			07:54:20	1500
10:20:09	4630	**10:21:47**	**1900**	08:00:07	3000
10:22:16	13050			08:05:31	1200
10:39:32	13470			**08:16:51**	**6700**
10:40:33	12910			08:29:27	5700
10:42:33	14000			08:50:19	1700
10:47:58	13500			08:58:19	2500
10:56:45	12910			09:03:12	1700
11:00:19	14150			09:11:00	8100
11:05:28	10020			09:12:03	1700
11:14:42	14200			09:14:53	2200
11:24:43	13650			09:22:12	1200
11:26:02	13920			**09:33:52**	**1700**
11:38:39	13140	**11:39:24**	**18100**	09:47:07	1600
11:39:43	13170			09:49:04	15500
11:45:24	13350			**09:59:57**	**8300**
11:45:52	13640			10:06:37	1200
11:54:11	14050			10:11:59	1200
11:57:42	13540			10:13:23	1900
11:58:51	12750			**10:21:47**	**1900**
12:00:45	13590			10:53:20	7200
12:02:05	13970			10:54:14	1200
12:02:50	13370			11:01:20	2100
12:10:00	14050			11:01:56	2100
12:12:58	13870	**12:13:33**	**8000**	11:08:06	1200
12:15:35	8560			11:10:33	1200
12:16:28	10800			11:12:37	1200
12:20:17	11470			11:31:53	1200
12:20:57	2810			**11:39:24**	**18100**
12:28:05	13600			11:40:11	2300
12:52:58	13180			11:45:23	7000
13:09:15	12540			11:50:52	1200
13:29:32	7490	**13:30:11**	**1200**	11:51:22	16100
13:30:33	12490			**12:13:33**	**8000**
13:31:29	12010			12:13:36	1200
13:32:45	3940	**13:34:11**	**2100**	12:15:02	1200
13:41:52	7890			12:27:41	1800
14:06:02	3510			13:00:18	11100
14:09:37	12340			13:05:03	2200

(Continue)

A Typical Matching Process of WIM GVWs with Static Scale GVWs
Date collected for November 2, 2006

TimeIn	Static weight (kg)	Matching		Northbound Vehicle Present Time	WIM weight (kg)
14:10:21	12390			13:06:40	1100
14:11:23	13010	**14:12:16**	**11300**	13:19:48	1200
14:18:50	13510			13:25:10	2000
14:19:57	3740	**14:21:39**	**1600**	**13:30:11**	**1200**
14:49:23	12190			13:31:28	6100
14:56:41	13080			**13:34:11**	**2100**
15:06:13	11890			13:40:00	6900
15:13:13	7300	**15:14:58**	**1200**	13:44:13	1200
15:22:14	13300			13:44:57	2700
15:25:00	12540			13:45:54	1200
15:29:56	12290			13:52:35	1800
15:35:54	13410	**15:36:10**	**1800**	13:58:20	1200
15:36:45	13200			**14:12:16**	**11300**
15:46:32	12360			14:15:37	1200
15:49:42	12630			14:18:09	1200
16:03:00	12190			**14:21:39**	**1600**
16:04:33	12970			14:28:18	2600
16:06:51	11510			14:35:12	1200
16:07:30	12410			14:43:24	1800
16:07:58	12840			14:53:34	1200
16:10:16	12650			14:58:31	7100
16:27:16	12940			15:03:37	1200
16:27:57	4330			15:13:31	1200
16:31:12	12750			**15:14:58**	**1200**
16:35:16	13400			15:32:51	2100
16:47:11	13400			15:33:18	6900
16:52:03	12900			**15:36:10**	**1800**
17:11:18	12620			15:40:40	1200
17:16:38	13140			15:51:35	2300
17:17:55	13200			15:52:55	12700
17:39:04	3230			15:59:26	1200
17:42:59	13210			16:09:54	1600
				16:15:17	7300
				16:19:38	2100
				16:22:55	1200
				16:52:17	13200

Appendix D

A WIM Full Scale Calibration at CPATT Test Track

A tandem dumps truck (3 axles, static weight of 14.540 tons measured from the static scale) from the Region of Waterloo. Pavement temperature changed from 21.0^{0}C at 8:00am to 32.4^{0}C at 11:30am during this process:

Lane 1 (North Bound) August 22, 2006

RUN #	Speed (kph)	GAIN	Calibration Factor	Measured GVW (tons)	Axle Number
1	20	15	4	0.5	
2	50	15	6	0.6	
3	50	15	6	2.3	
4	50	15	9	65.3	4
5	50	15	9	65.3	4
6	50	15	5	54.2	4
7	50	15	2	17.7	3
8	50	15	1.8	n/a	
9	50	15	1.8	18.2	4
10	50	15	1.8	3.7	5
11	50	15	1.8	3.1	4
12	50	15	2	65.3	3
13	50	16	2	65.3	
14	50	15	2	2.7	
15	50	16	2	22.1	4
16	50	16	2	1.7	4
17	50	15	2	1.7	4
18	50	15	2	44.2	4

Lane 2 (South Bound)

RUN #	Speed (kph)	GAIN	Calibration Factor	Measured GVW (tons)	Axle Number
1	20	12	4	26.2	
2	20	12	4	25.7	
3	20	8	4	45.5	
4	50	8	2	n/a	
5	50	8	2	1.3	
6	50	8	4	1.5	5
7	50	15	4	1.5	5
8	50	15	10	58.5	3
9	50	15	8	56.1	3
10	50	15	6	30.0	4
11	50	15	5.5	31.3	
12	50	15	5.5	33.4	6
13	50	15	5	31.8	4
14	50	15	4.5	30.7	6
15	50	15	4	30.2	5
16	50	15	3	28.3	
17	50	15	3	23.0	4
18	50	15	3	32.0	

Appendix E

LTPP WIM Cost Online

General Information

Estimate Title: Cost Estimate of a Typical Single Load Cell WIM System

Date: 2/07/2007 1:41:12 PM

Initial Inputs

Number of Sites: 1

Avg Number of Lanes per Site: 2

Number of Central PCs Required: 2

Central PC Software Required: Yes

Number of Sites with ACP Rehab.: 0

Number of Sites with PCC Rehab.: 0

Site Preparation Costs

ACP Rehabilitation Cost: $10000.00

PCC Rehabilitation Cost: $0.00

Hardware Costs

Initial System Cost

Piezo Cable: $0.00

Bending Plate: $0.00

Other Technology: $50,000

Cost Reduction Factor: 70%

Assumed Sensor Failure Rate

Piezo Cable:

Bending Plate:

Other Technology: 15%

Sensor Replacement Cost/ Staff(Days)

Piezo Cable:

Bending Plate:

Other Technology: $10000.00 / 5

Number of Sensors per Lane

Piezo Cable: 0

Bending Plate: 0

Other Technology: 2

Central PC Cost: $10,000.00

Central PC Software Cost: $15,000.00

Operating Costs

Office Processing Staff

Cost per FTE: $50,000.00

Staff FTE per Site: 3

Operating Expenses per Month per Site

Power Costs: $25.00

Telecommunication Costs: $35.00

Maintenance Expenses per Site

Costs: $5,000.00

Staff(FTE): 3

Calibration Efforts per Year: 3

Calibration Cost / Staff(Days) per Lane

Traffic Stream Weighing:

Two Loaded Test Trucks: $2,000.00 / 5

Other Techniques:

Calibration Cost Reduction for Extra Lanes: 70%

Type of Calibration Effort: Two Loaded Test Trucks

Other Potential Costs

Initial Maintenance Unit Cost: $5,000.00

Annual Rehabilitation Costs

Cost per Effort: $8,000.00

Percentage Needed Each Year: 15%

Results

Initial Costs: 122,000

Annual Costs: 31920

Annual FTEs Required: 3.30625

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