THE DEVELOPMENT OF AN EVIDENTIARY ON-BOARD MASS-MONITORING APPLICATION FOR HEAVY VEHICLES

David Cai
Engineer Major Project
Transport Certification Australia Ltd
Level 12, 535 Burke Street, Melbourne, VIC 3000, Australia
+61-3-8601-4678, davidc@tca.gov.au

Lloyd Davis
Principal Electrical Engineer
ITS & Electrical Technology, Planning Design & Operations Division
Queensland Department of Main Roads
477 Boundary Street, Spring Hill, QLD 4001, Australia
+61-7-3834-2226, lloyd.e.davis@mainroads.qld.gov.au

Dr Charles A. Karl
Manager Major Project
Transport Certification Australia Ltd
Level 12, 535 Burke Street, Melbourne, VIC 3000, Australia
+61-3-8601-4699, charlesk@tca.gov.au

ABSTRACT

This paper reports the work in progress in the development of an evidentiary on-board mass-monitoring (OBM) application for heavy vehicles in Australia. The project so far has involved three steps; a capability review on heavy vehicle OBM devices in Australia, the development of a technical feasibility project plan and the initial results from OBM pilot testing for accuracy and tamper. The initial results have led to the development of a full testing plan for a wide-scale OBM test program across Australia.

KEY WORDS

On-board mass monitoring, Intelligent Access Program

1. BACKGROUND

This paper reports the work in progress in the development of an evidentiary on-board mass-monitoring (OBM) application for heavy vehicles in Australia. The project is undertaken by Transport Certification Australia Ltd (TCA, www.tca.gov.au), in collaboration with the National Transport Commission (NTC, www.ntc.gov.au) to develop functional and technical requirements for the heavy vehicle on-board mass-monitoring devices as part of the Intelligent Access Program (IAP). The IAP is a voluntary program which provides heavy vehicle operators with access, or improved access, to the Australian road network in return for monitoring of compliance with specific access conditions.

TCA is looking in the medium-term to add a new parameter to the IAP, allowing for the capture of vehicle mass information. A capability review of OBM systems was carried out by ARRB Group Ltd (ARRB, www.arrb.com.au) in 2007, identifying the available technologies and a list of suppliers for future investigation (1).

Consequently, a project plan was developed to undertake a feasibility assessment of OBM devices for regulatory purposes. Four main areas of study were identified for this assessment, accuracy and robustness, additional data, human machine interface and tamper evidence.

As part of the project, a pilot study was carried out with two Australian suppliers to assess the accuracy of OBM devices and options to address tamper. Preliminary findings were evaluated from the pilot and led to the development of a revised test plan for the full scale OBM test across Australia.

2. CAPABILITY REVIEW

A review of the industry capability in OBM was undertaken, with focus on the current and expected future technologies as well as products and services associated with OBM (1). The areas covered in the review included mass determination methods, installation, operating conditions and maintenance of OBM systems, static and dynamic measurements, accuracy, use of data from electronic braking system (EBS), and potential requirements for an evidentiary system.

A typical OBM system is made up of two or three components (2):

- Mass sensor

  The primary component of an OBM system is the mass sensor. The types of mass sensors for on-board mass measuring vary depending on the type of suspension on the vehicle axle group. Generally, some form of transducer incorporated with the vehicle's suspension system is used to measure the mass of an individual axle or an entire axle group. Typically, load cells are used in steel-sprung suspensions, and air pressure transducers (APT) fed by air lines to the air bags are used in air bag suspension systems.
- Electronic buffers

  In some systems, the electrical signal from the transducer is fed into an electronic buffer (typically associated with an axle group or vehicle combination unit). This buffer may condition the incoming signal, combine/collate a number of incoming signals, convert an incoming analogue signal into a digital format, store a number of readings, or even convert the signal into an actual mass value based on some pre-defined formula.

- A display/control/interface unit

Virtually all on-board vehicle mass-monitoring systems provide some form of interface that allows users to configure the system, read mass measurements from, and connect to, other devices such as printers, wireless communications devices, etc. In some systems, this unit also performs the function of electronic buffers.

Typically an APT based system would cost around A$1,500-$2,000 for an axle group, while an equivalent load cell system for an axle group may cost from A$9,000-$12,000.

Installation of ATPs and load cells require different levels of skills. An APT based OBM system is fairly simple to install. Air supply lines are cut through and branched to the APTs via T-fittings. Some typical, basic, instructions for APT installation as recommended by an OBM supplier would include: always mount cables with connectors facing down or sideways, never up; run cables along existing air lines/cables in the truck chassis to avoid damage by moving parts; fix cable ties every 100mm. On the other hand, installing load cells is an entirely different process. Typically load cells are installed as an integral part of the vehicle or trailer structure (e.g. mounted under fifth wheel or chassis), and installation details are specified to areas such as welding procedures and bolt torque values. Installation location and configuration can also vary significantly to specific vehicle/combination.

Calibration and on-going use of the OBM system are the main factors that affect the accuracy of measurement. A number of steps are involved in the calibration process:

1. Each axle group has to be calibrated separately by reference to the certified scale and the indicator readout.
2. The calibration is required for both the empty weight and the fully laden weight. These two points will then serve to set the scale readings.
3. Each calibration has to be set into permanent memory. For regulatory purposes, it is likely that every calibration would have to be certified and recorded.

A set of conditions are also required when the calibration takes place. For example, park the vehicle on level ground, park brakes should be off, fuel load should be set at full, air bag temperatures should be stabilised, vehicle should be stationary with engine running. To ensure weighing under proper conditions, a few practices were suggested by various OBM suppliers (1):

- A height control valve that is in good repair and set at factory specified ride-height, with linkage that is also in good repair
- Weigh on a flat and level surface
- Brakes should be released: chocking as necessary
- For optimal accuracy, the driver should briefly dump the air in the suspension (approximately 5-10s) and then re-inflate the air bags fully before checking the weight
- The trailer or prime mover must not be in a twist or turn.

Once an OBM system is installed and calibrated, re-calibration may be required from time to time. A re-calibration period between three months to one year is commonly recommended depending on the operating conditions. Maintaining a good working height control valve and linkage was also pointed out as critical factors for high quality performance.

Currently, industry practice is to take on-board mass measurement statically. Drivers usually take the measurement at the point of loading as any redistribution or off-loading of the excess mass can be easily done at the same time. Industry has claimed that there was little need or benefit in dynamically monitoring mass once the vehicle has left the loading site, since any redistribution or off-loading would be cumbersome. However, dynamic measurement can be achieved by the same technology for static on-board mass measuring. Some suppliers acknowledged that static mass could be determined from dynamic data using suitable algorithms, but no commercial interest was received to develop this feature. The capability of doing so was identified by Davis and Sack (3). The interest showed suggested that dynamic mass monitoring has potential for commercial and regulatory applications, particularly in regards to road friendly suspension systems and operational effectiveness related to damage to pavements.

The accuracy of an OBM system needs to be related to the mass being measured: tare, payload or gross vehicle mass (GVM). In the laboratory, load cells can achieve accuracy to within 0.1%. Most suppliers claim an accuracy of 0.5% for their OBM systems, but a practical accuracy in field conditions is thought to be about 1-2%. Similar accuracies were also claimed for APTs although the variance of the measurements would be higher. In regard to dynamic accuracy, one supplier claimed that for a 45 tonne GVM vehicle, dynamic OBM readings would vary between 40-52 tonnes as it moved up and down hills, and transient spikes of 10-12 tonnes could be observed when the vehicle ran in ruts and hollows. Suppliers also commented that fuel usage, or operating conditions such as mud on logs/trailer and spare wheels could contribute an inaccuracy of 0.5% to 1.0%, or 100 to 200 kg to the OBM systems.

Electronic braking system (EBS) is an advanced system which operates independent of the driver and electronically manages the activation of the brakes to reduce response times and braking distances. EBS requires monitoring of the vehicle mass among other parameters, hence it has potential linkage with an OBM application. Instead of using additional devices such as load cells and APTs, EBS obtains axle mass from sensors within the system. Although the existing mass monitoring capability in EBS may prove to be useful and low-cost, the current fitment of EBS or similar systems on trailers was estimated at only 5% in Australia.

Based on the capability review, it was found that to function as an evidentiary application, an OBM system would need to:

- Record and report individual axle group and total vehicle combination mass, in kilogram. Instrumentation on the steer axle may not be available in some applications due to impracticable technology or cost.
- Be able to report the unique identity of the measuring component on each individual axle group.
- Be able to report the functioning conditions of the system, and any tampering attempt, relocation or removal of the system.

- Identify conditions which provide mass readings to an evidentiary level.

A recommended accuracy guideline for Austroads suggested that the maximum error for enforcement compliance be set at ±5% for GVM at the 95% confidence level (4).

3. PROJECT PLAN

A project plan (5) was developed to identify the main activities that should be carried out in the OBM project. A set of tasks were addressed for the technical feasibility assessment and the suitability and interoperability to the IAP was also discussed. The outcome of the feasibility assessment will result in a set of initial specifications for a regulatory OBM system.

A testing regime for the technical feasibility was developed and comprised of four key areas:

- Accuracy and robustness – assessment of accuracy of various OBM systems on different prime mover/trailer/suspension combinations in a range of operating environments across jurisdictions.
- Additional data – investigation of potential use of additional data from the electronic braking system (EBS) or engine control module (ECM) or the dynamic OBM data as a check data with the static data recorded by the OBM system.
- Human machine interface – identification of agreed ‘best practice’ guidelines and procedures for installation, calibration, operation and maintenance including consideration of tare mass.
- Tamper evidence – identification of the main areas of potential tamper and development of both technical and business options to ‘work-around’ these tamper points.

As part of the project, the resultant OBM application has also to be merged and function as part of the IAP system. The works would cover:

- changes to the IAP Functional and Technical Specification,
- the certification and auditing regime of the IAP, and
- the deeds of agreement.

The project plan was approved and the project commenced in December 2007. The initial technical and functional OBM specifications are expected to be available by May 2009.

4. PILOT STUDY AND PRELIMINARY FINDINGS

Prior to the full scale testing of OBM systems in Australia, a pilot study was carried out with the purpose to develop a test methodology for assessing OBM accuracy. The other purpose of this pilot was to investigate the feasibility of determining tamper events by examining unexpected changes in the dynamic data.

The pilot comprised of testing OBM systems from two suppliers. Each OBM supplier installed their systems on their test vehicle (a B-double in one test and a semi-trailer in the other as shown in Figure 1). Two static and two dynamic reference systems were also installed on the vehicles. It was found that taking multiple readings from a single load cell was not practical. Therefore, all the reference systems were only able to take measurement from the air bag suspensions.

Figure 1: Testing vehicles

Figure 2 shows two different sensors installed on a test vehicle. The picture on the left shows multiple APTs fed by air lines from the same air bag suspension on a trailer. The picture on the right shows a load cell fitted under the fifth wheel.

Figure 2: APTs (left) and load cell (right)

The on-board mass was measured by axle groups as well as GVM. All on-board measurements were compared against the weighbridge readings which are referred as the ‘actual’ weights.

4.1 Base Line Test

A theoretical assumption is that the relationship between the measured mass and the actual mass can be characterised by the equation y = ax + c, where y represents the measured mass taken from the on-board system, x represents the reference mass taken from the weighbridge, and a and c are constant values which indicate the quality and settings of the system. Ideally a constant would be 1 and c would be 0, and this represents a perfect linearity and accuracy of a system.

The test was conducted on level ground with brakes off and engine running. The results showed good correlation between all the on-board systems and the weighbridge. In fact, an almost linear relationship was found between the weighbridge readings and the on-board systems readings. Among all the systems tested, typical non-linearity was found in the ranges ±0.7% for trailer axle groups and ±1.3% for prime mover axle groups; typical inaccuracy was found in the ranges ±0.6% for trailer axle groups and ±1.15% for prime mover axle groups (6). Figure 3 shows an example of accuracy assessment for the on-board systems. Note that the characteristic equation y = ax + c did not appear to be perfect in any of the four systems shown. Nonetheless, all systems presented extremely high linearity.

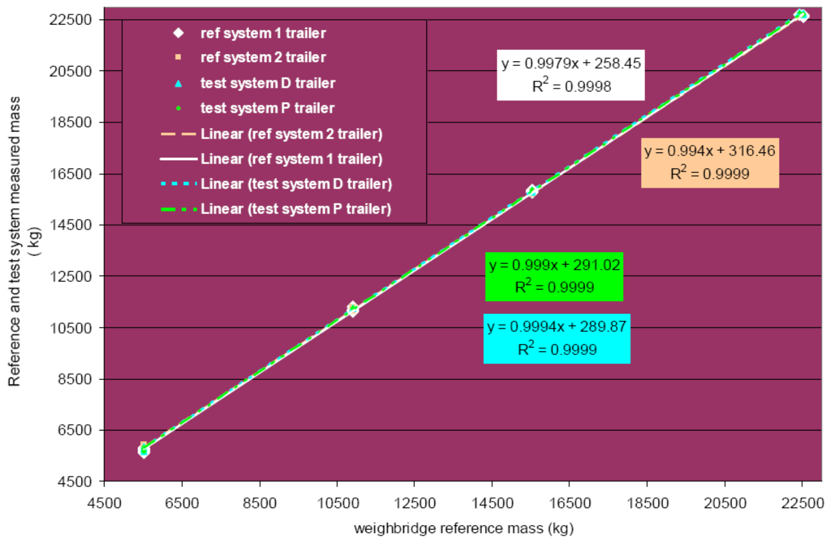

Figure 3: Example of accuracy assessment (6)

Another analysis used the average weighbridge reading as a reference mass, and compared all other readings against this reference mass to show the distributions of measurements. Figure 4 shows these distributions by axle groups, GVM and the weighbridge. It was found that all the measurements were approximately normally distributed.

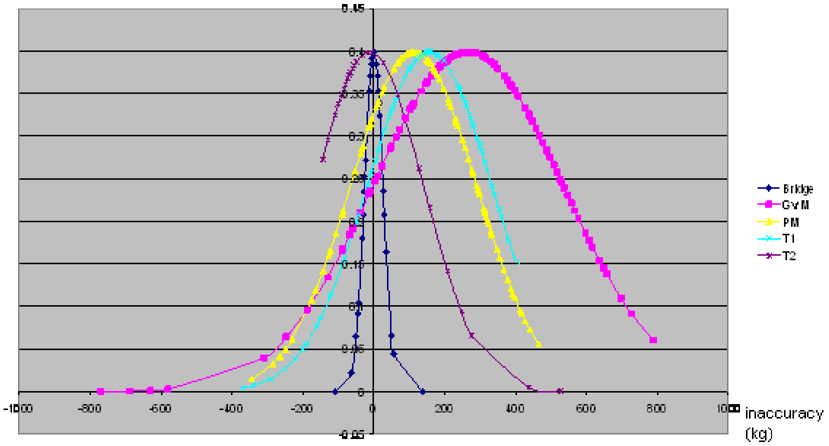

Figure 4: Distributions of measurements

The means and standard deviations of the distributions are summarised in Table 1. It was found that even the weighbridge readings varied by over 100 kg, while much larger variations were observed for the OBM systems. Another observation showed that OBM suppliers tend to be 'conservative' in determining (calibrating) their system readings, which were generally higher than the actual weights. Variations were also found to be larger on APTs based systems than load cells.

Table 1: Means and standard deviations

	Weighbridge	**Prime mover**	**Trailer 1**	**Trailer 2**	**GVM**
Mean (kg)	0.035	112	157	-12	266
Std. dev. (kg)	26.26	178	176	152	268

In addition, no consistent relationship was found between the inaccuracy of any systems and the load conditions. In other words, a heavier load did not always result in a greater error in the OBM readings. This finding suggested that the major contribution of inaccuracy could be the resolution of electronic components in the OBM systems.

4.2 Non-level Ground and 'Brakes On' Tests

A number of tests were conducted on non-level ground and with brakes on. The results showed that measurements taken under such conditions were not reliable. In fact, the differences between these measurements and the base line measurements varied from -430 kg to +820 kg. The standard deviations of these tests were also considerably higher.

4.3 Dynamic Test

A series of continuous recordings was conducted with the vehicle travelling. This test was designed to investigate the on-board system behaviours associated with different road situations via the use of dynamic data. The test circuit consisted of three corners and two speed bumps. Dynamic data was also collected for ride height adjustment on trailers.

Figure 5 shows the dynamic data collected from a trailer for one particular load condition. The samples were collected at frequency 100Hz and from both left and right sides of the trailer. It shows that spikes with different magnitudes and durations were detected at the corners. The magnitudes and durations were affected by the driver's force on the brakes so they were unpredictable. Much sharper spikes were detected at the speed bumps. The magnitudes of the spikes varied from approximately -1500kg to +2000kg about the dynamic mean. The fundamental frequency and damping ratio could also be determined from a zoomed-in view of the spike. This result further proved the capability of evaluating road friendliness of suspensions using dynamic OBM data as identified by Davis and Sack (3). The vehicle was then parked with brakes on to adjust the ride height control valve. An increase in mass measured was observed in the figure as brakes were held on. The dynamic data also shows similar patterns before and after the ride height adjustment.

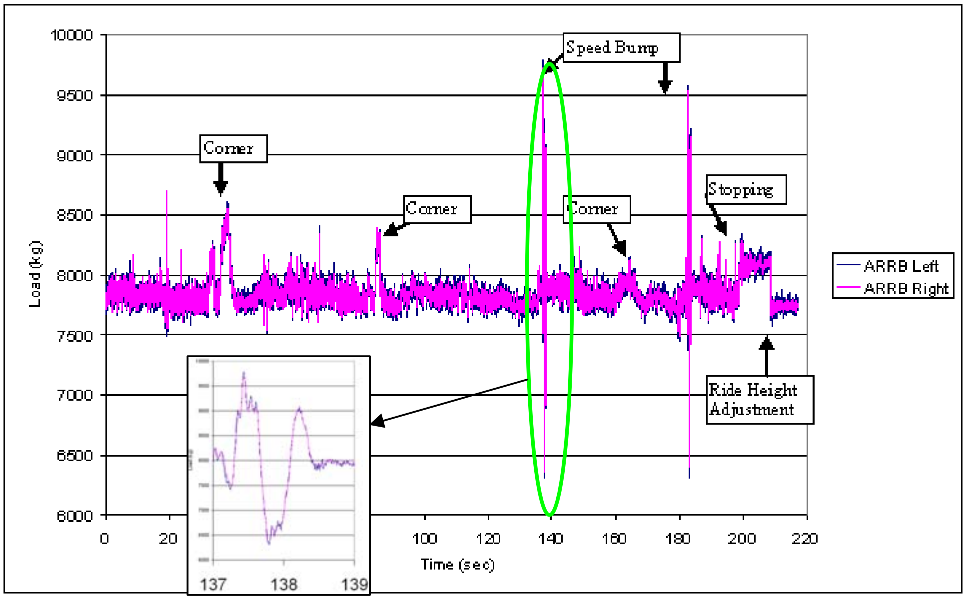

Figure 5: Dynamic measurement on trailer (7)

4.4 Air Blocking Test

An air blocking test was done by closing a ball valve that was installed between the APTs and the air bags. The aim of this test was to investigate the possibility of identifying tampering with the air line from the dynamic signature of the on-board systems.

Figure 6 shows the dynamic data collected from one reference system when the ball valves were shut. Closing the ball valves merely isolated the APTs from the air bags but had no impact on the air pressures that remained constant in the system.

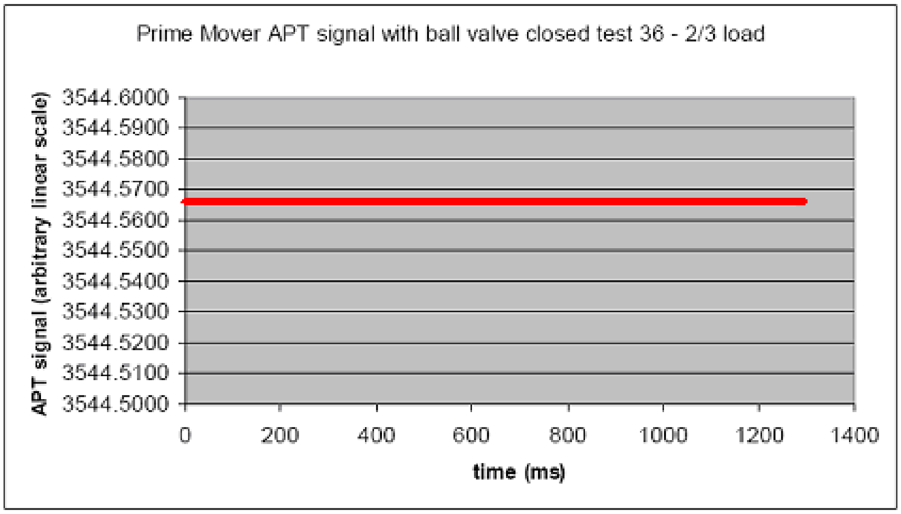

Figure 6: Effect of closing ball valves on air lines (6)

Figure 7 shows another completely different situation which air was leaking out of the joints due to improper installation. While the vehicle was moving on roads, after the valves closed, the APTs experienced a drop in pressure over time. As soon as the ball valves open again, the APTs were reconnected to the main air supply system and the pressure returned to its original level. It was found that although air leaked out while ball valves were open, the air suspension system kept pumping air into the air bags to maintain the same ride height (essentially same pressure). Therefore the APTs were able to report the correct mass level with ball valves open.

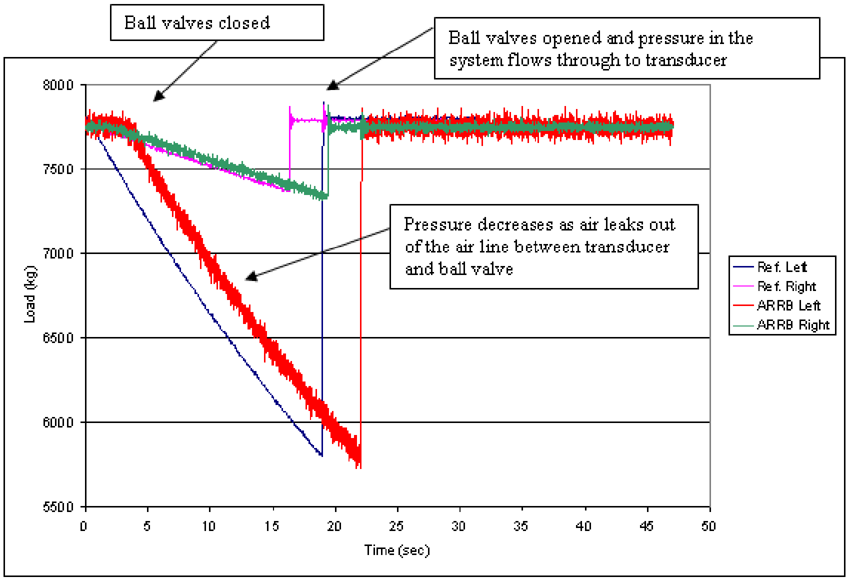

Figure 7: Effect of closing ball valves on air lines with air leaking (7)

4.5 Load cell Tamper Test

The purpose of this test was to investigate the effect of tampering with the load cells by inserting objects between the load cell and the upper part of fifth wheel. The test performed included inserting a steel bar and actively levering the upper part of the fifth wheel, and inserting a wooden chock. The levering test resulted in a measurement of 1320 kg less on the prime mover, while the chock had a smaller effect of only 220 kg removed. As expected, this tampering test had no effect on the APT based systems.

4.6 Fuel Tank Draining Test

This test aimed to investigate the OBM system’s capability of detecting changes in the fuel level. Fuel was drained out of the fuel tanks while the vehicle was in tare condition. On-board measurements were again compared with weighbridge readings. While the weighbridge showed a significant drop of 300-400 kgs after the fuel was drained, none of the on-board systems picked up a similar change. A similar test is to be conducted at full load to examine the sensitivity at the upper end of the scale.

5. REVISED TEST PLAN

As a result of the learnings from the pilot test, a revised test plan was developed for a full scale test across different states in Australia (8). This test plan aims to minimise the costs required from all parties and time consumed, while ensuring that all essential tests will be undertaken.

Eight OBM suppliers are expected to participate in this test. Each supplier will provide two test vehicles with their OBM systems installed. A range of vehicles will be covered in the test, vehicle classes being rigid truck, articulated truck and trailer, B-double/road train. A low-loader with hydraulic suspension will also be available in Western Australia. APTs and/or load cells will be tested depending on the supplier’s configuration. Mass feedback data from electronic braking system (EBS) will also be investigated where possible.

Weighbridge measurement will continue to be a reference mass to the on-board measurements. In addition, at least one static and dynamic APT based reference system will be equipped on each testing vehicle, except the low-loader which does not have any practical way of fitting a reference system. Furthermore, only one load cell based system can be fitted per vehicle. Thus, data collected from load cells on different vehicles will be compared against each other.

Although increasing the number of repeated measurements will increase the precision of the test program and reduce the error, it can also incur considerable amount of cost and time. A balance between the cost/time and acceptable error needs to be carefully decided. The pilot demonstrated an adequate sample size. Four load points; tare, 1/3, 2/3 and full will be tested. Six readings per test point will be carried out to achieve a 95% level of confidence (8). Each reading will be conducted on weighbridge (level ground) with brakes off and engine running. Dynamic recording and possible tampering with APT/load cell will be further investigated throughout the test. A fuel tank draining test will be conducted at full load instead of tare. All tests on non-level ground and with brakes on will be removed from the full scale test program since previous results showed unreliable readings under these situations.

6. SUMMARY

A detailed review of the capability in OBM systems was undertaken as an initial study for the evidentiary OBM application. Consequently, a project plan was developed identifying all the key tasks for the technical feasibility assessment as well as the fit with IAP. A pilot study was also carried out prior to the full scale OBM test. OBM measurements were compared with weighbridge readings and other on-board reference systems.

For the pilot tests, typical non-linearity was found in the range of ±0.7% for trailer axle groups and ±1.3% for prime mover axle groups; typical inaccuracy was found in the range of ±0.6% for trailer axle groups and ±1.15% for prime mover axle groups. A number of dynamic and tamper tests were also conducted, and the data was analysed to identify some of these events. Capability of using dynamic data to determine road friendliness for suspensions was also proved during the test. Learnings from the pilot have led to the development of a revised test plan for the full scale OBM test across Australia.

7. REFERENCE

(1) Karl, C.A. and Han, C., “Heavy Vehicle On-Board Mass-Monitoring – Capability Review”. ARRB Group, for Transport Certification Australia Ltd, Melbourne, Vic., Aus, September 2007.

(2) TCA, “Request for comment, IAP On-board Mass Monitoring”, Transport Certification Australia, Melbourne, Vic., Aus., March 2007.

(3) Davis, L. and Sack, R., “Determining Heavy Vehicle Suspension Dynamics Using An On-Board Mass Measurement System”. 27 ARRB Conference, Canberra, ACT., Aus., 2006.

(4) Austroads, “Heavy Vehicle Mass – Measurement Adjustments and Breakpoints”. Austroads Internal Report IR-49, Austroads, Sydney, NSW, Aus., 2006.

(5) Karl, C.A., “Project Plan: Technical Feasibility Assessment of On-Board Mass-Monitoring (OBM) Devices”. Transport Certification Australia Ltd, Melbourne, Vic., Aus., December 2007.

(6) Davis, L., “Technical Feasibility Assessment of On-Board Mass-Monitoring (OBM) Devices: a) Accuracy and Robustness b) Ancillary Systems Analysis, Interim Report On The Results For Pilot Test Plan – Melbourne and Brisbane Testing”. Queensland Department of Main Roads (QDMR), Brisbane, Qld., Aus., June 2008.

(7) Germanchev, A. and Eady, P., “Contract Report (Draft): On-Board Mass-Monitoring Accuracy and Robustness Testing”. ARRB Group, for Transport Certification Australia Ltd, Melbourne, Vic., Aus., June 2008.

(8) Davis, L., Bunker, J. and Karl, C.A., “Technical Feasibility Assessment of On-Board Mass-Monitoring (OBM) Devices: a) Accuracy and Robustness b) Ancillary Systems Analysis, Full-Scale Testing Plan Mk III”. Queensland Department of Main Roads (QDMR), Brisbane, Qld., Aus., June 2008.