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WEIGH-IN-MOTION TECHNOLOGY

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Austroads Incorporated

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- Transport South Australia
- Department of Infrastructure, Energy and Resources Tasmania
- Department of Transport and Works Northern Territory
- Department of Urban Services Australian Capital Territory
- Commonwealth Department of Transport and Regional Services
- Australian Local Government Association
- Transit New Zealand

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Executive Summary

Australian road transport managers require a vehicle data system to provide information that will enable them to manage the road transport network in the most economical and efficient manner. One such piece of required vehicle information is mass.

For many years, researchers and practitioners have sought to develop systems that could weight vehicles whilst they were travelling along the highway, at the same time retaining the accuracy of static systems for enforcement purposes or, failing that, of sufficient accuracy to enable traffic to be screened for later static weighing. In addition, the development of such systems was desirable as Road Authorities sought to obtain more accurate information regarding the type, and weight, of vehicles using their road networks.

The aim of this report is to concisely document the status of Weigh-In-Motion (WIM) technology, focusing on Australia's situation. As such, based on the WIM expertise and knowledge of the reader, the report caters for many needs such as a basic level primer, source book, application reference manual, and WIM system reference guide.

A WIM system is: '*a device that measures the dynamic axle weight of a moving vehicle to estimate the corresponding static axle mass.'*

WIM systems comprise a number of basic components, with the mass sensor being the most important and fundamental. The mass sensor produces a signal whose value depends on the instantaneous dynamic wheel mass of a moving vehicle.

There are numerous factors affecting the ability of a WIM system to reliably and accurately determine the static axle mass of a vehicle while that vehicle is in motion. Some of these factors are inherent to the chosen WIM system, in particular the mass sensor component. Others though, are generic to WIM technology as a whole.

The overall need for WIM was clearly identified by Australian and New Zealand WIM system users and current and potential data users.

A survey of WIM vendors and suppliers found that there are 18 WIM system types currently used or available in Australia. A critical requirement is to ensure that the most appropriate system is used for the chosen application(s). There is not one very good and one very poor WIM system, rather there are different systems for different applications. A significant number of applications for WIM technology were identified, which adhere to three broad groups as follow:

- infrastructure design and management,
- freight/trade planning and regulation, and
- detection and enforcement.

There are currently eight different high speed WIM system types being used in Australia, totalling 170 installations. Due to the overwhelming majority of WIM systems used in Australia originating from one vendor, namely ARRB Transport Research, there has generally been a uniform approach to the site requirements, evaluation encompassing accuracy determination and reporting, calibration and reporting of WIM data. In the last few years other WIM systems have been introduced and used, and this uniformity is being challenged.

Site selection and location characteristics are fundamental to the performance of a WIM system. Some work has been done in quantifying and setting acceptable tolerances to WIM location characteristics, with vendors and suppliers providing guidelines. Overall though, the selection of an appropriate site for WIM system installation is based on user experience and intuition. It was recognised by Australian and New Zealand WIM system users that location characteristics need to be quantified.

An accurate mass measurement is produced when the output of the mass sensor is properly calibrated. Calibration requirements vary among specific WIM systems. In general, it is desirable for WIM systems to be routinely (automatically or at regular intervals) calibrated. The survey of Australian and New Zealand

WIM system and data users, revealed a general dissatisfaction with the calibration of WIM systems, especially with regard the lack of uniformity, procedure and frequency of checking/auditing to alleviate possible calibration drift.

The evaluation of a WIM system is the process of quantifying its performance in undertaking the application for which it was chosen. There is no standard Australian specification or method to evaluate WIM systems. However, there are a number of standards available throughout the world for evaluation and accuracy determination. It may be appropriate to adopt or modify such a standard (whichever is most appropriate) for the evaluation and accuracy reporting of WIM systems in Australia.

The processing of output data to produce reports has traditionally served so called 'primary users'. Primary users are those for whom WIM technology was initially developed, such as road infrastructure applications. This had the effect of pushing secondary users away from WIM technology by forcing them to adopt complicated post-processing - summary and reporting techniques. Secondary users have only recently begun to apply WIM data to their specific areas. There is evidence to demonstrate that application driven analysis of traffic load data can not be vigorously pursued until standards are developed for the collection, summarising and reporting of WIM data. To this effect, it is important that WIM data be promoted and made available in a form that is accessible and suitable to all users. It is anticipated that the next few years in Australia will see a wide spread application of WIM data, more than experienced before, especially with secondary users.

New developments are constantly being considered in the WIM area. Accuracy, durability, maintainability, ease of installation, portability and initial and on-going cost are all important factors that are being evaluated. One of the most significant areas being addressed by the WIM industry is the increase in accuracy of mass sensors. The association of WIM systems with other traffic monitoring systems to form integrated traffic systems is now becoming reality.

There is no doubt that the expectations anticipated ten or so years ago in Australia with regard to WIM technology have been slow in coming. This has been witnessed in the area of mass sensor development, that is, predicted low cost and enforcement accuracy sensors that as yet have not arrived and the lack of use of WIM data by secondary users.

In order for the Australian WIM sector (WIM system vendors, suppliers, system and data users) to realise the maximum overall benefit from the development and application of WIM technology, the following recommendations are made:

- hardware:
  - development of low cost mass sensors, and
  - development of high speed enforcement accuracy level mass sensors.
- usage:
  - quantification and standardisation of WIM system site location characteristics,
  - quantification and standardisation of initial and on-going WIM calibration procedures,
  - establishment of a standard evaluation methodology, encompassing a common language to describe the performance of WIM systems, and
  - establishment of a standard specification (contract) for the supply, installation, calibration and maintenance of WIM systems.
- data:
  - establishment of a uniform/standard format for WIM data output, and
  - establishment of a QA system to screen all WIM data prior to acceptance.
- application:
  - promotion of the existence of WIM technology and its associated applications,
  - quantification of the level of WIM system accuracy required for different applications,
  - establishment of standard WIM data application reports, catering for specific users' needs, and
  - dissemination of WIM information via symposia and workshops.

1. INTRODUCTION

Australian road transport managers require a vehicle data system to provide information that will enable them to manage the road transport network in the most economical and efficient manner. One such piece of required vehicle information is mass.

Vehicle mass data has been collected in Australia for more than 50 years. Principally, the devices used to perform this function have been static weighers; that is, vehicles were weighed while at rest on scales designed for static operation. The types of static weighers range from those that can weigh the entire vehicle, to axle load scales that weigh all wheels on a single or tandem axle, to single wheel load scales that weigh only one, or possibly two, dual tyres on one side of an axle. Static weighing has long been recognised as inefficient and unsafe for people working with heavy vehicle volumes.

For many years, researchers and practitioners have sought to develop systems that could weight vehicles whilst they were travelling along the highway, at the same time retaining the accuracy of static systems for enforcement purposes or, failing that, of sufficient accuracy to enable traffic to be screened for later static weighing. In addition, the development of such systems was desirable as Road Authorities sought to obtain more accurate information regarding the type, and weight, of vehicles using their road networks.

Weigh-in-motion (WIM) systems were initially developed as research tools. Now they are routinely used throughout the world for the collection of vehicle mass data in an assortment of applications.

The aim of this report is to present, in a concise document, the status of WIM technology, focusing on Australian experience. As such, based on the WIM expertise and knowledge of the reader, the report will cater for many needs such as a basic level primer, source book, application reference manual, and WIM system reference guide. In particular, the report covers the following areas:

- WIM definitions and concepts;
- brief history of WIM technology;
- WIM system calibration and evaluation;
- WIM data output and reporting;
- applications of WIM technology;
- current WIM systems;
- current research and future developments; and
- recommendations on delivering Australia the best opportunities in overall WIM technology.

In addition to a detailed literature review, three groups were surveyed as follows:

- WIM system vendors and suppliers worldwide (Appendix A);
- current Australian and New Zealand WIM system users (Appendix B); and
- current and potential Australian and New Zealand WIM system data users (Appendix C).

The organisational groups surveyed were as follows:

- ARRB Transport Research Ltd (ARRB TR)
- Australian Bureau of Statistics
- Australian State and Territory Road and Transport Authorities
- Bureau of Transport and Communications Economics
- National Road Transport Commission
- Transit New Zealand
- WIM system vendors and suppliers (worldwide)

2. DEFINITIONS AND CONCEPTS

2.1 General

In everyday general use, the term 'weight' nearly always means 'mass'. Weighing is in fact the measurement of mass. Weighing can be done via a simple balance or through the most sophisticated electronic equipment.

A WIM system is defined as a device that measures the dynamic axle mass of a moving vehicle to estimate the corresponding static axle mass. WIM systems should not be confused with on-board vehicle weighing systems. On-board weighing systems are mounted or attached to the vehicle, while WIM systems are independent of the vehicle being weighed.

WIM systems fall into two broad groups with regards uto the 'motion' in their weighing:

- low speed (less than or equal to 15 km/h), and
- high speed (greater than 15 km/h).

There are two main reasons for low and high speed WIM systems, namely functionality and accuracy. The functional requirement is simply aimed at fulfilling low or high speed applications (eg. low speed weighing station to a quarry as opposed to a high speed enforcement filtering system on a bridge). The accuracy requirement is based on the current technical inability of high speed systems to weigh accurately enough for enforcement or fee payment purposes.

The concept of WIM is that of a science and an art. It is a science because advanced technology and scientific investigation go into developing mass sensors. It is an art because the location in which the mass sensor is installed will significantly influence its performance.

Many different mass sensors have been trialed, giving acceptable and accurate results in the laboratory (the science). Unfortunately, very few of these mass sensors, when installed in a road pavement, exhibit anywhere near the laboratory achieved results. What is known though, is that by moving a known good mass sensor to a more or less suitable site, significantly affects its performance and accuracy (the art).

2.2 Layout and Components of WIM Systems

2.2.1 General

Low and high speed WIM systems generally comprise the following basic components (*Figure 1*):

- mass sensor,
- vehicle classification and/or identification sensor,
- processor and data storage unit, and
- user communication unit.

2.2.2 Mass Sensor

The mass sensor (and the output signal it produces) is the most fundamental and important component of a WIM system. The other components are peripheral to it, in that their abilities are ultimately dependent and indirectly judged by its performance.

Mass sensors are positioned on or within the road structure. Based on this positioning, they adhere to one of three categories:

- temporary,
- semi-permanent, and
- permanent.

Temporary mass sensors are usually surface mounted and fixed so that they can be fully removed, transported and re-installed at another location. Semi-permanent mass sensors are similar to temporary ones, but only one component of the sensor can be removed and re-installed. Usually the housing or cradle is permanently fixed and the gauge, transducer or signal processor is removable. Permanent mass sensors are designed to be installed once (surface or in-depth) and not removed, at least without causing damage.

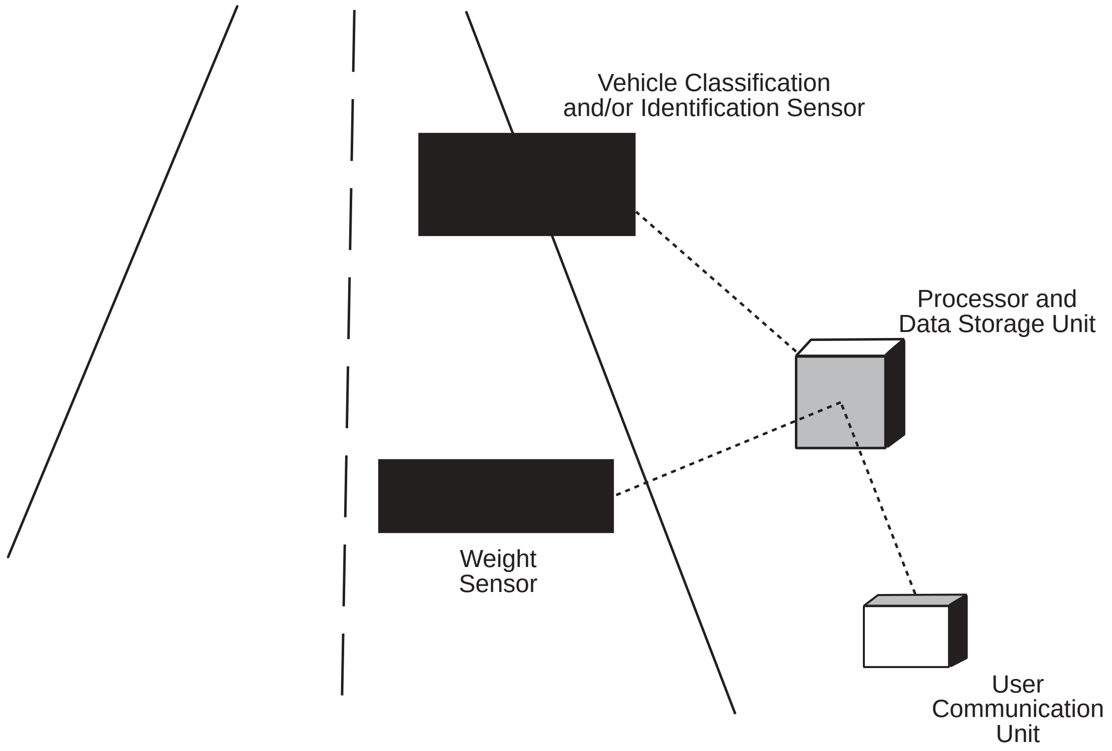

Fig 1. Components and layout of a typical WIM system

2.2.3 *Vehicle Classification and/or Identification Sensor*

In addition to axle mass determination, most WIM systems offer the ability to classify and/or identify the vehicle to which the weighed axle belongs.

Classification is accomplished via the use of a variety of different vehicle detection sensors, placed adjacent to the actual mass sensor. Typical vehicle detection sensors are as follows:

- loops,
- piezo electric cables,
- treadle switches, and
- tubes.

Vehicle identification takes the form of a picture or video image. The camera or video is placed off the road in a specialised housing, and is designed to identify or capture the vehicle's registration number or other unique feature. More advanced technologies allow identification of a weighed vehicle through so-called ‘smart cards’ carried on board the vehicle via a base station adjacent to the WIM system.

2.2.4 Processor and Data Storage Unit

The processor and data storage unit is usually installed at the roadside. Depending on the actual WIM system it is either secured to a fixed roadside item or in a protected cabinet. The processor is connected to the mass and vehicle classification and/or identification sensors, receiving and analysing the incoming signals to produce individual vehicle by vehicle and/or user defined summary reports.

This unit also powers the WIM system. This power can be mains, rechargeable battery or solar based.

2.2.5 User Communication Unit

The processor and data storage unit can also be the user communication unit in that it can directly display the collected data. Usually though, the user interfaces with the processor and data storage unit via a communication link as follows:

- specially designed retrieving unit linking directly into the processor and data storage unit,
- personal computer linking directly into processor and data storage unit, and
- modem and telemetry linking the processor and data storage unit into an offsite user unit.

2.3 Factors Affecting WIM Systems

2.3.1 General

There are numerous factors affecting the ability of a WIM system (low and high speed) to reliably and accurately determine the static axle mass of a vehicle while that vehicle is in motion. Some of these factors are dependent and inherent to the chosen WIM system, in particular the mass sensor component. Others though, are consistent and generic to WIM technology as a whole, and warrant further explanation. Of particular concern are the following:

- WIM location characteristics,
- vehicular characteristics, and
- environmental characteristics.

The ultimate aim of the WIM location choice and vehicular and environmental characteristics is to create the effect of a vehicle passing 'in motion' over the mass sensor with no vertical acceleration. In other words, even though the vehicle is moving horizontally, its mass (measured vertically) is unaffected.

One can appreciate the above mentioned characteristic via the simple everyday use of a domestic bathroom weighscale. During weighing, one must be perfectly still and allow the scale to stabilise to give an accurate weight reading. Any deviation or movement affects this reading - so imagine then the degree of difficulty in introducing the component of motion. As an experiment, take the domestic bathroom weighscale and place it in a hallway and then attempt weighing by simply walking in a straight line over the scale!

2.3.2 Weigh-in-Motion Location Characteristics

A fundamental factor in the performance of a WIM system is the characteristics of the location chosen to install the system. The WIM system location characteristics can be divided into two requirements:

- installation site, and
- approach to the installation site.

With low speed WIM systems, the installation site requirements are well defined by suppliers and vendors and require strict adherence. In most cases, the actual installation site is specially built or modified from the original.

For high speed WIM systems, the installation site approach is critical. Usually the 100 metres or so to the WIM system need to be smooth, straight, of good lane discipline and of free flowing (not accelerating or decelerating) traffic.

In particular, for both low and high speed WIM systems, the following parameters should be kept to a minimum:

- longitudinal profile,
- transverse profile,
- curvature,
- cross slope,
- pavement surface deflection, and
- pavement surface condition (rutting, cracking, depressions, shoving, heaving, etc.).

Some work has been done in quantifying and setting acceptable tolerances to the above location parameters. Most vendors and suppliers provide tolerances on parameters, for instance, the cross slope should be no more than 3 per cent from the centre line to the lane shoulder (ideally, less than 2 per cent). Others offer a more detailed WIM site selection scheme, incorporating a rating system (of the above location parameters) with acceptance cut-off levels (Davies and McCall 1988). Overall though, the selection of appropriate sites for WIM system installation using the above criteria is, as mentioned previously an art. This 'art' is practised by WIM system installers who have learnt the 'trade', but for all intents and purposes, it is based on experience and intuition. It was identified via the survey of WIM system users (Appendix B) that these parameters need to be quantified, that is, make the art a science. Furthermore, quantification of these parameters will permit suitable long term monitoring of the pavement for on-going calibration requirements.

2.3.3 Vehicle Characteristics

Vehicle speed, acceleration, deceleration, body and suspension type, tyre condition, aerodynamic effects, etc. are all factors that affect the performance of WIM systems. To this effect, vehicle characteristics are interconnected with location characteristics in that installation sites and their approaches are usually chosen to minimise or control vehicular characteristics. Factors such as acceleration and lane positioning can be influenced if not controlled, but suspension types and tyre conditions are more difficult.

2.3.4 Environmental Characteristics

Temperature (air and road pavement), wind and ice can have a significant effect on the performance of a WIM system. The majority of this information and its effects on the performance of a WIM system fall within the realm of the vendor. Effectively it is their proprietary information and most vendors are loathe to disclose it.

3. BRIEF HISTORY OF WEIGH-IN-MOTION TECHNOLOGY

The basic principles of WIM technology were developed in the 1950s. However, adequate instrumentation, data processing and storage and suitable mass sensors were non-existent or at best crude.

One of the earliest efforts to develop a WIM system was in 1952 by the United States Bureau of Public Roads (Norman and Hopkins 1952). The system's mass sensor included a reinforced concrete platform, constructed in the surface of the pavement. The platform was supported at each corner by columns to which resistance wire strain gauges were bonded. The system output consisted of an oscilloscope trace that took 10 seconds to acquire for each vehicle. Axle weights, spacings and vehicle speed were computed by manually analysing the oscilloscope readings.

The Mississippi State College in the United States was in 1955 experimenting with a metal-plate/rubber-sheet sandwich type capacitor scale for weighing heavy vehicles (Clyde 1985). With this system, difficulties were encountered with temperature, tractive forces, impact and edge effects.

The Transport and Road Research Laboratory installed a system similar to that developed by the United States Bureau of Public Roads, in 1957. A hydraulic-capsule transducer was tried in West Germany about this time, but was abandoned due to temperature and surging effects. A 2-load-cell, broken-bridge design was utilised in West Germany and in Denmark beginning in the 1950s. In the late 1950s, the University of Kentucky experimented with spring damping with the Bureau of Public Roads system and broken-bridge designs without success and also attached strain gauges to the aluminium girders of a special bridge section without overcoming the mass-oscillation problem (Clyde 1985).

Solid-state electronics and digital computers came into practicable use in the 1960s. Mass sensor development also continued.

In Australia, the late 1960s and early 1970s saw the Australian Road Research Board (ARRB) working on numerous methods of weighing vehicles at highway speeds. One of the systems consisted of a steel plate supported along two of its edges and mounted flush with the road surface. The system electronically measured the resulting strain produced (Tritt 1975).

In the mid-1970s, West Germany released three mass sensors, namely a hydraulic weighing sill, coaxial piezoceramic cable and a bending plate (Kalisch and Paatz 1995). For numerous reasons the hydraulic weighing sill and coaxial piezoceramic cable proved to be unsatisfactory for weighing in motion. The bending plate (fundamentally still used today) proved to be the most accurate and reliable mass sensor.

As a production tool, the first WIM system to appear in Australia was the Low Speed Electronic Mass Unit (LSEMU). Developed by ARRB (Tritt & Richards 1978, Samuels 1988), the LSEMU was a law enforcement device comprising a plate supported by four load cells.

Following extensive ARRB research and experience with LSEMU, the decision was made in 1978 to investigate the application of the system to high speed weighing. This culminated in the High Speed Electronic Mass Unit (HSEMU) (Samuels 1988).

Australia has also pioneered the use of strain gauge mass sensor systems. The Main Roads Department - Western Australia, developed a bridge based strain gauge system called AXWAY (Peters 1984). Experience with AXWAY led the Main Roads Department - Western Australia in conjunction with ARRB to develop CULWAY (Peters 1986). With CULWAY, strain gauges were mounted onto a culvert rather than a bridge.

Commencing from the late 1970s, other WIM systems were introduced into Australia. The Department of Main Roads - New South Wales installed a German built PAT DAW 200 high speed bending plate WIM system in 1985. Furthermore, the same Department installed a United States bridge based strain gauge system called FASTWEIGH.

During the mid-1980s, ARRB commenced using a temporary Golden River capacitive pad mass sensor based system. The weighing sensor was South African developed, but the remainder of the WIM system originated from the United Kingdom.

More recently, advances have been made to Australian developed WIM systems and a variety of other systems have been introduced from overseas. These are discussed further in the report.

4. WEIGH-IN-MOTION SYSTEM CALIBRATION AND EVALUATION

4.1 Weigh-In-Motion Calibration

A mass sensor produces a signal whose value depends on the instantaneous dynamic wheel weight of a moving vehicle. When the output for the sensor is properly calibrated, a mass measurement is produced. Calibration is the process of adjusting the output(s) of a mass sensor to match the measurements of the static mass. Calibration as such has two components:

- calibration of the mass sensor, and
- calibration of the location.

Calibration of the mass sensor is primarily performed by the WIM system's vendor or supplier at the laboratory and as required on location. This procedure is system dependent, that is, a function of the mass sensor being used. The survey of WIM system vendors (Appendix A) found that most vendors regard this calibration information as proprietary and are loathe to reveal or disclose it.

The calibration of the location, that is, vehicular and environmental characteristics are accomplished at the location by the installer. The initial calibration method and any subsequent re-calibrations are usually recommended by the vendor and supplier. This calibration information is not proprietary in nature and is generally public knowledge.

Much literature exists about WIM system location calibration (Koniditsiotis 1990, Dahlin 1990, Davies and Sommerville 1988, Papagiannakis and Senn 1995):

- test vehicle(s) and simulation models,
- comparison between pavement roughness and WIM system measurement error,
- comparison between static and dynamic weights of test vehicle(s), and
- distribution of gross vehicle mass.

There has been some scientific work in quantifying the frequency of re-calibration or on-going calibration. The majority of the re-calibrations are qualitative, for instance Dalgleish et al (1992) recommend a six monthly re-calibration period. More recently, on-going automatic calibration techniques have been proposed by Dahlin (1990) and Papagiannakis (1996). For instance, in Australia the continual monitoring of steer axles on six axle articulated trucks (A123). Another automatic re-calibration method uses the changing ratio of vehicle steer axle mass to gross vehicle mass (GVM) (Henny 1995). A statistical study undertaken by Papagiannakis (1996) on the use of auto calibration techniques such as steer axle mass to maintain calibration proved to be successful.

Quality Assurance (QA) software for WIM data has been developed as part of the US based Long Term Pavement Performance (LTPP) study. The software is designed to detect common types of WIM system failures and possible drifts in calibration, by comparing the data being reported for each site with expected ranges of data for that site (Hallenbeck 1995) The LTPP QA software is WIM system independent and performs the following:

- preliminary format and range check, and
- GVM distribution of five axle articulated trucks (A122) check (common heavy vehicle in the US),

A concern with the LTPP QA software and for that matter any automatic calibration system, is that the possible changing nature of vehicular loading at any particular site could be incorrectly interpreted or mistaken as a drift in calibration. This would have the effect of re-calibrating a WIM site to achieve an expected or predetermined result. The use of a steer axle, that is, a standard non-changing load, as the case of the Australian A123 vehicle would alleviate this problem.

The Australian developed WIMLINK software system has a QA component which is modelled on the US based LTPP study, but uses ‘continual’ calibration techniques (in addition to the field based methods) that are fine - tuned for individual WIM sites characteristics (Cropley et al 1998).

As part of the survey of Australian and New Zealand WIM system and data users (Appendices B and C), actual specifications for supply and installation of WIM systems were received. In all the specifications received, the initial calibration was deemed to be the responsibility of the vendor or supplier. Any re-calibration requirements were required to be fully explained and a method for accomplishing them detailed. It should be noted though, that the survey revealed a general dissatisfaction with the on-going calibration of WIM systems, especially with regards the lack of uniformity, procedure and frequency of checking/auditing to alleviate possible calibration drift.

As with other operational characteristics, the calibration requirement varies among specific WIM systems. In general, it is desirable for WIM systems to be routinely (automatically or at regular intervals) checked for possible calibration drift.

4.2 Weigh-In-Motion Evaluation

4.2.1 General

The evaluation of a WIM system is the process of quantifying its performance (fitness for purpose and condition) in undertaking the application for which it was chosen. Typical performance criteria used in the initial or on-going evaluation and appropriateness for specific application(s) of WIM systems are as follows:

- application – need, network or project level, low or high speed,
- installation requirements – location, vehicle types to be weighed, vehicle speeds, installation duration
- ease of use – power requirements, automation, permanent, semi-permanent or temporary, conspicuousness, communication capabilities, training, user manuals
- quality of data – data storage and retrieval, output data requirements and application specific reports,
- calibration – initial and ongoing,
- accuracy – required accuracy of data items given the application, and
- life span – initial and on-going costs, durability, reliability, maintainability and repairability.

It should be stressed that for most applications, the above criteria are not necessarily clear cut but interconnected and in some cases dependent on each other. For instance, the versatility, ease and speed of installation of a portable WIM system was found to balance its relative inaccuracy as compared to more permanent systems (Koniditsiotis 1990).

There is no standard Australian specification or method to evaluate WIM systems. There are though a number of standards available for evaluation and accuracy determination and reporting (Samuels 1988, ASTM 1994 and COST-323 1997). It would be appropriate to adopt or modify an existing standard (whichever is most appropriate) for the evaluation and accuracy reporting of WIM systems in Australia.

Increasingly the use of other traffic monitoring and surveillance systems are being used to fully quantify and evaluate the performance of WIM systems for particular applications (Henny 1995, Koniditsiotis 1996).

The Koniditsiotis (1996) study had as its aim the evaluation of a portable WIM system for collecting traffic load data on local streets and roads in urban areas. In the study, a vehicle classification system was installed adjacent to the portable WIM system being evaluated, in a local street in Melbourne, Victoria. The design of the study was to install both systems adjacent to each other at the same site, to compare the two sets of results on an individual vehicle by vehicle basis. To aid in the analysis of these results, the entire site was video taped, using a video system that made a recording only during vehicles trafficking the site. All three systems were synchronised to date and time, simplifying the analysis considerably.

The use of a vehicle classification and video recording system permitted a thorough evaluation of the WIM system to be undertaken, identifying and bringing to light a number of important issues (Koniditsiotis 1996):

- a difference in the total number of vehicles detected between the vehicle classification system, portable WIM system and video recording system. There were vehicles that passed over both ground based systems that were not detected, (portable WIM system more than vehicle classification system) but identified by the video recording system. There were a number of reasons identified for this phenomenon. Very importantly though, without the aid of a video recording system, there was no means of quantifying the detection ability of both ground based systems, and
- a number of vehicles were detected by the ground based systems, but observance of the video recording revealed that they had been mis-classified. There were a number of reasons for this phenomenon, primarily though, the video recording permitted proper evaluation of the installation site for its appropriateness.

Hence, the evaluation criteria need to be clearly distinguished given the identified application(s) and the method to quantify and assess them defined.

4.2.2 Life Span

Similarly to all component and modular based technologies, WIM systems have a life expectancy corresponding to the life span of each of its components. It is no coincidence that the most important and unfortunately readily damaged component of a WIM system is the mass sensor. For this reason, when determining overall life cycle costs, the mass sensor is the component used to quantify the on-going costs of the WIM system.

Little quantitative or field test information exists about the life-span or long term performance of different mass sensors. According to vendors and suppliers though, the life-span of weigh sensors ranges from three to 12 years (Caprez 1995). More detailed WIM system specific life spans are presented in *Tables III* and *IV*. There is no doubt that there is a degree of uncertainty regarding any equipment or system left unattended on a road, undergoing a multitude of vehicle axle passes. Such factors, in addition to the expected life, must be taken into account when considering the life span of mass sensors.

4.2.3 Accuracy

The accuracy of a WIM system is the degree of agreement or closeness between the item weighed and the accepted known (usually statically measured) value of the item. The term item applies to a vehicle's individual axle mass (IAM), group axle mass (GAM) and GVM.

There are three types of errors affecting the accuracy of a WIM system as follow:

- actual error, associated with the error in determining the true mass of a vehicle (ie. the error in static weighing),
- systematic error, associated with flawed initial or drift in existing calibration, and
- random error, associated with WIM system errors and vehicular characteristics.

The systematic error is quantified as the mean or average, while the random error is quantified as the standard deviation.

It is relatively simple to calibrate a WIM system to repeatedly measure one type of vehicle. That is fine-tune the mean or systematic error to zero. The overall requirement though, in WIM technology, is to achieve an acceptable level of accuracy for a variety of vehicles, travelling at a variety of speeds and mass conditions. That is, control or minimise the standard deviation or random error.

In Australia, there is no standard method of determining and presenting WIM system accuracy results. This has led to a diversity of methods in determining and accuracy of WIM systems and more so, in reporting their results.

An acceptable reporting mechanism for accuracy is to quote the tolerance for 95 per cent (assuming a normal distribution - two standard deviations of confidence) of the vehicles being weighed. For example, an accuracy result such as 95 per cent of vehicles weighed were within 10 per cent and 20 per cent for GVM and IAM respectively has far greater meaning and application than to simply say the accuracy was within 10 per cent.

The determination and reporting of accuracy results by vendors and users alike, has been found to be confusing if not misleading. Following are only some of the practices of particular concern:

- quoting calibration or re-calibration results as overall accuracy results,
- using one or two vehicles to derive accuracy as opposed to a larger random vehicle survey, and
- reporting accuracy results in a confusing manner, for instance:
  - 66 per cent of vehicles weighed had a GVM within 5 per cent of the static GVM, or
  - 95 per cent of vehicles weighed had a GVM within 10 per cent of the static GVM.

In this example the same WIM system is being reported. By assuming a normal distribution, both cases are reporting the same level of accuracy. The first reporting case though 'appears' to be more accurate. More confusion occurs when the percentage of vehicles (66 or 95) is omitted.

The survey of current Australian and New Zealand WIM system providers (Appendix B) resulted in a number of specifications for the supply and installation of WIM systems. The specifications contained satisfactory conditions of tender and conditions of contract, no doubt the standard conditions let out for any contract. Specifications for the WIM system requirements, evaluation and acceptance criteria were in many cases lacking in two main areas:

- required application(s) not clearly identified
- the evaluation criteria to be used in accepting the WIM system not defined.

For example, in one specification, the requirement was for IAM, GAM and GVM to have a minimum accuracy of ±10 per cent. In light of the previous example, at least two fundamental issues are unresolved and could cause confusion between vendor, supplier and user as follow:

- how will the accuracy be determined, that is, what method will be used, and
- how will the accuracy be reported, that is, does 10 per cent refer to the mean, one standard deviation (66 per cent) or two standard deviations (95 per cent) of vehicles being weighed?

5. WEIGH-IN-MOTION DATA OUTPUT AND REPORTING

5.1 WIM Data Output

The majority of WIM system outputs are observations of individual vehicle passes or events, including the following data items:

- location information (road, number of lanes, direction of traffic flow),
- vehicle count number,
- date and time of vehicle event,
- vehicle classification,
- vehicle speed,
- vehicle axle spacings, wheelbase and length, and
- IAM, GAM and GVM.

To derive information from the data items above, processing either by the 'Processor and data storage unit' or post collection processing is utilised. Some WIM systems such as CULWAY, process the output data in the 'Processor and data storage unit' to derive a basic application level report. Most WIM systems however, produce output data as presented above and require significant post processing to derive report summaries.

5.2 WIM Data Reporting

The processing of output data to produce reports have traditionally served so called primary users. The primary users are those for whom WIM technology and data collection were initially developed. In the WIM area, primary users have traditionally been the infrastructure design and performance monitoring users (McLean 1982). To this effect, the overwhelming majority of final data reports have been geared towards infrastructure (pavement and to a lesser degree bridge) requirements.

This has had the effect (especially in the past) of pushing secondary users away from WIM technology by forcing them to adopt complicated post-processing techniques to take the individual vehicle events and convert them to useable application driven information (Lim 1992). McLean (1996) reports that even given the enthusiasm of secondary users to the initial implementation of WIM technology, to a large extent its application, for example in the freight area has not occurred.

Overall, there are a number of reasons why use of WIM data has not occurred to the extent initially envisaged:

- primary users have lead the WIM technology agenda in the form of data storage, handling, analysis and reporting software,
- WIM data can require considerable and complicated post-processing before it is in a suitable (secondary) application driven format,
- secondary users are not necessarily aware of the existence and availability of WIM data, and
- WIM system sites are not necessarily located where the data needs are greatest (specific road links and urban areas).

The response from Australian and New Zealand current and potential WIM data users (Appendix C) on this issue was as follows:

- some (secondary) and potential users questioning the need for WIM technology or at least embarking on investment strategies or benefit/cost analysis to justify their investment in WIM, and
- many current and potential users demanding application based WIM data reports, as they become more aware of what can be provided through WIM technology.

Taking note of the above mentioned concerns, it is fundamentally important that WIM data be promoted for its existence, but also making it available in a form that is accessible and suitable to all users. Otherwise, as was found by George and Gallic (1995), substantial storage costs might be encountered, or worse data being unusable because it becomes too difficult to recover and not validated and hence useless.

With the established WIM systems in Australia, user groups were also set up to cater for the need of output data, reporting and use. The largest of these groups is the Australian CULWAY Users Group. In the May 1996 meeting of the Group, it was resolved that the group should promote the existence and availability of CULWAY WIM data more widely, especially to potential new users.

More recently, specialised WIM data storage and reporting software has been developed. These software systems are WIM system independent and offer a means of making data readily available to the user.

The Europeans are proposing a unified standard database structure for the storage and reporting of WIM data (Henny 1995b). This will permit a common language and use of data across the European continent that is increasingly becoming borderless. The US has developed the LTPP Traffic Database, which has been designed to store, maintain and provide access to not only WIM data, but traffic data generally (Hallenbeck 1995b). The beauty of these systems is that in addition to storage and reporting, they also offer QA and on-going calibration abilities.

In Australia, most State and Territory Road Authorities have a storage and data reporting system. These systems were generally developed as part of the CULWAY system and also offer QA and on-going calibration abilities. Their user friendliness and accessibility, however vary between States and Territories.

Roadways, developed by Telstar, has been designed for the storage, analysis and reporting of traffic data collected from WIM systems. Roadways is WIM system independent and offers the following benefits (Harding 1996):

- central database of WIM collected data,
- ability to interrogate collected data and extract key information, and
- ability to compile statistical and trend reports.

WIMLINK developed by ARRB TR, is the WIM technology module of the traffic software system. Similarly to Roadways, its is WIM system independent and offers the following general features (Cropley et al 1998):

- WIM network/site management
    - daily (or under defined frequency) status check of all telemetry linked WIM sites, and
    - monthly (or user defined frequency) WIM site lane calibration check.
- WIM data management
- data down - load (user - defined frequency) from telemetry linked WIM sites,
- data quality assurance, including short and long term trends in vehicle parameters, and WIM system/site parameters,
- central database of WIM collected data,
- ability to interrogate data,
- presentation and dissemination of end-user tailored reports, and
- interfacing with existing agency databases.

Research activities conducted by Blewett (1996) revealed that substantive analysis of transportation related issues could not be vigorously pursued until standards were developed for the collection and summarisation of traffic monitoring data.

Since all Australian States and Territories have WIM and, to varying degrees, handling and storage systems catering for their specific needs, it would be inappropriate to impose a new system on the entire data storage process. Rather, it seems more realistic, that on the national level, different levels of aggregation of WIM data output should occur so as to develop different application based reports. This would have the additional benefit of creating uniform and standard application reports for all users.

6. APPLICATIONS OF WEIGH-IN-MOTION TECHNOLOGY

6.1 General

The need for effective monitoring of vehicle mass has been documented in numerous studies (Kent 1981, McElhoney 1985, Koniditsiotis 1993, AUSTROADS 1988, McLean 1982, NAASRA 1984, Kempen 1987, Dalgleish 1992). The survey of Australian and New Zealand WIM system users and current and potential data users (Appendix B and C) clearly identified a need and application(s) for WIM technology.

The usefulness of WIM technology had not always been so documented and apparent. An Australian survey questionnaire outlining various possible, then, applications for vehicle weighing systems was conducted of Australian State Road Authorities in 1975. The questionnaire produced the following order of only three priorities (Tritt 1976):

- a screening device for use at static weighbridges. All to be weighed in motion and only those near or above legal limits to be directed to the weighbridge,
- a portable static weighing device as an alternative to loadometers, and
- a system for weighing vehicles at highway speeds to enable data for pavement and bridge design and transport economics studies to be collected.

Like in many other high technology fields, the WIM discipline has for many years been technology driven. While this might have been inevitable in the early stages of development, the current level of technology allows WIM to now become application driven.

Ultimately the choice of WIM system to research and develop or purchase off the shelf, the question of its accuracy, installation and data output and presentation is fundamentally inherent to its intended purpose and application. The relative accuracy requirements for different network and project level WIM applications are shown in *Figure 2*.

Some work has been undertaken in quantifying accuracy requirements for different applications. In a survey of European countries, De Henau (1995) characterised accuracy levels based on requirements (*Table I*). These accuracy requirements though, are broad, and should only be regarded as indicative.

As part of this report, a survey was conducted in addition to a literature review, to ascertain current and future possible uses and applications of WIM technology. In particular, surveyed were Australian and New Zealand WIM system and data current and potential users and WIM system vendors worldwide (Appendices A, B, and C). Identified were a number of uses and applications, which can be categorised into three broad areas as follow:

- infrastructure design and management,
- freight/trade planning and regulation, and
- detection and enforcement.

Within each of these three broad areas are overall network and specific project level applications.

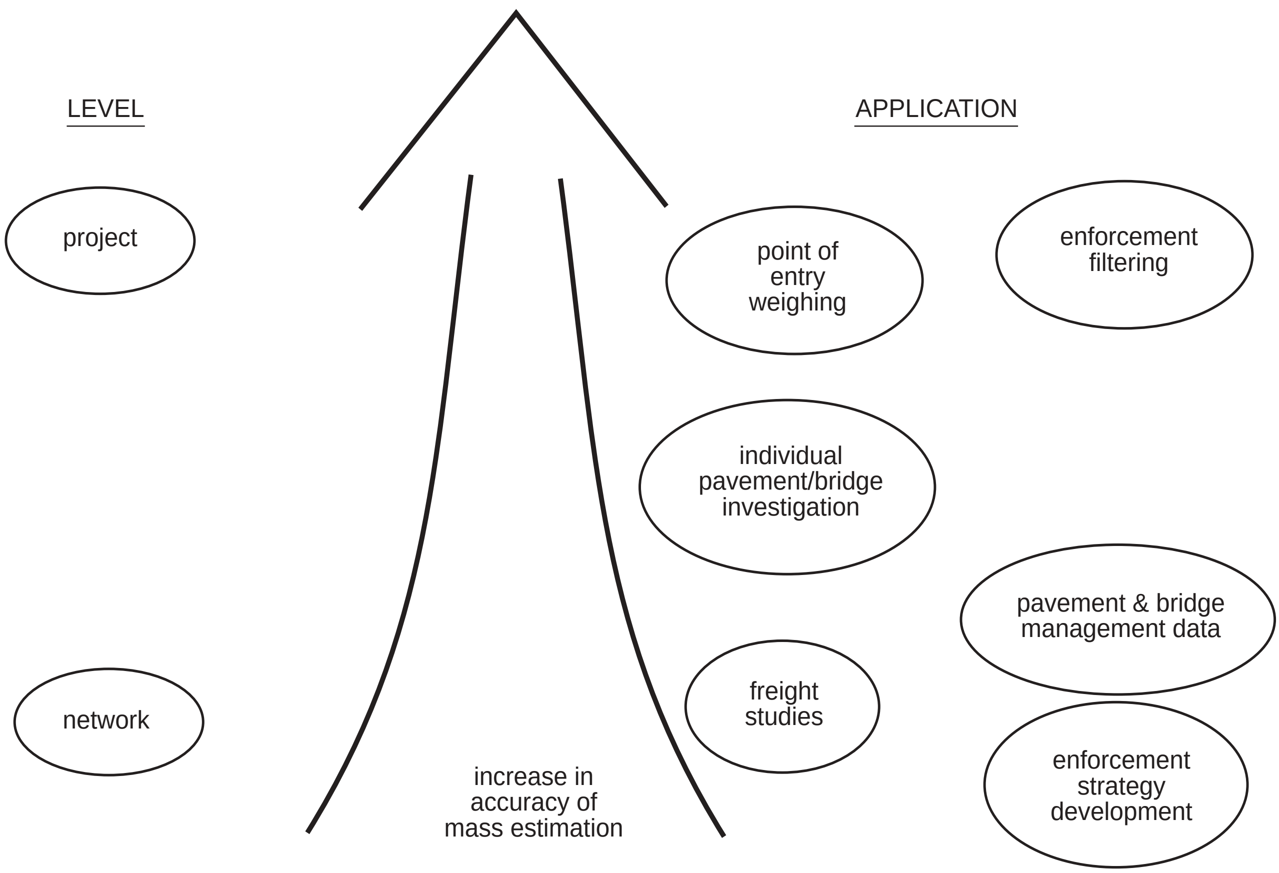

Fig. 2 Relative required accuracy of different applications

Table I — Typical European WIM Accuracy Requirements

Requirement	Typical Applications	WIM Accuracy (GVM for 95% of Vehicles)
Statistics	Economic Analysis Transport Studies Classification of Vehicles	< 20%
Infrastructure and Presentation	Road and Bridge Management Overload Warning Threshold Preselection for Static Weighing Road Safety	< 15%
Control	Enforcement Regulation Trade Industry Needs	< 5%

A key element running through all the areas is the advancement and betterment of that area or discipline through research. For instance, the technological advances in the collection of vehicle mass data in the road pavement area have developed from people estimating vehicle mass by standing at the roadside to the use of high speed WIM systems. This advance has produced a better estimate of the actual vehicle traffic loads and thus more accurate data being used either in the initial design or subsequent management procedure. Furthermore, sufficient data using WIM systems have been collected to allow upgrades and revisions to actual road pavement design and management theorems (Koniditsiotis 1998).

6.2 Weighing for Infrastructure Design and Management

The Australian land transport infrastructure network encompassing road pavements and bridges is being constructed and managed to withstand a variety of conditions imposed on it. One of the most important of these conditions is vehicle loading.

It is somewhat difficult to quantify the financial benefits or return to the Australian road infrastructure network via WIM technology. Specific cases though can be quantified.

A number of high speed WIM surveys on specific road links in Canberra using the Golden River Weighman have indicated a significantly lower number of Equivalent Standard Axles (ESAs) per commercial vehicle than previously believed and used (Koniditsiotis 1994). In the past, for Road Functional Class 6 roads, the New South Wales value of 1.9 ESAs per commercial vehicle was used in initial and rehabilitation designs in Canberra, whereas an ESA value of around 1.0 via the WIM surveys was found to be more appropriate. In a 600 metre long, two lane carriageway requiring rehabilitation work, this result produced a saving of $12,000.

The Austroads Pavement Design Guide - Traffic Loading Design Chapter is being updated as follows (Koniditsiotis 1998):

- to model traffic loading for Australian sealed heavily and lightly traffic roads, and
- to develop an Australian Traffic Loading Design procedure that revises and extends the current Austroads Pavement Design Guide.

The current Austroads Pavement Design Guide caters for traffic loading using a coarse model based on simplistic methods, legal loading and ad-hoc static vehicle load surveys, performed at least ten years ago. The update involves using currently available high speed WIM systems in Australia (discussed further in report) to make the Guide more representative of today's traffic loading (Koniditsiotis 1998). The benefits of this work have not been precisely quantified, but preliminary investigations have clearly shown that in a pavement design situation, a more ‘conservative’ pavement would be constructed if the current traffic loading design procedure were used. Depending on the pavement materials and type this ‘conservativeness’ could be interpreted as a thicker pavement or a pavement where stabilising agents were used to enhance its properties.

A series of traffic load surveys using a portable WIM system were conducted on the West Gate Bridge, Melbourne, Victoria. A one week long survey was conducted in each of the outer two lanes (heavy vehicle lanes) in each direction over the bridge. The reason for the traffic load surveys on the West Gate Bridge was to quantify the bridge's traffic loading condition in light of a number of fatigue cracks that were discovered in the weld joints (Koniditsiotis 1990a). Another bridge application, examined the changing headway between heavy vehicles as a function of vehicle classification, speed and proportion of gross vehicle mass. The overall purpose of the study was to determine the minimum headway actually realised between two heavy vehicles travelling faster than 15 km/h with a gross vehicle mass of 42.5 tonne or greater (Koniditsiotis *et al.* 1997).

Applications in weighing for Infrastructure Design and Management are as follows.

6.2.1 Network Level

- Collection of heavy vehicle mass data for the development of infrastructure asset design and management strategies:
- Bridge management and design strategies (Koniditsiotis at el 1997, Michael 1994, Pearson 1994, Heywood 1994, Chou 1995)
- Pavement management and design strategies (Haas 1993, OECD 1992, Chou 1995, Koniditsiotis 1996, Anderson and Rhodes 1992, George and Gaillac 1995))
- Determination and adjustment of loading criteria for bridge codes (AUSTROADS 1992)
- Dynamic loading effects on bridges (Cantieri and Barella 1995, Heywood 1995)
- Input into Pavement and Bridge Management Systems (Gupta 1996)
- Knowledge of axle configurations and individual axle masses for derivation of group average ESAs for commercial vehicles and axle configurations. Furthermore, information on the number and types of heavy vehicle axles (Angell 1987, World Bank 1993, AUSTROADS 1992, Ilves and Kamran Majidzadeh 1992)
- Assessment of road pavement damage and wear (Martin 1995, Potter *et al*. 1995, Cole *et al.* 1992))
- Modelling pavement response and overall performance as a result of applied vehicle loads (Chatti at al 1995, Hardy 1995, Huhtala 1995)
- Spatial repeatability - measurement of systematic (repeatable) patterns of axle impact forces along pavements (Jacob 1995, Moran 1995, Gyenes and Mitchell 1992, Huhtala and Jacob 1995).
- Collection of heavy vehicle mass data for the planning of heavy vehicle road network routes (World Bank 1993)
- Enhanced risk management and reliability in pavement design (Potter 1994, Cropley 1996)

6.2.2 Project Level

- Investigation of premature deterioration of specific road pavements and bridges, encompassing the collection of heavy vehicle mass data for specific rehabilitation and maintenance designs (Koniditsiotis 1993 & 1994, Kim et al 1995)
- Triggering the switching on of exhaust fans in tunnels, not as a result of the build-up of CO_2 and other emissions, but rather on the use of tunnels by heavy vehicles.

6.3 Weighing for Freight / Trade Planning and Regulation

In the past 20 years, Australian road freight rose from 27 billion to 95 billion tonne-kilometres per year, an increase from 20 to 34 per cent of the yearly total for all freight modes (vehicular, rail, sea and air) (AUSTROADS 1994). In terms of freight tonne-kilometre, Australia has the most transport demanding economy of all OECD countries. Overall the growth in travel by articulated trucks exceeds the growth in travel by passenger cars, so that articulated trucks represent an increasing proportion of total traffic (McLean 1996).

It is difficult to put an economic value on WIM data for freight/trade aspects (Henny 1995). However, as a broad indication, the annual cost of road freight in Australia is about $30 billion. If, through better data, road investment was better targeted to the needs of the road freight industry such that industry costs were reduced by only 0.1 per cent, this would represent an annual benefit of $30 million.

Austroads has developed a performance management framework within which road system and agency performance may be reported. As part of the framework a series of national indicators aimed at delivering objective tools for reporting purposes have been developed. One of Austroads' national indicators is the Lane Occupancy Rate for Freight which is defined as 'the average number of tonnes of freight per lane per hour during a specified period' (AUSTROADS 1997). This Austroads' indicator allows the quantification of heavy vehicle use and efficiency in carrying freight and a measure of the usage of different road links as part of the road network.

Applications in weighing for Freight/Trade Planning and Regulation are as follows.

6.3.1 Network Level

- Collection of GVM data for the determination of the Austroads Performance Indicator - Lane Occupancy Rate for Freight (AUSTROADS 1997, Koniditsiotis 1997)
- Collection of GVM data for ascertaining aggregate freight movements and the development of freight/trade strategies and time series for inter - regional corridors (Anderson et al 1992, Harrison 1996).
- Ascertaining vehicle weight limits and regulations (Billing 1995, Missen 1995, Wright 1992)
- Collection of truck mass data for the planning of specific heavy vehicle routes (Harrison 1996, Sleath 1995).
- Ascertaining the extent of road use by different classes of heavy vehicles for potential taxation or cost attribution (Martin 1995).
- Input of vehicle mass data for financial investment and work programming. Revenue estimation and forecasting, energy supply, consumption and forecasting as well as commodity movement studies (Fernandes et al 1995 and Frith *et al*. 1995).

6.3.2 Project Level

- Monitoring of material movement at entry or departure points at quarries, mines, ports and freight depots (Castle Rock Consultants 1989).
- Monitoring of material movements at port entry or departure points to allow freight load optimisation,
- Ascertaining the utilisation of the load carrying capacity of freight/trade vehicles (Koniditsiotis 1997).
- Collection of GVM and IAM data as a basis for toll collection, such as road and bridge tolls and ferry operators (Whorlow and Compton 1995, George and Gaillac 1995).

6.4 Weighing for Detection and Enforcement

To ensure that overloaded vehicles do not cause excessive damage to roads, most countries, including Australia, impose axle load limits on vehicles.

Successful detection of overloaded vehicles is expected to lead to a reduction in the overall road network rehabilitation and maintenance costs.

Weighbridges have been deemed by some as being too costly to operate, with their fixed location allowing enforcement avoidance. Furthermore, portable static scales were regarded as too slow and cumbersome. The resulting benefits to the community accrue for the reduced disruption to the transport industry through the selective interception of overloaded vehicles. The effects on industry using heavy vehicles would be significant in terms of reduced disruption to general operations through the process of targeting overloaded vehicles only. Some Australian State Road Authorities identified a potential ten-fold reduction in disruption costs utilising this process as compared with the existing static process of total interception.

On such system is the High Speed Electronic Mass Unit (HSEMU). HSEMU is a system that automatically classifies, measures dimensions (length, height and width) and weighs each vehicle as it passes at highway speed.

The HSEMU is used in New South Wales as a heavy vehicle screening system. The typical layout of HSEMU, and for that matter most screening or filtering systems, is shown in *Figure 3*. All vehicles in excess of three tonnes are diverted off the main highway to a dedicated HSEMU lane. HSEMU classifies the vehicle and measures dimensions and weight. The system automatically diverts vehicles that do not conform to predefined weight and dimension parameters into an enforcement (static weighbridge) checking station. Vehicles that conform to the HSEMU check are directed back on to the highway proper (*Figure 3*).

Another integrated system used in New South Wales is Safe-T-Cam. Safe-T-Cam was designed to capture video images of heavy vehicles, identifying their number plates. A series of video cameras are used to monitor (detect) and capture images of vehicles. The automatic image analysis consists of finding the vehicle's number plate and reading it. Safe-T-Cam is a high speed 24 hour, fully automated system.

In addition, to the routine collection of vehicle statistical data, the Safe-T-Cam's purpose is to detect heavy vehicles that are deemed to be in violation of one or more regulations, as follow:

- long distance speeding (measured between two or more Safe-T-Cam installations),
- unregistered vehicles,
- stolen vehicles,
- pollution regulation breaches, and
- overloaded vehicles (WIM).

WIM technology is but one 'stand alone' system that can be integrated with other systems to form Safe-T-Cam.

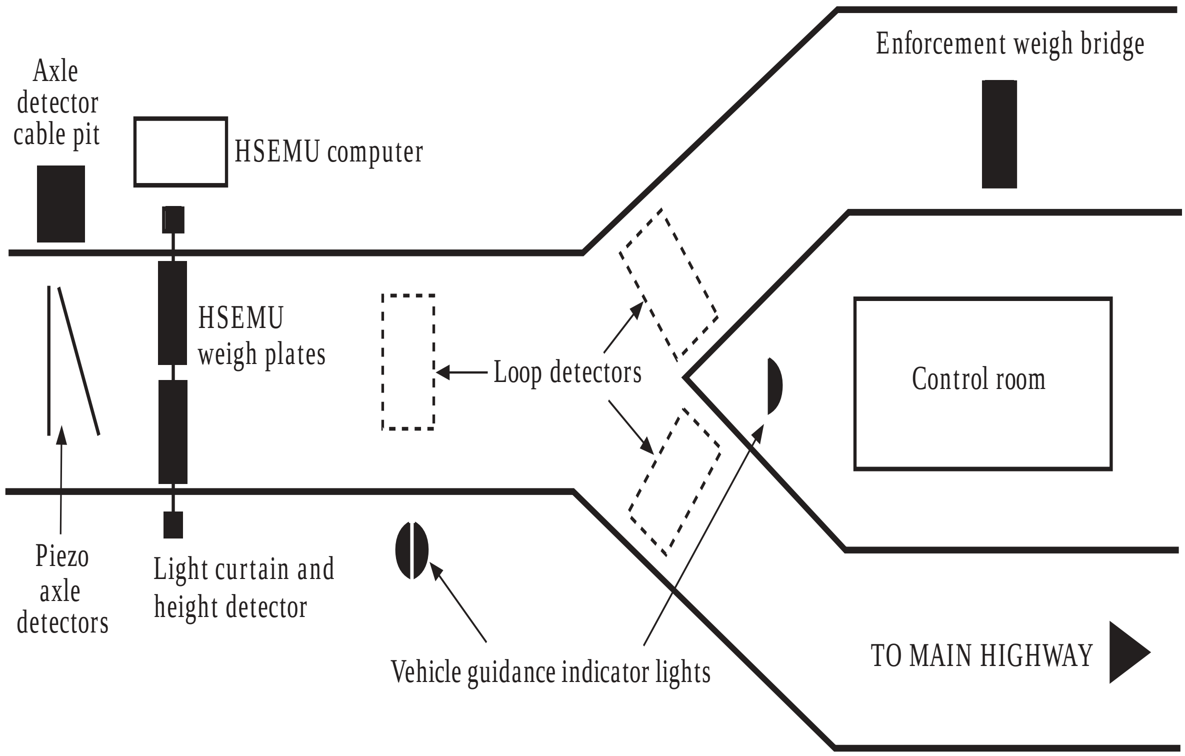

Figure 3. Typical Layout of HSEMU

Over the past eight years CULWAY has been used in some regions of Victoria to assist with the identification of times and days of the week (overall trends) that enforcement activities can be utilised. Since 1992, a 'live time observation' data version of CULWAY has been used which has allowed for instant load enforcement (Welsh 1996).

As a result of the traffic load surveys using a portable WIM system conducted on the West Gate Bridge, discussed previously. A heavy vehicle mass enforcement strategy (using the collected traffic load data) was developed. The aim of the strategy was to determine the most suitable periods in which to undertake traditional static load enforcement (Koniditsiotis 1990b).

A study was undertaken by the National Road Transport Commission (1998) with the aim of quantifying the degree of gross overloading of the heavy vehicle section of the Australian traffic stream (that is, five axle articulated and above vehicles). The total data sample used in the study comprised 104 WIM sites throughout Australia, 21,761 total days of monitoring (ie. equivalent to over 59 years at a single WIM site) and over 5.6 million individual heavy vehicle observations.

Applications in weighing for Enforcement and Detection are as follows.

6.4.1 Network Level

- Collection of vehicle load data to quantify the occurrence of overloading for compliance, policy and strategy formulation (National Road Transport Commission 1998),
- Screening or filtering high speed WIM systems designed to improve the efficiency of more accurate static weighing systems or low speed WIM systems (Truck and Bus 1995, Public Roads 1995, Finch 1996),
- Collection of GVM and IAM data for the development of enforcement strategies allowing efficient utilisation of enforcement resources (Welsh 1996, Sleath and Edgar 1992),
- Collection of vehicle load data on a route or network level to access potential environmental impact,
- Development of vehicle load based safety programs.

6.4.2 Project Level

- The protection of specific road pavements, bridges or unsound structures (road based or otherwise) from vehicles above a pre-defined mass (Koniditsiotis 1990b),
- Overload warning threshold (De Henau 1995),
- Audit of vehicle based on-board weighing systems,
- Reduce static weigh-station congestion, vehicle backup and air pollution during testing (Arhuleta 1996)
- Collection of vehicle load data on specific sites to correlate with noise measurements (George and Gaillac 1995).

7. CURRENT WEIGH-IN-MOTION SYSTEMS

7.1 Weigh-In-Motion system Use In Australia

As of the date of this report, there were nine different high speed WIM system types being used in Australia, totalling over 170 installations (*Table II*).

The survey of Australian (and New Zealand) WIM system users and current and potential data users (Appendix B and C) clearly identified a need for WIM technology.

The overwhelming majority high speed WIM system type being used in Australia is CULWAY (*Table II*). CULWAY requires a boxed culvert in which to install the strain-gauged (mass sensor) transducers. Australia's road network has a significant number of boxed culverts that has made CULWAY suitable. In areas were culverts are not present, especially in the urban area, bending plate and capacitive pad WIM systems have been used. In the past few years, as the need for traffic load data in urban areas has become a necessity for infrastructure management, planning and freight movements, a number of IRD Bending Plate, Mikros HSWIM and PAT DAW 100 WIM systems have been installed (*Table II*).

There has been a need in Australia for temporary one to two week long traffic load surveys. To facilitate this need the Golden River Weighman system has been utilised.

High speed enforcement filtering of vehicles in Australia has been predominantly undertaken by the HSEMU (discussed previously). Other WIM systems such as CULWAY have, to a lesser degree been used for enforcement filtering.

Due to the overwhelming majority of WIM systems used in Australia originating from one vendor, namely ARRB TR, there has generally been a consistent and uniform approach to the installation site requirements, evaluation encompassing accuracy determination and reporting, calibration and reporting of WIM data. The benefits of this harmonious approach have been quite significant. For instance, a standard report is produced for each CULWAY installation. This has permitted each CULWAY installation to be directly compared to one another, producing a consistent analytical picture of heavy vehicle use throughout Australia.

Table II — High Speed WIM Systems Used in Australia

WIM System Name	Mass Sensor Type	Country of Origin	Installations in Australia
ARRB TR CULWAY	Strain Gauge	Australia	140
ARRB TR HSEMU	Load Cell	Australia	4
ARRB TR Multi Lane CULWAY	Strain Gauge	Australia	2
Golden River Marksman 660	Capacitive Strip	United Kingdom	2
Golden River Weighman	Capacitive Pad	South Africa / United Kingdom	2
IRD Bending Plate	Bending Plate	Canada	6
Mikros HSWIM	Capacitive Pad	South Africa	4
PAT DAW 100	Bending Plate	Germany	10
Trevor Deakin Consultants PIMS	Piezo Electric Cable	United Kingdom	1

Unfortunately these benefits have not been fully appreciated by users because they have never been part of a non-uniform environment. In the last few years with other WIM systems being significantly used, this harmony and uniformity has being challenged. For instance, as mentioned previously, because there is no

Australian standard accuracy determination and reporting procedure (apart from the one used by ARRB TR) there exists significant confusion amongst vendors, suppliers and users.

There is no doubt that the expectations anticipated ten or so years ago in WIM technology have been at best slow in coming. This has not only been witnessed in the area of mass sensor development, that is, predicted low cost and enforcement accuracy sensors that as yet have not arrived, but also and more importantly in the overall application of WIM data, especially with regards secondary users. This has lead some Australian State Road Transport Authorities to question the need and investment in WIM technology.

7.2 Weigh-In-Motion Systems

7.2.1 General

All (worldwide) known vendors and suppliers of WIM systems (Appendix A) were surveyed. The summaries of high and low speed WIM systems *used and available* in Australia are presented in *Tables III* and *IV* respectively. Currently in Australia, there are 12 high speed and five low speed WIM systems, either being used or available. With time, some of these WIM systems will become obsolete, while new ones will become available. Hence, *Tables III* and *IV* do not represent the final definitive status of WIM systems in Australia, rather they are a snap shot of a technology under continual development.

The purpose of *Tables III* and *IV* is to bring together in one consistent and uniform manner information about individual WIM systems used and available in Australia. The structure of *Tables III* and *IV* is such that the most important parameters and specifications of each WIM system are presented. Furthermore, the tables allow for direct comparison of these parameters and specifications from one WIM system to another. As such, *Tables III* and *IV* provide the ‘first port of call’ of prospective purchasers and users of WIM systems in Australia.

The majority of information presented in *Tables III* and *IV* was supplied by individual vendors and suppliers about their particular WIM system. Efforts were made by the author to verify this information, ultimately though, the provided detail is the responsibility of the vendors and suppliers.

The origin of the WIM systems were varied, from Australia, Canada, Germany, South Africa and the United Kingdom (*Tables III* and *IV*).

7.2.2 Mass Sensor Type

As mentioned previously, the mass sensor is the most fundamental component of a WIM system. Mass sensor technology is constantly evolving with new sensor types being tested and evaluated and some past failures being revisited given advances in technology.

As of the date of this report, the most widely used in production work, mass sensors were as follows:

- bending plate: Bending plate technology incorporates a steel/rubber plate with strain gauges attached to its underside. Unlike pure strain gauge mass sensors, the gauges in a bending plate are usually permanently attached and behave as one with the plate. The strain gauges develop a strain signal proportional to the deflection of the plate under a vehicle axle. The strain signal is amplified and processed to produce the vehicle axle mass.
- capacitive pad: The capacitive pad mass sensor is a rubber and steel mat device. The pad comprises three sheets of steel, separated by a soft rubber dialetric material. Compression of the pad under a vehicle axle produces an increase in capacitance, which is interpreted as a mass.
- capacitive strip: The capacitive strip responds to the downward pressure of a vehicle axle. The strip's top surface is deflected by the vertical force, causing a change in capacitance. This change is interpreted as a mass.
- load cell: A load cell type sensor comprises one or more fabricated steel or other material beams or plates that are simply supported by a load cell at each corner.
- piezo electric cable: The piezo electric cable is usually mounted in an aluminium U shaped channel. The channel is placed into the road surface. The passage of a vehicle axle over the cable creates a wave form of current that is proportional to the axle mass.

- strain gauge: These systems are similar to the bending plate, but the strain gauges are mounted to an already existing structure rather than being manufactured integrally into a plate. The strain gauges are attached either to an existing road based structure, such as a culvert, or specially constructed housing. As a vehicle axle passes over the structure or housing, the induced strain is measured and related to mass.

TABLE III — HIGH SPEED WEIGH-IN-MOTION SYSTEMS USED AND AVAILABLE IN AUSTRALIA

MASS SENSOR TYPE	Bending Plate	Bending Plate	Bending Plate	Capacitive Pad	Capacitive Pad	Capacitive Strip
WIM SYSTEM NAME	IRD[8] Bending Plate	PAT[9] DAW 100	Trevor Deakin Consultants[10] BIMS	Golden River[11, 13] Capacitive Pad	Mikros[12] HSWIM	Golden River[11] Marksman 660
COUNTRY OF ORIGIN	Canada	Germany	United Kingdom	South Africa/ United Kingdom	South Africa	United Kingdom
INSTALLATION MODE	Permanent flush mounted	Semi-permanent flush mounted	Semi-permanent flush mounted	Temporary surface mounted	Semi-permanent flush mounted	Permanent flush mounted
MAX. # OF LANES	8	4	8	1	4	8
WHEELS WEIGHED	All	All	All	Left side	All	All
TOLERANCES						
AXLE LOAD ($\times$ '000 kg)	20	20	20		20	
TEMPERATURE (°C)	-40 to +50	-40 to +75	-40 to +85	0 to +80	-30 to +65	-40 to +80
MASS SENSOR LIFE SPAN (Years)	5				5	10
VEHICLE CLASSIFICATION	Yes - AUSTROADS	Yes - AUSTROADS	Yes - AUSTROADS	Yes - AUSTROADS	Yes - AUSTROADS	Yes - AUSTROADS
ACCURACY						
VENDOR	GVM [66% ± 5%]	GVM [95% ± 10%] IAM [95% ± 20%]	GVM [66% ± 5%]	GVM [95% ± 10%]	GVM [95% ± 9%] IAM [95% ± 10%]	GVM [95% ± 10%]
THIRD PARTY				GVM [95% ± 18%][1] IAM [95% ± 34%][1]	GVM [66% ± 10%][4]	GVM [66% ± 22%][15]
INSTALLATIONS						
AUSTRALIA	6	10	0	2	4	2
ELSEWHERE	116	600			63	

TABLE III — HIGH SPEED WEIGH-IN-MOTION SYSTEMS USED AND AVAILABLE IN AUSTRALIA (continued)

MASS SENSOR TYPE	Load Cell	Load Cell	Piezo Electric Cable	Piezo Electric Cable	Strain Gauge	Strain Gauge
WIM SYSTEM NAME	ARRB TR[13] HSEMU	IRD[8] Single Load Cell	IRD[8] Piezoelectric	Trevor Deakin Consultants[10] PIMS Series	ARRB TR[13] CULWAY	ARRB TR[13] Multi-lane CULWAY
COUNTRY OF ORIGIN	Australia	Canada	Canada	United Kingdom	Australia	Australia
INSTALLATION MODE	Semi-permanent flush mounted	Permanent flush mounted	Permanent flush mounted (Temporary Avail.)	Permanent flush mounted	Semi-permanent within pavement culvert installed	Semi-permanent within pavement culvert installed
MAX. # OF LANES	user defined	8	8	16	1	4
WHEELS WEIGHED	All	All	All	All	All	All
TOLERANCES						
AXLE LOAD (× '000 kg)	80	25	20		50	50
TEMPERATURE (°C)	-20 to +70	-40 to +50	-40 to +50	-40 to +75	-10 to +70	-10 to +70
MASS SENSOR LIFE SPAN (Years)	15	12	3	5	10	10
VEHICLE CLASSIFICATION	Yes - AUSTROADS	Yes - AUSTROADS	Yes - AUSTROADS	Yes - AUSTROADS	Yes - AUSTROADS	Yes - AUSTROADS
ACCURACY						
VENDOR	GVM [95% ± 5%]	GVM [66% ± 3%]	GVM [66% ± 8%]	GVM [66% ± 8%]	GVM [95% ± 10%]	GVM [95% ± 10%]
THIRD PARTY	GVM [66% ± 3%][2] GVM [66% ± 2%][3]				GVM [95% ± 7%][5]	GVM [95% ± 6.5%][16]
INSTALLATIONS						
AUSTRALIA	4	0	0	1	140	2
ELSEWHERE	0	74	257	72	5	0

TABLE IV — LOW SPEED WEIGH-IN-MOTION SYSTEMS USED AND AVAILABLE IN AUSTRALIA

MASS SENSOR TYPE	Capacitive Pad	Capacitive Pad	Load Cell	Load Cell	Load Cell
WIM SYSTEM NAME	IRD[8] Model 6700 WIM Mat	Mikros[12] VLM	ARRB TR[13] PCEMU	PAT[9] DAW 50	Transcale[14] AS1 Axle Scale
COUNTRY OF ORIGIN	Canada	South Africa	Australia	Germany	Australia
INSTALLATION MODE L × W × D (m)	Temporary surface mounted 2×(1.14 × 0.5 × 0.01)	Temporary surface mounted 2×(1.0 × 0.49 × 0.11)	Semi-permanent flush mounted 4.0 × 0.73 × 0.49[6]	Semi-permanent flush mounted 3.0 × 0.9 × 0.39	Semi-permanent flush mounted 3.0 × 0.75 × 0.3
MAX. # OF LANES	1	1	1	1	1
WHEELS WEIGHED	All	All	All	All	All
TOLERANCES					
AXLE LOAD (× '000 kg)	20	20	30	25	40
TEMPERATURE (°C)	-25 to +55	-30 to +65	-20 to +70	-40 to +75	0 to +60
MASS SENSOR LIFE SPAN (Years)	3		20		
ACCURACY					
VENDOR	GVM [66% ± 3%]	GVM [66% ± 3%] IAM [66% ± 5%]	GVM [95% ± 1%]	IAM [± 100 kg]	IAM [± 50 kg]
THIRD PARTY			IAM [± 250 kg][7]		
INSTALLATIONS					
AUSTRALIA	0	20	22	0	1
ELSEWHERE	5	400	7	43	0

<u>Notes for Tables III and IV</u>

1.	Koniditsiotis (1990)	Pakenham (Victoria), three passes of three trucks (R12, R22 and A123) at two different loads and three speeds (40, 60 and 80 km/h). In total, 18 passes per truck.
2.	Finch (1996)	Mt. White (NSW), repeated passes using a number of different trucks.
3.	Finch (1996)	Mt. Boyce (NSW), repeated passes using a number of different trucks.
4.	Doupal and Caprez (1996)	Zurich (Switzerland), 2128 randomly selected vehicles from the traffic stream.
5.	Samuels (1988)	Pakenham (Victoria), three passes of three trucks (R12, R22 and A113) at two different loads and three speeds (40, 60 and 80 km/h). In total, 18 passes per truck.

6. PCEMU also comes in 6 and 8 metre versions.
7. National Safety Council (NATTA approved testing results)
8. Philips Electronic Australia / International Road Dynamics (see Appendix A)
9. Electronic Load Weighing Company of Australia / Pat Pietzsch (see Appendix A)
10. W.W.Wedderburn / Trevor Deakin Consultants (see Appendix A)
11. Harding Traffic Systems Pty. Ltd.
Silverwater Central
75 Parramatta Road
Silverwater NSW 2141
/ Golden River Traffic (see Appendix A)
12. Central Weighing Australasia / Mikros Systems (see Appendix A)
13. ARRB Transport Research Ltd. (see Appendix A)
14. Transcale (see Appendix A)

15.	Doupal and Caprez (1996)	Zurich (Switzerland), 1951 randomly selected vehicles from the traffic stream.
16.	IMIS (1998)	Broadmeadows (Victoria), calibration results of operation of Multi-Lane Culway

7.2.3 Installation

Available are a variety of installation modes for the mass sensors namely permanent, semi-permanent and temporary. Furthermore, some are positioned on (surface or flush mounted) or within the road structure (*Tables III* and *IV*).

Some WIM systems allow up to eight lanes to be monitored simultaneously, while others only allow one. Consultation with vendors and suppliers revealed that most WIM systems can be specifically configured to cater for numerous traffic lanes based on the application. Furthermore some mass sensors weigh all the vehicle's wheels, while others weigh only half of the axle - usually the closest to the kerb or left side (*Tables III* and *IV*).

7.2.4 Vehicle Measurement

All WIM systems produce basic level vehicle data items on a vehicle by vehicle occurrence as follows:

- WIM installation and site details,
- date and time of vehicle occurrence,
- vehicle axle numbers and spacings, wheel base and total length (total length is usually only for high speed WIM systems),
- vehicle classification,
- vehicle speed (usually only for high speed WIM systems), and
- IAM and GVM.

In addition to the basic level data items some WIM systems offer application specific outputs, such as the imbalance between left and right vehicle load distributions for enforcement needs. Furthermore, there are an assortment of other non-WIM specific vehicle measurement items than can be monitored, based on specific applications, such as vehicle width and height and vehicle identification.

There are few WIM systems which in addition to the above basic level data items, offer detailed summary reports, aimed at catering for specific applications. In most cases, these reports are based on binning data into summaries based on user specified time intervals or other thresholds. As mentioned previously, these summary reports generally cater for primary users, while secondary users require post-processing to develop suitable application specific outputs.

7.2.5 Accuracy

The reported accuracy of individual WIM systems in *Tables III* and *IV* is two fold as follows:

- vendor, (accuracy reported by vendor and/or supplier), and
- third party, (accuracy reported by independent third parties).

The vendor accuracy varies in the method used to report the results, that is, 66 or 95 per cent of vehicles being weighed and in the method used to determine the accuracy. Both these issues have been discussed previously in the report. Assuming a normal distribution in accuracy results allows a comparison between the 66 and 95 per cent of vehicles weighed (as discussed previously), but very little information was available regarding the method used (random survey of vehicles, one vehicle passing several times, calibration results, etc) to determine the accuracy.

Where available, independent third party accuracy results were reported in *Tables III* and *IV*. The use of third party results not only gave a level of independence and veracity in the accuracy, but also allowed the method used to determine and report the accuracy results to be fully documented.

8. FUTURE DEVELOPMENTS IN WIM

8.1 WIM Systems

All the WIM system vendors (Appendix A) responding to the survey had an active research and development program. not just in the area of creating new products, but in the improvement of their existing WIM systems. In particular the following areas were being examined:

- temperature variation factors,
- improved WIM system calibration techniques,
- development of better vehicle detection systems, such as, ground based detectors, signal processors, video number plate recognition technology and ‘smart card’ systems,
- improved processor and data storage units, and
- development of new ‘more accurate’ mass sensors.

New developments are constantly being considered in the WIM area. Accuracy, durability, maintainability, ease of installation, portability and initial and on-going costs are all important factors that are constantly being questioned and evaluated.

One area being addressed by the WIM industry is the betterment and increase in accuracy of mass sensors. There are a number of different approaches that have been adopted as follows:

- improvement and modification of existing mass sensor technology,
- development of new mass sensor technology, and
- holistic approach encompassing vehicle, site installation and environmental characteristics.

Examples of these approaches follow.

Like many research organisations throughout the world, ARRB TR has investigated a number of potential advances and totally new high speed mass sensor types as follow:

- concrete culverts - different version of CULWAY,
- strain plates and cables,
- piezo electric cables,
- hydraulic tubes - consisting of a pneumatic tube filled with an incompressible fluid and embedded in a rubber pad, and
- capacitive strips.

These new weigh sensors have demonstrated promising results in the laboratory. That is, under controlled scientific conditions, the measured load response from the mass sensor was similar to that imposed by the testing equipment. Unfortunately, during actual field tests, that is real traffic loading conditions, the results were not as good.

Quartz mass sensors are being investigated. A major benefit in the use of a quartz mass sensor and its housing system is that it only detects loads applied to it in the vertical direction. Thus a vehicle axle passing over the sensor will only have its vertical load component measured rather than its horizontal component. The dependence of the mass sensor on speed, vehicle type, climatic conditions and its variation with time is currently being examined (Calderara 1996).

Geophones are being investigated as possible mass sensors. The use of geophones involves the placement of sensors adjacent to the road pavement, a relatively cheaper installation process from the traditional mass sensor. Determination of vehicle axle mass is accomplished by quantifying and processing the vibration caused by its passage (Elbring 1996).

The approach by some WIM system vendors is to concentrate more on improving the location characteristics as a means of bettering the accuracy.

There have been a number of improvements to accuracy via the use of two or even three mass sensors, that is, multiple mass sensor WIM systems. Much work has been done in deriving the best spacing and position of the mass sensors (Barbour and Newton 1992, Gyeres and Mitchell 1992).

The response of such sensors must be made independent of changes in pavement response. Typically, sensors in pavements are subject to bending, stretching and twisting as well as direct vehicle axles. Concerns such as calibration, signal processing and installation methods are yet to be resolved (SHRP 1990, Cosentino and Grossman 1996).

On-going development and improvement are progressively increasing our knowledge base on mass sensor technology. However, it must not be forgotten that the criteria and parameters of WIM technology are complex and as variable as each potential installation site.

8.2 Traffic System Integration

Evidence around the world and emerging now in Australia is the combination of WIM technology with other traffic monitoring systems to form fully integrated traffic information systems.

Finch (1996) states that ‘in relation to vehicle regulation, HSEMU is, and will in the foreseeable future be, a primary component in many (Roads and Traffic Authority) developing systems. The current development with HSEMU involves integration with other technologies and systems to give a ‘complete’ record of vehicle compliance at the time of passage through the screening lane... The future developments are aimed towards automatic weighing of trucks on a static weighing platform and ultimately unmanned operation of the checking station with automatic issuing of infringement notices.’ In effect, for vehicle regulation and enforcement applications the integrated systems will in addition to the current standard WIM data deliver additional information as follows:

- load overhang,
- origin and destination data - via electronic log book, ‘smart-card’ and Global Positioning System,
- registration compliance, and
- date since last mechanical inspection.

9. CONCLUSIONS

This report presents the status of WIM technology, focusing on Australian experience.

A WIM system is a device that measures the dynamic axle weight of a moving vehicle to estimate the corresponding static axle mass.

There are numerous factors affecting the ability of a WIM system to reliably and accurately determine the static axle mass of a vehicle while that vehicle is in motion. Some of these factors are inherent to the chosen WIM system, in particular the mass sensor component. Others though, are generic to WIM technology as a whole.

The overall need for WIM was clearly identified by Australian (and New Zealand) WIM system users and current and potential data users.

Weighing vehicles while they are in motion is no longer a research task but rather, a standard data collection tool. WIM systems adhere to one of two categories - low and high, with regard the 'motion' in their weighing.

The survey of WIM vendors and suppliers found that there are 18 WIM system types currently used or available in Australia. A critical requirement in their selection is ensuring that the most appropriate system is used for the chosen application(s). There is not one very good and one very poor WIM system, rather there are different systems for different applications. A number of applications for WIM technology were identified, which adhere to three broad groups as follow:

- infrastructure design and management,
- freight/trade planning and regulation, and
- detection and enforcement.

There are currently eight different high speed WIM system types being used in Australia, totalling 170 installations. Due to the overwhelming majority of WIM systems used in Australia originating from one vendor, namely ARRB TR, there has generally been a uniform approach to the installation site requirements, evaluation encompassing accuracy determination and reporting, calibration and reporting of WIM data. The benefits of this harmonious approach have been significant. However, these benefits have not been fully appreciated by users because they have never been part of a non-uniform environment. In the last few years other WIM systems have been introduced and used, and this uniformity is being challenged.

Site selection and location characteristics are fundamental to the performance of a WIM system. Some work has been done in quantifying and setting acceptable tolerances to WIM location characteristics, with vendors and suppliers providing guidelines. Overall, the selection of an appropriate site for WIM system installation is based on user experience and intuition. It was recognised by Australian and New Zealand WIM system users that location characteristics need to be quantified.

When the output for the mass sensor is properly calibrated, a mass measurement is produced. Calibration requirements vary among specific WIM systems. In general, it is desirable for WIM systems to be routinely (automatically or at regular intervals) calibrated. The survey of Australian and New Zealand WIM system and data users, revealed a general dissatisfaction with the calibration of WIM systems, especially with regard the lack of uniformity, procedure and frequency of checking/auditing to alleviate possible calibration drift.

The evaluation of a WIM system is the process of quantifying its performance in undertaking the application for which it was chosen. There is no standard Australian specification or method to evaluate WIM systems. There are though a number of standards available throughout the world for evaluation and accuracy determination. It would be appropriate to adopt or modify such a standard (whichever is most appropriate) for the evaluation and accuracy reporting of WIM systems in Australia.

The processing of output data to produce reports has traditionally served so called primary users. Primary users are those for whom WIM technology was initially developed, that being, for road infrastructure applications. This had the effect of pushing secondary users away from WIM technology by forcing them to adopt complicated post-processing - summary and reporting techniques. Secondary users have only recently begun to apply WIM data to their specific areas. There is evidence to demonstrate that application driven analysis of traffic load data can not be vigorously pursued until standards are developed for the collection, summarising and reporting of WIM data. To this effect, it is important that WIM data be promoted for its existence, but also making it available in a form that is accessible and suitable to all users. It is anticipated that the next few years in Australia will see a wide spread application of WIM data, more than experienced before, especially with secondary users.

New developments are constantly being considered in the WIM area. Accuracy, durability, maintainability, ease of installation, portability and initial and on-going cost are all important factors that are being evaluated. One area being addressed by the WIM industry is the increase in accuracy of mass sensors

The association of WIM systems with other traffic monitoring systems to form fully integrated traffic systems are now becoming reality. In Australia, the driving force behind this is not simply the technological ability to integrate systems, but the applications identified by the road user community.

There is no doubt that the expectations anticipated ten or so years ago in Australia with regard to WIM technology have at best been slow in coming. This has been witnessed in the area of mass sensor development, that is, predicted low cost and enforcement accuracy sensors that as yet have not arrived and the lack of use of WIM data by secondary users.

10. RECOMMENDATIONS

In order for the Australian WIM sector (WIM system vendors, suppliers, system and data users) to realise the maximum overall benefit from the development and application of WIM technology, the following recommendations are made:

- hardware:
  - development of low cost mass sensors, and
  - development of high speed enforcement accuracy level mass sensors.
- usage:
  - quantification and standardisation of WIM system site location characteristics,
  - quantification and standardisation of initial and on-going WIM calibration procedures,
  - establishment of a standard evaluation methodology, encompassing a common language to describe the performance of WIM systems, and
  - establishment of a standard specification (contract) for the supply, installation, calibration and maintenance of WIM systems.
- data:
  - establishment of a uniform/standard format for WIM data output, and
  - establishment of a QA system to screen all WIM data prior to acceptance.
- application:
  - promotion of the existence of WIM technology and its associated applications,
  - quantification of the level of WIM system accuracy required for different applications,
  - establishment of standard WIM data application reports, catering for specific users' needs, and
  - dissemination of WIM information via symposia and workshops.

REFERENCES

ANDERSON, J.M., RHODES, F.H. (1992). The prediction of traffic loading at specific . Proc. 3rd International Symposium on Heavy Vehicle Weights and Dimensions. Univ of Cambridge. p.299.

ANDERSON, K.O., BERVELL, J.A. & TEPLEY, S. (1992). Impact of changes in vehicle legislation on pavements in Alberta, Canada. Proc. 3rd International Symposium on Heavy Vehicle Weights and Dimensions. Univ of Cambridge. p.316.

ANGELL, D. (1987). Loading data requirements for pavement design and management. Seminar on Road Traffic Data Collection using Weigh-in-Motion. ARRB.

ASTM (1994). Standard specification for highway weigh-in-motion (WIM) systems with user requirements and test method. ASTM E 1318 - 94.

ARCHULETA, K. (1996). Weigh-in-motion for Enforcement Screening of Trucks. Proc. National Traffic Data Acquisition Conference. Albuquerque, New Mexico May 1996.

ARRB (1994). Enforcement weigh-in-motion and general support. ARRB Project Proposal (1994/95) 94/EB/0004.

AUSTROADS (1997). Australian and New Zealand Road System and Road Authorities - National Performance Indicators. AUSTROADS.

AUSTROADS (1988). Guide to Traffic Engineering Practice - Traffic Studies, Part 3. AUSTROADS. (AP-11.3/88)

AUSTROADS (1992). Pavement Design - A guide to the design of standard pavements. AUSTROADS (AP-17/92)

AUSTROADS (1992). Bridge Design Code. AUSTROADS (AP-15/92)

AUSTROADS (1994). RoadFacts - An overview of Australia's road system and its use. AUSTROADS AP 18/94.

BARBOUR, I.A. and NEWTON, W.H. (1992). Improving the accuracy of weigh-in-motion system. Proc. 3rd International Symposium on Heavy Vehicle Weights and Dimensions. U.K.

BILLING, J.R. (1995). Implementation of vehicle weight and dimension regulations. Proc. 4th International Symposium as Heavy Vehicle Weights & Dimension. p 107.

BLEWETT, C. (1996). The Development and Application of the New Mexico State Traffic Monitoring Standards. Proc. National Traffic Data Acquisition Conference. Albuquerque, New Mexico May 1996.

BUCKMASTER, R. and TAPANES, E. (1996). Australian developments in fibre optic weigh - in - motion. Proc. Weigh-in-Motion Symposium, May 1996. ARRB Transport Research Ltd.

CALDERARA, R. (1996). Long -Term Stable Quartz WIM Sensors. Proc. National Traffic Data Acquisition Conference. Albuquerque, New Mexico May 1996.

CANTENI, R & BARELLA, S. (1995). Swiss testing of medium span bridges. Proc. Dynamic loading of heavy vehicles and road wear - mid term seminar. OECD Sydney. February 1995.

CARPEZ, M. (1995). Testing of Weigh-in-Motion Systems. Proc. 1st European Conference on Weigh-in-Motion of Road Vehicles. p187.

CASTLE ROCK CONSULTANTS (1989). Port of Entry Weigh-in-Motion feasibility study. Castle rock consultants. HPR-PL-1(31)ITEM 702 1987.

CHATTI, K. MAHONEY, J.P., MONISMITH, C.L. & MORAN, T. (1995). Response and dynamic modelling field of an asphalt concrete pavement section under moving heavy trucks. Proc. 4th International Symposium as Heavy Vehicle Weights & Dimension. p 201.

CHOU, C.J. (1995). Effects of overloaded heavy vehicles on pavement and bridge design in Taiwan. Economic. Proc. 4th International Symposium as Heavy Vehicle Weights & Dimension.

COLE, D.J., COLLOP, A.C., POTTER, T.E.C. and CEBON, D. (1992). Use of a force increasing mat to compare the road damaging potential of heavy vehicles. . Proc. 3rd International Symposium on Heavy Vehicle Weights and Dimensions. Univ of Cambridge. p.266.

COSENTINO, P. J. and GROSSMAN, B. G. (1996). Microbend Fibre-Optic Traffic Sensor. Proc. National Traffic Data Acquisition Conference. Albuquerque, New Mexico May 1996.

COST-323. (1997). European Specification on Weigh-in-Motion of Road Vehicles (Draft). European cooperation in the field of scientific and technical research EURO-COST/323/5/97.

CROPLEY, S. (1996). Weigh-in-motion (WIM) systems: Use in pavement design. Proc. Weigh-in-Motion Symposium, May 1996. ARRB Transport Research Ltd.

CROPLEY, S., KONIDITSIOTIS, C., and BUCKMASTER, R., (1998). WIMLINK - The Fully Integrated Information Management System for Weigh - in - Motion. Proc. 5th International Symposium on Heavy Vehicle Weights and Dimensions , Maroochidore, Queensland April 1998.

DAHLIN, C. (1990). Proposed method for calibrating WIM systems and for monitoring that calibration over time. TRB 1364. USA.

DALGLEISH, M.J., MOLE, A. and MILLS, P. (1992). High speed weigh-in-motion systems and applications. Heavy vehicles and roads, technology, safety and policy. Proc. 3rd International Symposium on heavy vehicle weights and dimensions. U.K.

DAVIES, P. and McCALL, B. (1988). A Low-Cost Automatic Weigh and Classification System Based on Piezo Electricity. Proc. 14th Australian Road Research Board Conference, Canberra.

DAVIES, P. and SOMMERVILLE, F. (1988). Calibration and accuracy testing of WIM systems. TRB 1123. USA.

DE HENAU, A. (1995). Requirements and Policies for WIM in Europe. Proc. 1st European Conference on Weigh-in-Motion of Road Vehicles. p33.

DOUPOL, E. and CAPREZ, M. (1995). European Test of . Weigh-in-Motion Systems in Switzerland. Proc. 1st European Conference on Weigh-in-Motion of Road Vehicles. p189.

ELBRING, G. (1996). Geophones for traffic monitoring. Proc. National Traffic Data Acquisition Conference. Albuquerque, New Mexico May 1996.

FERNANDES, J.L., WILOUR, J.A. & SORIA, M.U.A. (1995). Economic Impacts of Axle load limits and Heavy Vehicle Configurations on the Performance of Pavements in Brazil’s. Proc. 4th International Symposium as Heavy Vehicle Weights & Dimension. p 47.

FINCH, K. (1996). ARRB Transport Research - High Speed EMU. Proc. Weigh-in-Motion Symposium, May 1996. ARRB Transport Research Ltd.

FIRTH, B.A., MITCHELL, C.G.B. & NEWTON (1995). Impacts of increased goods vehicles weight limits: A European Case Study. Proc. 4th International Symposium as Heavy Vehicle Weights & Dimension. p 55.

GEORGE, L.A. and GAILLAC, M. (1995). Weigh - in - Motion, A User View: Cofiroute’s Experience. Proc. 1st European Conference on Weigh-in-Motion of Road Vehicles. p83.

GUPTA, H. K. (1996). Comparison of Design, Historical Estimates and Monitored ESALS at Long Term Pavement Performance (LTPP) Sites. Proc. National Traffic Data Acquisition Conference. Albuquerque, New Mexico May 1996.

GYERES, L. & MITCHELL, C.G.B. (1992). The special repeatability of dynamic pavement loads caused by heavy goods vehicles. Proc. 3rd International Symposium on Heavy Vehicle Weights and Dimensions. Univ of Cambridge. p.95.

HAAS, R. and HUDSON, W.R. (1993). Modern pavement management. McGraw Hill.

HALLENBECK, M. (1995a). Quality Assurance and Automated Error Detection for WIM and AVC Equipment in the LTPP Project. Proc. 1st European Conference on Weigh-in-Motion of Road Vehicles. p209.

HALLENBECK, M. (1995b). A Description of the Long Term Pavement Performance Project- Traffic Database. Proc. 1st European Conference on Weigh-in-Motion of Road Vehicles. p285.

HARDY, M.S.A. (1995). Simulation of the response of sealed flexible pavements to surface loads. Proc. 4th International Symposium as Heavy Vehicle Weights & Dimension. p 235.

HARDING, M. (1996). WIM Business systems. Proc. Weigh-in-Motion Symposium, May 1996. ARRB Transport Research Ltd.

HARRISON, R. (1996). Weight Analysis of Truck Entering the United States Through the Port of Laredo, Texas. Proc. National Traffic Data Acquisition Conference. Albuquerque, New Mexico May 1996.

HENNY, R.J. (1995a). Weigh-in-Motion on Dutch State Roads. Proc. 1st European Conference on Weigh-in-Motion of Road Vehicles. p47.

HENNY, R.J. (1995b). European Database on Weigh - in - Motion. Proc. 1st European Conference on Weigh-in-Motion of Road Vehicles. p279.

HEYWOOD, R.J. (1994). Truck load models for Australian bridges. Proc. (2) AUSTROADS Bridge Conf. 1994.

HEYWOOD, R.J. (1995). Dynamic bridge testing: short span bridges. Proc.Dynamic loading of heavy vehicles and road wear - mid term seminar. OECD Sydney. February 1995. paper # 19.

HUHTALA, M. (1995). The effects of wheel loads on pavements. Proc. 4th International symposium as Heavy Vehicle Weights & Dimension. p 189.

HUHTALA, M. and JACOB, B. (1995). OECD Divine Project - Spatial Repeatability of Axle Impact Forces. Proc. 1st European Conference on Weigh-in-Motion of Road Vehicles. p121.

ILVES, G.J. & KAMRAN MAJIDZADEH (1992). An evaluation of damage caused by heavy loads in Ohio. Proc. 3rd International Symposium on Heavy Vehicle Weights and Dimensions. Univ of Cambridge. p.78.

IMIS (1998). Culway Freight Performance Indicators - Final Report. VicRoads, Victoria

JACOB, B. (1995). Special repeatability of the impact forces on a pavement and multiple sensor WIM - Research element 5 of the OECD IR6 DIVINE Project. Proc. 4th International symposium as Heavy Vehicle Weights & Dimension. p 273.

KALISCH, M. and PAATZ, B. (1995). 20 Years of WIM in Germany. Proc. 1st European Conference on Weigh-in-Motion of Road Vehicles. p99.

KEMPEN, J.P. (1987). Potential uses of weigh-in-motion data. Seminar on road traffic data collection using weigh-in-motion. Australian Road Research Board.

KENT, P. (1987). Untitled internal report. Highway Statistics Division, Federal Highway Administration.

KIM, S, NOWAK, A.S. & SOKOLIK, A.F. (1995). Site specific truck load study. Proc. 4th International Symposium as Heavy Vehicle Weights & Dimension. p 159.

KONIDITSIOTIS, C. (1990a). Traffic load survey - West Gate Bridge, Victoria. Australian Road Research Board Contract Report DN 1719

KONIDITSIOTIS, C. (1990b). Load enforcement data - West Gate Bridge,Victoria. Australian Road Research Board Contract Report DN 1724.

KONIDITSIOTIS, C. (1990). The Golden River capacitive pad weigh-in-motion system - its life and times. Proc. 15th Australian Road Research Board Conference, Darwin.

KONIDITSIOTIS, C. (1993). Weigh-in-motion technology. Axle Loads Workshop. Central Weighbridge Unit project. Indonesia.

KONIDITSIOTIS, C. (1993). Traffic load survey, Pascoe Vale Road, Broadmeadows, Victoria. RI 025 603.

KONIDITSIOTIS, C. (1994). Traffic load survey, Parkes Way, Parkes, ACT. ARRB Contract Report RI 025 002/1.

KONIDITSIOTIS, C (1996). Update of Traffic Design Chapter in the AUSTROADS Pavement Design Guide - Status Report. ARRB TR Working Document WD TI96/024.

KONIDITSIOTIS, C., and CROPLEY, S. (1997). Headway Determination for Bridge Design. ARRB TR Contract Report RE6096.

KONIDITSIOTIS, C (1997). AUSTROADS National Indicator - Lane Occupancy Rate (Freight) Study. ARRB TR Contract Report RC 6027.

KONIDITSIOTIS, C (1998). Update of AUSTROADS Pavement Design Guide - Traffic Design Chapter Final Draft of Traffic Design Chapter ARRB TR Working Document WD R98/030

LEE, E.C. (1985). Concepts, history and future of in-motion weighing. 2nd National Weigh-in-Motion Conference. Georgia. Department of Transport, USA.

LIM, E. (1992). Secondary uses of CULWAY data: comparison of three Victorian sites. ARRB Working Document WD TE 92/009.

MARTIN, T.C. (1995). Estimating Australia's heavy vehicle road wear cost responsibilities (Load related road wear). Proc. 4th International Symposium as Heavy Vehicle Weights & Dimension. p 67.

McELHONEY, D. (1985). The need for weigh-in-motion. 2nd National Weigh-in-Motion Conference. Georgia. Department of Transport, USA.

McLEAN, J.R. (1982). Axle load surveys and measurement: review and proposals. Australian Road Research Board. Internal Report AIR 1108-1.

McLEAN, J.R. (1996). Use of WIM data in Freight Studies and strategy development. Proc. Weigh-in-Motion Symposium, May 1996. ARRB Transport Research Ltd.

MICHAEL, K.C. (1994). Building bridges for the future. Proc. (2) AUSTROADS Bridge Conf. 1994.

MISSEN, R. (1995). Vehicle size and weight limits - attempts towards legislative harmonisation within the European Union. Proc. 4th International Symposium as Heavy Vehicle Weights & Dimension. p 121.

MORAN, J., SULLIVAN, M., MAHONEY, J. & CHATTI, K. (1995). A demonstration of the theory of special repeatibility. Proc. 4th International Symposium on Heavy Vehicle Weights & Dimension. p 189.

NAASRA (1984). The NAASRA roads study, 1984. NAASRA.

NATIONAL ROAD TRANSPORT COMMISSION (1998). Incidence of Gross Overloaded Heavy Vehicles. NRTC Report 1998.

NORMAN, O.K. and HOPKINS, R.C. (1952). Weighing vehicles in motion. Bulletin 50. Highway Research Board, National Research Council.

OECD (1992). Dynamic loading of pavements. Report of the OECD Road Transport Research Program. IR2 OECD.

PAPAGIANNAKIS, T & SENN, K. (1995). On-site WIM system calibration; An overview of NCHRP Study 3-39(2). Proc. 4th International Symposium as Heavy Vehicle Weights & Dimension.

PAPAGIANNAKIS, T. (1996). Developing Alternative WIM System Evaluation/Calibration Methods. Proc. National Traffic Data Acquisition Conference. Albuquerque, New Mexico 1996.

PEARSON, R.A. (1994). Tomorrow's bridging needs - a view from the cabin. Proc. (2) AUSTROADS Bridge Conf. 1994.

PETERS, R.J. (1984). AXWAY - a system to obtain axle weights. Proc. 12th ARRB Conf. 12(1).

PETERS, R.J. (1986). CULWAY - an unmanned and undetectable highway speed vehicle weighing system. Proc. 13th ARRB Conf. 13(6).

POTTER, D. and KONIDITSIOTIS, C. (1992). APRG Workshop - 16th ARRB Conference, Perth.

POTTER, T.E.C., CEBON, D, COLE, D.J. (1995). Assessing the Relative Road Damaging Potential of HGV's.). Proc. 4th International Symposium as Heavy Vehicle Weights & Dimension.

PUBLIC ROADS (1995) Advantage I-75. Public Roads 1995. p 16.

SAMUELS, S.E. (1988). Development and evaluation of highway speed weigh-in-motion systems in Australia. Australian Road Research Board Special Report 40.

SHRP (1990). A low-cost fibre optic weigh-in-motion sensor. Strategic Highway Research Program. SHRP - IDEA/UFR - 90-002.

SLEATH, L. (1995) Investigation into the feasibility of heavy transport routes in New Zealand. Proc. 4th International Symposium as Heavy Vehicle Weights & Dimension. p 125.

SLEATH, L. and EDGAR, J. (1992). Weight regulations, overweight vehicle policy and enforcement procedures in New Zealand. Proc. 3rd International Symposium on Heavy Vehicle Weights and Dimensions. Univ of Cambridge. p.434.

THORESEN, T. (1987). Wider applications of road use data collected by CULWAY and similar automated systems. Seminar on Road Traffic Data Collection using Weigh-in-Motion. ARRB.

TRITT, B.H. (1976). ARRB research into methods of weighing vehicles. Australian Road Research Board Internal Report AIR 121-1.

TRITT, B.H. and RICHARDS, B. (1978). Determination of vehicle axle mass. A description and demonstration of the ARRB system. Proc. Axle Mass Determination Workshop.

TROTT, J.J. and WILLIAMSON, P.J. (1993). Measuring classifying and counting wheel loads of moving vehicles. The Engineer.

TRUCK & BUS (1995) High speed weigh-in-motion for Hume Highway runners. Truck & Bus, October 1995. p 9.

WELSH, J. (1996). History to Culway Operation by VicRoads Enforcement Branch. Proc. Weigh-in-Motion Symposium, May 1996. ARRB Transport Research Ltd.

WHORLOW, D.J. & COMPTON, J. (1995). Technology & business issues of electronic toll collection. Proc. International Conference on Application of New Technology to Transport Systems. Melbourne, Australia.

WORLD BANK (1993). Central weighbridge unit project - Indonesia. Final Report.

WRIGHT, D.S. (1992). Optimisation of LGV weight: an enforcement policy. Proc. 3rd International Symposium on Heavy Vehicle Weights and Dimensions. Univ of Cambridge. p.409.

APPENDIX A — WEIGH-IN-MOTION SYSTEM VENDOR AND SUPPLIER DETAILS

ARRB Transport Research Ltd AUSTRALIA	Auto-Count Instruments AUSTRALIA
AVIAR Inc. UNITED STATES OF AMERICA	AWA Limited AUSTRALIA
Central Weighing Australasia AUSTRALIA	Data Dynamics CANADA
Electronic Load Weighing Company of Australia AUSTRALIA	Elphinstone Lodec AUSTRALIA
GEC-Marconi Ltd UNITED KINGDOM	GK Instruments Ltd/Peek Traffic UNITED KINGDOM
Golden River Traffic Ltd ENGLAND	International Road Dynamics (IRD) CANADA
Leader Weighing Machines ENGLAND	Mikros Systems SOUTH AFRICA
Pat Pietzsch Automatisierungstechnik GmbH GERMANY	Philips Electronic Australia Ltd AUSTRALIA
Serco Transport Technology Pty Ltd AUSTRALIA	Stering Weighing Ltd ENGLAND
Transcale Pty Ltd AUSTRALIA	Trevor Deakin Consultants Ltd UNITED KINGDOM
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APPENDIX B — WEIGH-IN-MOTION SYSTEM OPERATORS

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Department of Transport & Works NORTHERN TERRITORY	Queensland Department of Main Roads QUEENSLAND
Transport SA SOUTH AUSTRALIA	Department of Infrastructure Energy and Resources TASMANIA
VicRoads VICTORIA	Main Roads WESTERN AUSTRALIA

APPENDIX C — RESPONDENTS TO QUESTIONNAIRE*

ARRB Transport Research AUSTRALIA • Transport Economics • Transport Efficiency • Pavements Group	Australian Bureau of Statistics AUSTRALIA
Australian Local Government Association Ltd AUSTRALIA	Department of Transport & Communication AUSTRALIA
Bureau of Transport & Communication Economics AUSTRALIA	National Road Transport Commission AUSTRALIA
Road User Research Pty Ltd AUSTRALIA	Urban Services AUSTRALIA • Transport Strategy
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Local Government & Shires Associations of New South Wales NEW SOUTH WALES	Department of Transport & Works NORTHERN TERRITORY • Transport Economist • Materials and Pavement Group • Bridge Section • Asset Management Section
Northern Territory Local Government Association NORTHERN TERRITORY	Northern Territory Community Government Association NORTHERN TERRITORY
Queensland Department of Main Roads and Queensland Transport QUEENSLAND • Policy and Planning • Materials and Pavement Group • Bridge Section • Asset Management Section • Transport Policy	Local Government Association of Queensland QUEENSLAND 4006
Local Government Association of South Australia SOUTH AUSTRALIA	Transport SA SOUTH AUSTRALIA • Infrastructure Planning • Materials and Pavements Group • Bridge Section • Vehicle Operations

Department of Infrastructure Energy and Resources TASMANIA • Policy & Strategic Planning • Materials and Pavement Group • Vehicle Standards • Bridge Section • South Western Region	Municipal Association of Tasmania TASMANIA
Municipal Association of Victoria VICTORIA	VicRoads VICTORIA • Manager Western Bypass • Materials and Pavement Group • Bridge Section • South Western Region • Freight Policy
Main Roads WESTERN AUSTRALIA • Investigation & Systems Engineer • Materials and Pavement Group • Bridge Section	• Country Shire Councils' Association of Western Australia WESTERN AUSTRALIA
Local Government Association of Western Australia WESTERN AUSTRALIA	

INFORMATION RETRIEVAL

Austroads (2000), **Weigh-in-Motion Technology**, Sydney, A4, 50pp, AP-R168/00

KEYWORDS:

WIM system, axle weight, motion, mass sensor, site selection, accuracy, data.

ABSTRACT:

A Weigh-in-Motion (WIM) system is defined as a device that measures the dynamic axle weight of a moving vehicle to estimate the corresponding static axle mass.

This report documents the status of WIM technology, focusing on Australia's situation. Recommendations on delivering Australia the best opportunities in overall WIM technology are also included.

Topics covered in the report include WIM concepts, history of WIM technology, calibration and evaluation, data output and reporting, applications of WIM technology, current research and future developments.

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