MainRoads

Connecting Queensland

Technical Feasibility Assessment of On-Board Mass-Monitoring (OBM) Devices:

a) Accuracy and robustness

b) Ancillary systems analysis

Full-scale testing plan

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Executive Summary

A pilot test programme to determine the feasibility of testing for heavy vehicle on-board mass accuracy and tamper-evidence has been completed by Transport Certification Australia. The testing was executed *per* the pilot test plan (Davis, Bunker, & Karl, 2008) in Melbourne and Brisbane from April to June 2008. The results of that pilot test programme are still being analysed but preliminary analysis indicates the following results for on-board mass (OBM) measurement systems for heavy vehicles:

- The OBM systems tested during the pilot showed extremely good correlation with each other and with the weighbridge readings;
- Typical non-linearity figures found were in the ranges +/- 0.7% for trailer axle-groups and +/- 1.3% for prime-mover axles groups but much better results than this were found for some systems tested;
- Typical inaccuracy figures found were in the ranges +/- 0.6% for trailer axle-groups and +/- 1.15% for prime-mover axles groups; some OBM systems tested improved on these figures;
- The analysis indicates a maximum imprecision value (as determined by a standard deviation (σ) in Figure 4) of less than 150kg for any axle group measured by any system tested; and
- this is a better-than-expected result, give previous work (Davis, 2006).

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A full-scale test programme will be initiated now in accordance with this document (the full-scale test plan) after circulation and revision.

A reasonable response to transport industry pressure for increasing efficiency is for road authorities and regulators to allow higher mass limits (HML) heavy vehicles onto the road network. This forms part of an overall strategy to encourage “multi-combination vehicles” or MCVs (Haldane, 2002) onto portions of the road network that can withstand greater mass loadings. One of the tools used currently and increasingly by regulators and road authorities in Australia to monitor heavy vehicles

(HVs) is the Intelligent Access Programme (IAP) under the auspices of Transport Certification Australia (TCA). The IAP monitors the location, timing, speed and configuration of a HV using vehicle telematics and usually incorporates GPS satellite tracking.

The first large-scale application of IAP to HVs will be on HML vehicles. To manage the mass aspects of expanded HML access in the meantime, an interim solution involving a self-declaration function allowing transport operators to identify when they were operating at HML will be part of the initial monitoring of HML HVs under IAP. The reason for this was, in setting up IAP Stage 1, the TCA Board realised that an on-board mass monitoring solution for HVs was potentially several years away. In so doing, the TCA Board realised that the long-term solution to managing HV mass would be *via* on-board mass monitoring technology. To this end, TCA's 2006/07 business plan, endorsed by the TCA board in July 2006, contained two new research projects to ensure the expansion and value adding of its services to the transport industry and road authorities. The projects have identified technical issues regarding on-board mass monitoring systems including:

- Determination of tare *vs.* payload using OBM system at an evidentiary level;
- Accuracy, robustness and tamper issues of OBM components (mass sensors, connections, power supply, display unit etc.);
- Potential use of electronic brake system data to cross-check measurement results from OBM system; and
- Potential standardization of OBM components to achieve interoperability between trailers fitted from different supplier.

Accordingly, one of these projects will provide a standard to ensure interoperability between any IAP certified prime mover and trailer monitoring devices. The other project will investigate the feasibility of on-board vehicle mass-monitoring devices for IAP use.

This test plan addresses that portion of the feasibility assessment project concerned with:

- accuracy as determined by measuring OBM outputs *vs*. certified scales; and
- tamper-evidence as garnered from changes to dynamic signals from OBM systems, including from electronic braking systems and engine control modules.

To do so it sets out a programme to test suitable and available OBM systems to be reported by the TCA when the on-board vehicle mass feasibility of project is completed in 2009.

1. Introduction

As expressed in its 2006-2007 business plan, Transport Certification Australia Limited (TCA) has four organisational objectives. Under the fourth objective, to enhance product and service offerings, TCA is committed to commence, jointly with the National Transport Commission (NTC), investigating the feasibility of on-board heavy vehicle (HV) mass-monitoring devices for the intelligent access programme (IAP). This task is simply one of many TCA will undertake on its journey to providing its members and the market it serves with a comprehensive set of certified parameters for monitoring HVs. The set of parameters (location, time, speed, tamper-evidence, and proprietary trailer identification) monitored under IAP Stage 1 provides a robust platform on which Australia can commence providing a third level for regulating HV access: “intelligent access”.

On-board mass, along with interoperability between any IAP certified prime mover and trailer monitoring device, expands the range of applications to which IAP can be applied. This ultimately increases jurisdictional confidence in operational compliance and increases the negotiating power of the IAP for transport operators.

To this end, TCA’s fourth objective provides for two projects for enhancing the technical capability of the IAP, *viz*:

- a project to provide a standard to ensure interoperability between any IAP certified prime mover and trailer monitoring devices; and
- a project to investigate the feasibility of on-board vehicle mass-monitoring devices for IAP use.

These new research projects will ensure the expansion and value adding of its services to the transport industry and road authorities. The projects have identified technical issues regarding on-board mass monitoring systems including:

- Determination of tare *vs.* payload using OBM system at an evidentiary level;
- Accuracy, robustness and tamper issues of OBM components (mass sensors, connections, power supply, display unit etc.);

- Potential use of data to cross-check measurement results from OBM system; and
- Potential standardization of OBM components to achieve interoperability between trailers fitted from different suppliers.

Accordingly, one of these projects will provide a standard to ensure interoperability between any IAP certified prime mover and trailer monitoring devices. The other project will investigate the feasibility of on-board vehicle mass-monitoring devices for IAP use.

1.1. Overall objective of OBM feasibility

The objective in determining technical feasibility of on-board mass is to ascertain the ability to monitor HV mass to an evidentiary level. This objective *via* delivery of a mass measure that can be utilised for a range of policy objectives including evidentiary-level data that can be produced and judged valid in court of law.

The broad purpose of the feasibility assessment is to:

a) Produce a report that identifies the state-of-the-art in on-board mass-monitoring technologies and the range of commercial and (quasi-) regulatory applications to which it is applied. The state-of-the-art will be determined by an international literature review and survey of both the Australian telematics and transport industries.

b) Demonstrate the feasibility of on-board vehicle mass-monitoring with consideration to matters of:

- impact on, and participation of, industry and jurisdictions (usage);
- accuracy of mass management;
- cost; and
- technology (across all its elements).

c) In partnership with the NTC, identify, broadly, what jurisdictions will have to do to accommodate on-board vehicle mass monitoring as a part of an IAP system. This would cover:

- changes to internal processes and systems;
- changes to legislation/regulation[a]; and

- an articulation of the positives and negatives of nationally consistent approaches to the above[a].

d) Identify broadly what TCA will have to do to accommodate on-board vehicle mass monitoring as part of an IAP system.

This would cover:

- changes to the IAP functional and technical specification;
- the certification and auditing regime, and
- the deeds of agreement.

e) Associated with d) above, deliver a draft functional and technical specification for onboard mass-monitoring devices.

The latter project would lead the way for the introduction of mass as an IAP-monitored vehicle parameter.

[a] It is anticipated that these activities would be part of the NTC work

1.2. Aims & purpose of this test plan

One of the results from the TCA OBM feasibility project will be a determination of the accuracy and tamper-evidence of such systems. This document addresses that portion of the feasibility assessment concerned with:

- accuracy as determined by measuring OBM outputs *vs*. certified scales; and
- tamper-evidence as garnered from changes to dynamic signals from OBM systems, including from electronic braking systems and engine control modules.

To do so it sets out the requirements of a full-scale programme to test suitable and available OBM systems. It may be seen from Figure 1 (Karl, 2007) that this test plan will produce results that will inform the 4 tasks of the OBM feasibility project.

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The results from the testing programme described in this document will contribute to a TCA report that will cover the following issues in four key areas:

Accuracy and robustness:
The test programme will develop and assess accuracy of various OBM systems on a range of rigid vehicles and combinations, with various suspension types in a range of operating environments across jurisdictions.

Additional data:
The test programme will investigate the potential use of additional data from the electronic braking systems, engine control modules or other dynamic OBM data as validation against data from the static data recorded by these OBM systems.

Human machine interface:
The test programme will develop agreed best practice guidelines and procedures for installation, calibration, operation and maintenance including consideration of tare mass.

Tamper evidence:

The test programme will identify the main areas of potential tamper and development of both technical and business options to work-around these tamper points.

These four key areas for investigation are shown diagrammatically in Figure 1 and detailed further in Section 2.5.4. The task of field testing is the key sub-project that will assesses the technical feasibility of on-board vehicle mass monitoring.

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Queensland has operated IAP-like on-board mass-monitoring trials for several years, and has recently built on this work by undertaking testing on the accuracy and tamper vulnerability of particular on-board mass-monitoring system(s) being used (Davis, 2006).

It is proposed that the testing will leverage off the Queensland work to date to maximise the value of that work and the already established network of contacts.

The detailed arrangements for this task are dependent on a series of factors that will only be quantifiable after the experimental design is finalised and the availability and suitability of different systems is determined (including the commercial arrangements pertaining to their use and testing).

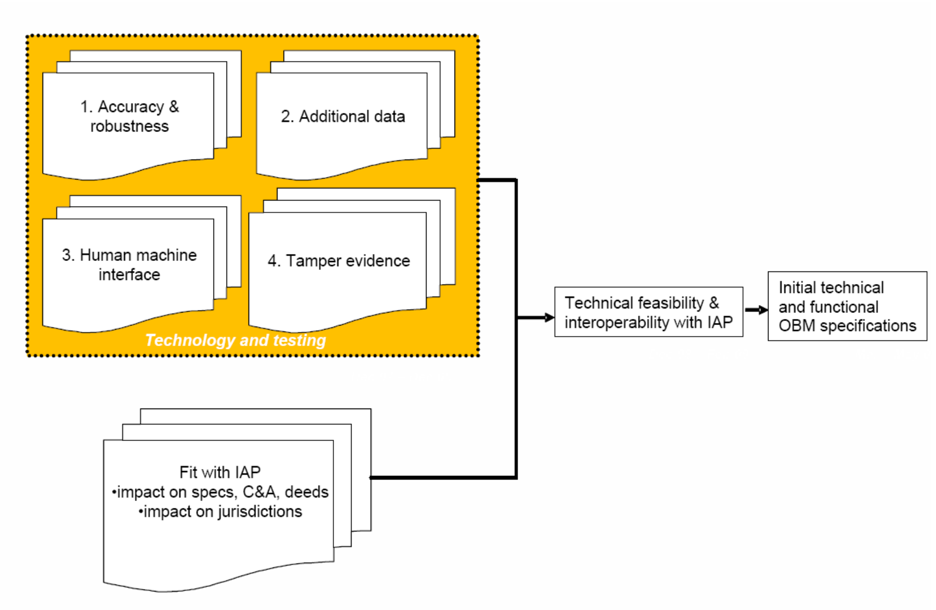

Figure 1. Overall OBM feasibility project task/activity interrelations (Karl, 2007).

1.3. Organisation of this test plan

The testing outlined in this test plan involves determining the performance of HV OBM systems as mentioned above:

- accuracy as determined by measuring OBM outputs *vs*. certified scales; and
- tamper-evidence as garnered from changes to dynamic signals from OBM systems, including from electronic braking systems and engine control modules.

The divisions in this test plan are designed to lead the reader through the following steps toward the realisation of the testing of OBM for accuracy and to inform tamper-evidence as part of the larger project. Accordingly, the sections associated with the realisation of those aims and objectives are listed in summary here with an indication of the section content to which the reader is directed for detailed commentary on each:

Section 2 provides the background needs that have resulted in the push for OBM testing and the rationale that has led to the current state of events: *viz*, now that OBM feasibility is being investigated. **Section 2** also outlines the activities such as the literature review undertaken by ARRB and the tasks required under the overall OBM feasibility programme.

Section 3 outlines the values under which this test plan will be realised. This sets out, in the broadest macro view, the fundamental principles of the testing defined by this test plan.

Section 4 provides detail on the design philosophy for the experiments that will form the input data for analysis under this accuracy and tamper-evidence sub-project. **Section 4** includes explanations for the choices made, as embodied in the testing as part of the experimental design, in the process of forming the test methodology. These include the choice of test HVs, how they will stand, rudimentary tamper procedures, alterations to HVs under test and the number of tests to be carried out. It also outlines the provisions for cross-validation of the test measurements against two reference OBM systems as well as certified weighing devices to be used.

Section 5 outlines the experimental requirements for this test plan. This includes the equipment to be used, and the roles and responsibilities of the various parties involved.

Section 6 defines the procedures to be used for the testing under this test plan and includes a cross-reference to Appendix 1 - Test data recording form.

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Section 7 defines the mandatory and statutory requirements and obligations as set out under the policies of the authorship organisations with concluding observations in **Section 8**.

Three figures are included in the test plan. The first, Figure 1 above, shows the interlinkages between the OBM feasibility elements and the IAP in general. The second, Figure 2, shows how the OBM feasibility programme tasks are aligned temporally and conceptually with respect to the broader IAP framework. Precision is an assessment of the variation in measurement of the same value. The difference between precision and accuracy is shown as a visual representation in Figure 4, which is also used to illustrate the test plan design philosophy for sample size in Section 4.5.

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1.4. Actions arising from the pilot test plan and this test plan

The pilot test plan (Davis *et al.*, 2008) was circulated to jurisdictions and OBM industry stakeholders and modified according to comments received. ARRB and TCA undertook testing in Brisbane in April 2008 and Melbourne in June 2008 in accordance with that pilot test plan. This full-scale test plan incorporates the learnings from those tests and is now being circulated. Jurisdictions and OBM system suppliers or their representatives are invited to comment in the requested time-frame. From comments received on expiry of that time-frame:

- This test plan for a full-scale testing programme will be modified;
- final implementation of full-scale testing involving all vehicles, the OBM team and all OBM suppliers or their representatives will now occur.

Timing of these activities will be advised to all stakeholders as the stages of the testing are undertaken. It is envisaged at the time of releasing this version of the test plan that the final round of testing will be from July to September 2008.

2. Background

2.1. General

Road authorities and transport regulators are under continuous pressure from the transport industry to allow “freight efficient” vehicles onto the road network. Outputs from the final report of the DIVINE project (OECD, 1998) were used in Australia to support the argument that air-sprung HVs should carry greater mass under the micro-economic reform popular in the 1980s and 1990s in Australia. One of these reforms was the mass limits review (MLR) project as implemented under the second heavy vehicle reform package (National Transport Commission, 2003). This was concluded that HVs would be allowed to operate at HML loadings if:

- certain vehicle design standards were met; and
- HVs at HML loadings kept to specified routes (*viz*: the “HML network” in each State).

This resulted in the implementation of HML schemes in various guises in all Australian States. Details vary between Australian States in terms of HML access and conditions but, in terms of additional mass, HML generally allows increases above statutory mass of Δ2.5t on a HV tri-axle group and Δ0.5t on a HV tandem axle group.

The implementation of the various HML schemes in Australia has not stopped the road transport industry pressuring road authorities and transport regulators for more concessions on mass and vehicle combinations, however. The road transport industry’s response to continued pressure from their clients for ever-increasing efficiency generally involves proposing HVs towing more trailers with:

- a greater number of axles or axle groups;
- more gross vehicle mass (GVM);
- greater axle loadings; and/or

- greater axle group loadings.

Fewer prime movers and drivers for a given freight task make these scenarios more attractive financially to transport operators and their clients. Accordingly, increasing numbers of HVs with more trailers, greater axle masses and axle group masses have been rolled out in response to such pressures. The first serious post-HML wave of these types of HVs is now operational although these vehicles have been on the network in various forms since the 1980s (Haldane, 2002) under the generic term "multi-combination vehicles" or MCVs.

In an effort to manage these non-standard HVs (including those operating at HML) and keep them to their permitted routes, regulators and road authorities developed the Intelligent Access Project in the late 1990's. This project has now borne fruit in the form of a regulatory body, Transport Certification Australia and implementation of the Intelligent Access Programme.

The first tranche of vehicles considered for Intelligent Access Programme monitoring in NSW and Queensland were HML vehicles. Indeed, the agreement between two Australian States and the Commonwealth (Australia Department of Transport and Regional Services, 2005a, 2005b) specified that greater network access for HML vehicles was contingent on their being tracked using GPS technology *via* the IAP. Up until that point, the IAP managers had considered implementation of on-board mass monitoring as a Stage 2 activity within the IAP implementation framework. This was due to the complexity of OBM coupled with an already intricate and exhaustive Stage 1 programme negotiated with 6 Australian States, 2 Australian Territories and set up to monitor location, timing, speed and configuration of HVs.

2.2. The need for OBM monitoring

In light of the growing freight task, asset protection has become an increasingly important issue for transport jurisdictions and regulators. With the demand for higher productivity vehicles driving national agendas such as performance-based standards (PBS), TCA has embarked on a programme of improving the number and value of its services. One of these expansions may be OBM. To this end, this test programme will inform the feasibility of OBM systems with a view to adding that feature to the IAP. Accordingly, this test programme will result in broad potential benefits and applicability to TCA stakeholders as outlined in Section 2.4.

2.3. The need for OBM testing

All Australian States have a Bilateral Infrastructure Funding Agreement (BIFA) with the Australian Government. These are also known as the "AusLink agreements". Each BIFA is an agreement between individual States of Australia and the Commonwealth, which covers arrangements applying to "funding made available by the Australian Government to [all Australian States] under the first five-year AusLink investment programme (2004-05 to 2008-09) and any agreed subsequent changes to, and extensions of, the programme. It also covers agreed arrangements for infrastructure planning, identification of investment priorities, development and assessment of project proposals and evaluation of completed projects" (Australia Department of Transport and Regional Services, 2005b).

An alteration to the focus of TCA occurred with respect to OBM (see Background). This was triggered by NSW's and Queensland's BIFA (Australia Department of Transport and Regional Services, 2005a, 2005b) obligations in that HML vehicles be monitored by the IAP.

Specifically Queensland's BIFA states (authors' bolding for emphasis):

"74) Accordingly, both parties agree to work co-operatively towards ensuring a structured sensible extension of **HML vehicle** access onto a broader strategic network. It is agreed that further extensions will reflect the following principles:

a) Both parties commit to accelerating the development of the Intelligent Access Program (IAP). Specifically, both parties:

i. support vehicle tracking with suitable **mass compliance functionality being implemented for all HML vehicles** on a national basis, and eventually to other restricted access heavy vehicle categories; and

ii. agree that access to **HML will be conditional on an enforceable commitment from all operators to participate in the full IAP process** from the time that it is operational and available.

The Australian Government will provide funding to:

- the National Transport Commission (NTC) and/or Transport Certification Australian Limited, as appropriate, to accelerate this process with a view to ensuring that both route access and mass compliance can be accurately monitored and regulatory breaches enforced….."

NSW's BIFA contains the following provisions:

"66) **Access conditions for HML-eligible vehicles** operating on the NSW network shall be as follows:

…c) vehicles **shall be enrolled in a route-compliance monitoring regime using the Intelligent Access Program (IAP)**, from the time that it is operational and available…"

2.4. IAP Stage 2

At its August 2005 meeting, the TCA Board of Directors considered and endorsed Version 1 of the 2005/06 business plan. At that meeting, the Board of Directors agreed to move to Stage 2 of IAP. The move was triggered by the NSW and Queensland obligations under their respective BIFAs to use IAP as a condition to the expansion of their HML network (Australia Department of Transport and Regional Services, 2005a, 2005b). The Board also requested that a revised business plan be developed to address this move to Stage 2. This decision introduced a new complexity to the IAP domain.

As mentioned above, Stage 1 of IAP was designed to manage the location, timing, speed and configuration of a HV. The large-scale application of IAP to HML vehicles requires the management of vehicle mass. Though it was acknowledged that the ideal way to manage mass is *via* on-board mass monitoring technology; in setting up IAP Stage 1, the TCA Board realised that solution was potentially several years away. To manage the mass aspects of expanded HML access in the meantime, the Board endorsed an interim self-declaration function allowing transport operators to identify when they were operating at HML. This is supported currently by a slightly revised National Heavy Vehicle Accreditation Scheme (NHVAS).

The TCA's 2006/07 business plan was endorsed by the TCA board at its meeting in July 2006. That business plan included two projects for enhancing the technical capability of the IAP:

- a project to provide a standard to ensure interoperability between any IAP certified prime mover and trailer monitoring devices; and
- a project to investigate the feasibility of on-board vehicle mass-monitoring devices for IAP use.

2.5. Tasks under the Technical Feasibility Assessment for OBM

This section details the tasks, as part of the background to the OBM test programme, that are defined in the current project plan for the overarching TCA project entitled *Technical Feasibility Assessment of On-Board Mass-Monitoring (OBM) Devices.*

The report generated by this project is not the same report as, but will be informed by, the report required under Section 6 to be provided by TCA's testing contractor.

2.5.1. Literature Review of On-board Mass-Monitoring Technologies

This literature review will include coverage of the issues canvassed in the TCA Request for Comment On-board Mass-Monitoring (Transport Certification Australia Limited, 2007). This report was produced and paid for by TCA in September 2007.

2.5.2. Identify Current and Likely Future Applications

The range of commercial and (quasi-) regulatory applications to which on-board mass monitoring technologies are applied will be determined by:

- Reviewing the responses to the TCA Request for Comment On-board Mass-Monitoring.
- Engaging with members of both the TCA IAP Focus Group, IAP User Group and the Jurisdictional Liaison Group (JLG).

The focus of this task would be to identify the benchmark for on-board mass-monitoring technologies to address these applications. This will inform the work of the NTC in identification of specific applications based on policy requirements. It is anticipated the range of applications will include:

- certified weights and measures applications a subset of which will likely be enforcement and compliance of vehicle mass limits;
- commercial fleet and freight management;

- asset management applications including, but not limited to, the use of on-board mass-monitoring to manage access to vulnerable road network assets (bridges, culverts, pavements, alignment constraints, etc); and
- envisaged IAP applications.

2.5.3. Analyse Responses to Request for Comment On-board Mass-Monitoring

The responses to the TCA Request for Comment On-board Mass-Monitoring will be analysed and used to:

- augment the literature review; and
- ratify the identified applications.

2.5.4. Report Findings

The report will:

- present the results of the literature review with individual technologies and solutions;
- draw conclusions as to the suitability of different technologies and solutions to address the various applications including implication for Australian Design Rule (ADR) compliance (eg: wiring or engine management requirements associated with providing a tamper proof system);
- incorporate the findings from the analysis of the Request for Comments responses; and
- articulate a way forward listing the costing and technological issues researched in preparation for a continued joint NTC/TCA work on the development of TCA certified on-board mass-monitoring devices.

The report will also cover:

- an overview of the existing approaches to measuring mass;
- definitions of mass and the implication of different definitions in measuring mass (gross mass, mass *per* axle etc);
- devices available, including claimed accuracies and conditions of operation;
- a report of the devices in terms of being accurate, tamper proof and monitored for compliance (tamper evident);
- an estimation of the costs associated with implementation and operation of devices;
- potential linkages to IAP capabilities;
- identification of the current limitations of the technology; and
- any emerging developments to overcome these limitations (including expected timelines).

2.6. Technical Feasibility

The final report on the OBM industry will then lead into the feasibility assessment as shown in Figure 2 (Karl, 2007) below. TCA's technical feasibility assessment is described in the following subsections. The outcome of the feasibility assessment will be a set of initial specifications for a regulatory OBM system and anticipated impact across TCA and jurisdictional systems from an IAP implementation perspective. The technical feasibility assessment will be complemented by a parallel investigation by the NTC that will focus on the policy issues and implications. The testing regime will comprise the four key areas as outlined previously in Section 1.2 and shown previously in Figure 1.

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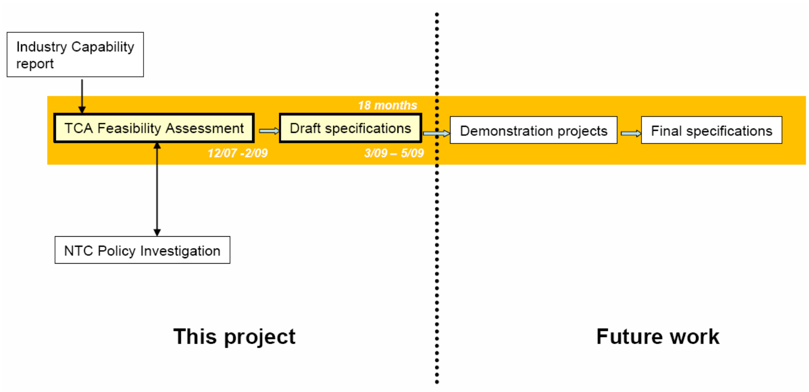

Figure 2. Linkages between feasibility assessment and future work (Karl, 2007).

Field testing under this test plan is a key sub-project that will assesses the technical feasibility of HV on-board mass monitoring. Accordingly, a robust experimental design (see Section 4) will be undertaken to test suitable and available OBM systems.

2.7. Suitability and Interoperability to the IAP

A consultancy will be undertaken that will identify, broadly, what TCA will have to do to accommodate on-board vehicle mass monitoring as part of an IAP system (Figure 1). This will cover:

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

2.8. Summary of this section

Stage 1 of the implementation of IAP did not consider OBM as feasible within the project framework. This due to the complexity of introducing a new HV monitoring regime in Australia, the novelty of OBM and the original intent that Stage 1 of IAP would monitor only the location, timing, speed and configuration of HVs.

With its Stage 1 programme almost implemented, TCA is investigating the feasibility of OBM for HVs under Stage 2 of its on-going business programme. Should OBM be implemented under IAP, the first tranche of HVs to be thus equipped and monitored will be HML vehicles. This due initially to the provisions of the BIFAs between the Australian Government and both NSW and Queensland. Other States and Territories have joined with this approach at the Board level of the TCA. This means that two projects for enhancing the technical capability of the IAP have been initiated:

- a project to provide a standard to ensure interoperability between any IAP certified prime mover and trailer monitoring devices; and
- a project to investigate the feasibility of on-board vehicle mass-monitoring devices for IAP use.

The second of these projects, entitled *Technical Feasibility Assessment of On-Board Mass-Monitoring (OBM) Devices* will address:

a) an overview of the existing approaches to measuring mass;

b) definitions of mass and the implication of different definitions in measuring mass (gross mass, mass *per* axle etc);

c) devices available, including claimed accuracies and conditions of operation;

d) a report of the devices in terms of being accurate, tamper proof and monitored for compliance (tamper evident) including the practical aspects of certifying devices to national accuracy standards;

e) an estimation of the costs associated with implementation and operation of devices;

f) potential linkages to IAP capabilities;

g) identification of the current limitations of the technology; and

h) any emerging developments to overcome these limitations (including expected timelines).

3. Principles

The testing to be undertaken under this test plan and the associated test programme defined herein will operate under the following principals:

- all parties operate in good faith toward the outcome of this test programme, *viz*; determine the feasibility of using on-board mass systems to monitor HV mass at the evidentiary level and thus achieve the objectives and aims as set out herein;
- all parties will attempt to minimise their expenditure;
- experimental rigour will be applied in the design of the testing. This will include, but not be limited to:
  - ☞ the use of OBM reference systems; and
  - ☞ the supply and cross-validation of manufacturer's suspension data against measured values derived from OBM test data;
- existing, installed OBM systems on working HVs will be the subject of the testing;
- TCA will meet the following costs:
  - ☞ test team/s costs; and
  - ☞ reasonable pre-testing procedures (such as those necessary to determine suspension parameters of nominated test vehicles);
- as the main beneficiaries of OBM monitoring of HVs through the IAP, in-kind support from OBM suppliers or their representatives will facilitate this test programme;
- type and configuration selection of test vehicle/s will be by the TCA OBM team in consultation with the IAP jurisdictions and the IAP Board;

- supply of the test vehicles will be facilitated by the OBM suppliers or their representatives and be as *per* Section 5.3;
- test sites will be negotiated jointly by the OBM suppliers or their representatives and the TCA OBM team;
- as the primary point of contact between existing OBM systems and the transport operators who use them, the OBM suppliers or their representatives will be key in facilitating negotiations between the owners of the test vehicles and the TCA team;
- TCA and OBM suppliers or their representatives wish to safeguard their respective rights in and to their respective confidential information and intellectual property; and
- in the course of the Participant’s participation in the Project, both TCA and the Participant will provide to the other access to certain confidential proprietary information and intellectual property (IP), the ownership of which will remain with the originating party.

4. Experimental design philosophy

4.1. General

Robust experimental design involves the use of:

- cross-validation of data;
- provision of a “control” test group or data-set with which to compare the “test” data set;
- consistent test procedures;
- consistent test methodology;
- reduction, to the greatest possible extent, of variation in external influences between tests; and
- adequately sized sample sets.

The following section details the testing to be undertaken using this test plan and how it will achieve the requirements for robust experimental design.

This test plan forms part of an overall robust experimental design to test suitable and available on-board mass measurement systems. The overarching drivers for the testing have been outlined previously in Section 2.2 and 2.3. This test plan document defines the experimental methodology to resolve some of the issues with respect to OBM and other systems. To do this the testing described in this test plan covers:

- accuracy and robustness: Development of test methodology for, and assessment of the accuracy of, various OBM systems on a range of rigid vehicles and combinations, with various suspension types in a range of operating environments across jurisdictions;

- additional data: Investigation of the potential use of additional data from the electronic braking systems, engine control modules or the dynamic OBM data as a cross-reference to the static data recorded by other portions of OBM systems; and

- tamper evidence: Investigation of the feasibility of determining tamper events by examining sudden changes in the dominant frequencies present in electronic braking systems, engine control modules or the dynamic OBM data.

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Electronic braking system or engine control module data will be requested from HV brake system manufacturers either directly or via the test programme outlined herein. Accordingly, the availability of such data may or may not be available to TCA's testing contractor during the course of the test programme. Nonetheless, this data will be analysed by TCA and the results included in the TCA project entitled *Technical Feasibility Assessment of On-Board Mass-Monitoring (OBM) Devices.*

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4.2. Reference OBM systems

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Each OBM system tested will produce its own set of data. These data sets will be measured against the weighbridge or certified scales using the forms in Appendix 1 - Test data recording form.

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As a cross-validation of the data set from each test OBM, particularly for the dynamic data to be recorded, another set of data needs to be recorded. This data needs to be recorded by a system that is universal for all tests, regardless of vehicle. The data from this system will provide a set of static and dynamic reference data. Two OBM systems common to all the tests and vehicles will be used and are termed the *reference OBM systems*. One of them will record static and dynamic data contemporaneously with the OBM system under test. The other will record static data only. The reference OBM systems will be installed on all test HVs to provide a consistent set of data across all test HVs. One outcome of the use of the reference OBM systems will be the ability to compare the measured mass (MM) reading of the reference OBM systems to the MM reading of the test system and to the reference mass (RM) reading from the weighbridge. Accordingly, three measured mass (MM) readings will be taken *per*

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test, one from each of the reference OBM systems and one from the test OBM system. This will be done using three copies of the form in Appendix 1 - Test data recording form.

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n.b: the RM will be measured from the weighbridge or other certified scales: there will be three MM readings per test, one for each reference OBM system and one from the test OBM system.

Accordingly, the reference OBM systems (including APTs and other ancillary equipment necessary for their proper function):

- will be supplied by TCA &/or TCA's testing contractor;
- will be installed on each test HV by TCA &/or TCA's testing contractor or organisations convenient to TCA constituent members;
- will record and store a static dataset for each test on each test HV;
- will be common across all test vehicles; and
- will, in the case of one reference system, record and store a dynamic dataset for each test on each test HV.

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In summary:

- the dataset recorded and stored by the OBM reference systems will be used as the common reference dataset *across all test vehicles*. This will be for the purposes of comparison with the static and dynamic datasets recorded from the OBM systems under test; and
- the measured mass (MM) of the reference OBM systems will be recorded against the reference mass (RM) from the weighbridge or certified scales using the form in Appendix 1 - Test data recording form, no differently from the procedure for the test OBM system, providing a further cross-check under this test regime.

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4.3. Modifications to test HVs if air spring equipped

Some test HVs will utilise air-spring pressure to determine on-board mass readings. For those cases, a blanked-off ¼" tee-piece will need to be inserted in the high pressure air line to the air springs of the axle group where pressure is measured to determine the mass on that group. These will need to be connected from all test APTs (in use for the tests) to the high-pressure air spring air lines using auxiliary air line(s) with a ball valve or turncock valve interposed between the tee-piece and the APT. These additional air lines with the valve installed will enable full or partial closure of the auxiliary air line(s) to all installed APTs for the readings under Step 8 in Section 6.2.

4.4. Choice of test HVs

This test programme will prefer to source HVs with certified road friendly suspension (RFS). This is because:

- the Queensland and NSW BIFAs define HML access to be monitored under the IAP operating environment;
- the requirement to monitor HML vehicles using IAP has prompted an OBM experimental programme to be implemented (of which this document describes a part) through the TCA business plan (refer to Background - Section 2.4 for details);
- HVs operating at HML loadings are required to have RFS; and
- HVs operating at HML loadings are the target group for OBM implementation.

Accordingly, any HV operating at HML loadings will be monitored under the aegis of IAP, potentially using an OBM system. The proposal therefore has RFS & OBM present concurrently on HVs accessing the HML network. Accordingly, under this OBM test programme, it will be preferable to use RFS-equipped HVs. One benefit of this approach is that the suspension manufacturer can provide the RFS characteristics of frequency and damping ratio as part of the RFS certification.

Some jurisdictions are interested in the application of OBM to special purpose vehicles (SPVs) - in particular, cranes. If appropriate vehicles with OBM systems installed are readily available, the testing program will include these SPVs.

Where:

- HVs without RFS are nominated for testing; or
- HVs with RFS but without RFS certification are nominated for testing,

these vehicles have their suspensions tested for fundamental frequency and damping ratio characteristics before the tests start. The co-ordination of this testing will be by TCA and carried out by TCA's testing contractor.

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4.5. Choice of sample size

Reduced error, increased accuracy and increased precision in test programmes arises from repeated measurements. Measurements, necessarily, involve cost. Accordingly, a balance needs to be struck between the number of tests and the acceptable error. This issue is a major influence in the choice of sample size.

For each load condition, *viz*: tare, 1/3, 2/3 and full load; data readings will be taken a number of times to improve the reliability and accuracy of the results.

The sample size has been determined from the process outlined in Appendix 3 and summarised here.

If a 95% level of confidence is chosen and reasonable assumptions are made about:

- an experimental error value; and
- the spread of measurements from the population of OBM systems,

this leads to the necessity for 6 readings *per* load condition. This means 6 readings of the reference mass (RM) and the measured mass (MM) *per* test load condition without changing any other variables.

4.6. Tampering

HV regulators regard tampering as a major issue. Controlled tampering during the tests will be carried out to determine if the effects of that tampering can be detected from changes in the data. Accordingly, some basic tampering has been included in Section 6.2 that involves changing the operation of the test vehicle or its systems.

4.7. Choice of test loads

As mentioned in Section 4.5, a large number of repeated measurements is the ideal and reduces error. Measurements, however, necessitate expenditure, complexity, difficulty, resources and time. Accordingly, the compromise when designing experimental methodology will always be between the quantity of tests and experimental error. The quantity of measurements is therefore determined, ultimately, by an acceptable level of error.

For a given number of test load conditions, as a proportion of full load, a certain error is expected when the reference mass (RM) is plotted against the measured mass (MM) for each vehicle and each OBM system. Accordingly, a balance between fairness to the OBM system under test and the complexity, cost and time required for testing and number of load conditions needs to be struck. The following reasonable assumptions have been made:

- ☞ the OBM system under test will be tested from no-load (tare) to full-scale deflection (FSD); hence tare and full-load will be two of the load conditions; and
- ☞ linearity of the scale of the OBM under test is important; hence, two[b] more test points (load conditions) are required between tare and FSD.

Equi-spacing these test point across the scale of the OBM under test provides the following four load conditions *viz*:

- tare;
- 1/3 load;
- 2/3 load; and
- full load.

The intermediate loadings need not be exact since a pragmatic tolerance of (say) +/- 5% will not interfere with the process of plotting the reference mass (RM) against the measured mass (MM) for each vehicle.

Where HVs operating at other than HML loadings, such as statutory mass or concessional loading schemes, are chosen for testing, the maximum load of that HV will be nominated as "Full load" for the testing, partial loads calculated accordingly and all loads noted as such on the form in Appendix 1 - Test data recording form.

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4.8. Alterations to the test vehicle

Some OBM system use an algorithm to determine steer axle mass as a proportion of the moment of the load on the 5th wheel. Most OBM manufacturers recommend that their systems be calibrated with the fuel tank full. The tests will need to determine whether altering 5th wheel sliders (where fitted) or fuel loads have an effect on pre-programmed OBM algorithms. A basic test altering these variables has been designed into the methodology outlined in Section 6.2.

4.9. Test routes

The suspension of the HV will need to be exercised between test readings to ensure that bushing hysteresis, inter-leaf friction, air bag stretch, etc, are averaged out over the readings. This means that each test HV will be required to perform some travel

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[b] A minimum of one more point between tare and FSD would provide, in theory, a measure of linearity provided the MM *vs*. RM relationship was linear and not bi-modal. The choice of 4 points eliminates the possibility of a bi-modal MM *vs*. RM relationship going undetected.

activity before returning to be weighed again. It would be preferable that the circuit be pre-defined, depending on logistical arrangements.

4.10. Test HV stance

The effect on OBM systems when the HV is standing on different slopes and any effect that brake wind-up may exert on the OBM reading has been measured in the pilot testing. Sufficient data have been gathered showing the differences in OBM readings when the HV was level with the brakes on and off as well as on different cross-slopes and longitudinal slopes. No further testing of non-level HV stances will be necessary for the project outcomes. Deleting these tests will also reduce the amount of time that the test HVs will be required under the full-scale test programme.

4.11. Summary of this section

This section has set down the background philosophy for the choices used in the experimental design of this test plan. These have resulted in a requirement for 4 approximately equi-spaced test loads, some travel activity between tests, and 6 measurements *per* test vehicle *per* test load condition. Some basic tampering will need to be carried out to determine if data will change as a result during the tests.

5. Experimental requirements

5.1. General

The test programme to be undertaken as part of the project entitled *Technical Feasibility Assessment of On-Board Mass-Monitoring (OBM) Devices* and as defined in this document will use resources from Main Roads WA (MRWA), Transport South Australia (TSA), Victorian (VicRoads) and Queensland (Main Roads) jurisdictions. The procurement and deployment of these resources will be co-ordinated by the OBM project manager, Dr. Charles Karl, the TCA, testing contractors and officers seconded to the TCA from member jurisdictions. As well as these resources, HVs fitted with various forms of OBM systems such as air-spring pressure measurement and load cells will be used.

The OBM systems will be tested for:

- accuracy
- precision (repeatability);
- dynamic data and
- tampering, as evidenced by changes in dynamic data.

The following section outlines the equipment and procedural requirements for the test programme.

5.2. Equipment

The following equipment will be required to perform the testing:

Items	No.	Source
Certified scales or weighbridges	t.b.a.	QT, VicRoads, MRWA or access to private weighbridges facilitated *via* participating OBM system manufacturers &/or suppliers.
HV with OBM installed and calibrated to the manufacturer's specifications.	"	OBM system manufacturers &/or suppliers
OBM systems, instrumentation, recording devices, ancillary equipment and wiring attached and installed by the OBM suppliers or their representatives.	"	OBM suppliers or their representatives;
A set of extra air line extension pieces.	1 air line and valve *per* APT	These to connect all APTs (in use for the tests) to the high-pressure air spring air lines. These additional air lines to have a pneumatic turncock or manual ball valve installed enabling full or partial closure of the auxiliary air line(s) to all installed APTs. TCA &/or TCA testing subcontractor.
OBM reference system/s	2 *per* test HV, including all necessary APTs	Supplied and fitted by TCA &/or TCA testing subcontractor.
Wheel chocks	"	Participating jurisdiction, TCA &/or TCA testing subcontractor,
Tamper devices	"	TCA &/or TCA testing subcontractor,
Personnel	"	Participating jurisdictions, testing contractors & TCA.
Test loads	3	OBM suppliers or their representatives. Rigid mass used as test loads would be preferable to ensure minimal movement of load during testing and thereby increase accuracy and lower variation in the readings.
Workplace health and safety equipment	t.b.a.	Governed *per* participating jurisdiction.

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5.3. Description of the test requirements, equipment & data – OBM suppliers or their representatives

The testing will be an experimental process that incorporates the following equipment, activities, data outputs, certifications, locations and associated responsibilities:

1) test HVs supplied by the OBM suppliers or their representatives. It is envisaged that this could be facilitated by OBM suppliers or their representatives holding over a HV with a newly-fitted and calibrated OBM system for a few days before delivery or facilitating contact with transport operators working HVs in locations convenient to weighbridges;

2) OBM suppliers or their representatives to ensure that test HVs have current registration, safety and any other necessary certification to operate in the jurisdiction where the testing is being carried out;

3) test loads supplied by the OBM suppliers or their representatives;

4) Rigid test masses as loads would be preferable to ensure minimal movement of load during testing and thereby increase accuracy and lower variation in the readings.

5) OBM systems, instrumentation, recording devices, ancillary equipment and wiring attached and installed by the OBM suppliers or their representatives;

6) rigorous calibration of OBM systems, over the range of static loading conditions from tare to full-load, by the OBM suppliers or their representatives;

7) OBM suppliers or their representatives to witness the testing;

8) static and dynamic data recorded at intervals not larger than 1/20th of a second as follows:

   a) OBM readings comprising:

      i) for strain gauge-based systems: load cell strain readings; and

      ii) for air spring pressure-based systems; air pressure transducer (APT) readings.

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9) a copy of all raw data from the OBM under test:

   (a) during the static tests; and

   (b) from the on-road test circuits in a digital format

   supplied to the TCA team by the OBM suppliers or their representatives; and

10) raw data digital format: raw data variable *vs*. a linear time-series able to be readily mapped to commercially-available spreadsheet software[c] such as Microsoft Excel® or MATLAB® *without macros or other post processing*.

11) The location of the test routes, flat measurement surface and the sloping site(s) may vary depending on logistical arrangements between jurisdictions, OBM suppliers or their representatives, HV availability and TCA personnel. The suitability of the routes, flat areas and the sloped areas for measurements will be determined by consensus between TCA personnel and OBM suppliers or their representatives.

12) HV manufacturer's VSB11 testing data or certification to VSB11 supplied by the OBM suppliers or their representatives (who may wish to source sufficient VSB11 information from vehicle manufacturers).

[c] Excel is the product of Microsoft Corporation; MATLAB is the product of The MathWorks, Inc.

5.4. Description of the test requirements, equipment & data – TCA &/or TCA's testing contractor

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1) Where HVs without RFS or HVs with RFS but without RFS certification are nominated for testing, these vehicles will have their suspensions tested for fundamental frequency and damping ratio characteristics before the tests start. This testing will be by the project manager;

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2) Two OBM systems, nominated as *the OBM reference systems*, will be supplied by TCA and installed on each test HV by TCA, TCA's testing contractor or organisations convenient to TCA constituent members;

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3) Forward a copy of all data gathered from OBM suppliers or their representatives to TCA as listed in 5.3 9) &10); and

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4) Supply materials, equipment and personnel as otherwise defined under the requirements of TCA &/or TCA's testing contractor in Section 5.2.

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TCA's testing contractor is to formulate a report analysing the data gathered in Section 6 as agreed under separate documentation.

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6. Testing procedure

6.1. General

The overall methodology will be to measure the reference mass (RM) of the supplied HV and its measured mass (MM) using the forms in Appendix 1 for the reference OBM systems and the test OBM system. The axle/axle group RM from the reference OBM systems and the test OBM systems will be recorded a number of times for the HV stance of parked on level ground with the brakes released.

To ensure that the suspension of the HV is suitably exercised between test readings, the HV will travel a pre-defined circuit and return to the original weighing station or another weighing station. Differences in readings for the latter option will be evident and these will be compensated for, in the event of this eventuality, by the use of the reference OBM systems. The pre-defined circuit need not be lengthy, just sufficient to exercise the HVs suspension and dependant on logistical arrangements. The circuit may be part of the test HV's normal activities and route or comprise driving off the weighbridge, onto the network and up to normal operating speed, U-turn and back onto the weighbridge.

In addition to these data above, the dynamic data from the reference OBM systems and the test OBM system will be recorded.

The measurement and recording process for the data will be undertaken using:

- certified scales as supplied by jurisdictions participating in this test programme or commercial weighbridges commissioned for the purpose;
- HVs with the reference OBM systems and the test OBM system installed (HVs and test OBM systems supplied by OBM suppliers participating in this test programme); and
- personnel from TCA, testing contractors and participating jurisdictions.

The scales may vary depending on logistical arrangements in each State, OBM supplier and jurisdiction. As part of the analysis phase, the RM will be compared with the measured mass (MM) as read from the reference OBM systems and the test OBM system installed in each test HV. This will be to determine the accuracy of the system under test by comparing the RM reading with the MM reading for the HV on level ground.

TCA's testing contractor is to formulate a report analysing the data gathered under the procedures listed in Section 6. The report format will be as agreed under separate documentation.

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The dynamic data will be analysed by the OBM team for frequency and range dynamics using Fast Fourier Transform (FFT) and other techniques as evidence of tampering.

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6.2. Detail

6.2.1. Test tasks

These are the tasks for the tests:

Task 1

using Appendix 1 - Test data recording form, record:

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- the registration number;
- vehicle make and model; and
- axle group configuration of the HV under test.

Task 2

- Test HV to comes to a stop and parks on a weighbridge or certified scales; with suitable wheel-restraints in place; brakes off.

Task 3

- Record the test OBM system static reading (MM) using Appendix 1 - Test data recording form.

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Task 4

- Record the reference OBM system/s static reading (MM) using Appendix 1 - Test data recording form.

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Task 5

- Record the weighbridge static reading OBM system/s static reading (RM) using Appendix 1 - Test data recording form.

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Task 6

- Test HV to proceed on the pre-defined circuit.

Task 7

- Record the dynamic data from the dynamic reference system/s on the test HV.

Task 8

- using suitably-sized wedges under the strain gauges for load-cell based OBM systems;
- using the manual ball valve/turncock listed in Section 5.2 in the air-lines to the APTs for OBM systems measuring air-spring pressure; or
- employing other means as may be devised to alter the signals from the OBM first element transducers:
  - block up totally, partially or otherwise interfere with the proper operation of first element transducers (i.e. those providing the signals from the primary HV component that is used to determine mass on the OBM system) to simulate readily-available tampering techniques.

Task 9

- alter the ride-height control valve/s by a significant but not dangerous amount.

Task 10

- if a turntable slider is fitted, shift the slider to the opposite end of its travel from the position in which the OBM systems on the HV were calibrated.

Task 11

- drain the fuel tank leaving just enough fuel to complete the test circuit.

6.2.2. Initial conditions and associated tasks

The test HV(s) will be delivered to a nominated site and allowed to cool down from normal operation (cold start) with:

- a full fuel tank;
- the turntable slider (if fitted) in the position that it was in when the OBM was calibrated;
- a dynamic reference system installed;
- two static reference systems installed; and
- the OBM system under test installed.

The OBM team:

- Task 1.

6.2.3. Tasks at tare load

The OBM team:

- Tasks 2, 3, 4, 5, 6 & 7 for 6 readings *per* task.

6.2.4. Tasks at 1/3 load

The OBM team:

- Tasks 2, 3, 4, 5, 6 & 7 for 6 readings *per* task.

6.2.5. Tasks at 2/3 load

The OBM team:

- Tasks 2, 3, 4, 5, 6 & 7 for 6 readings *per* task.

6.2.6. Tasks at full load

The OBM team:

- Tasks 2, 3, 4, 5, 6 & 7 for 6 readings *per* task.

No turntable slider fitted:

- for the 7th reading, task 8 then tasks 2, 3, 4, 5, 6 & 7 for one reading *per* task.
- for the 8th reading, task 9 then tasks 2, 3, 4, 5, 6 & 7 for one reading *per* task. Return the ride height control valve/s to normal position.

Turntable slider fitted:

- for the 7th reading, task 10 then tasks 2, 3, 4, 5, 6 & 7 for one reading *per* task.
- for the 8th reading, task 9 then tasks 2, 3, 4, 5, 6 & 7 for one reading *per* task. Return the ride height control valve/s to normal position.
- for the 9th reading, task 10 then tasks 2, 3, 4, 5, 6 & 7 for one reading *per* task. Return turntable slider to the position in which the OBM systems were calibrated.

Final activity for full load test:

- Task 11 then tasks 2, 3, 4, 5, 6 & 7 for one reading *per* task.

6.2.7. Summary of tasks

The flowchart in Figure 3 summarises the flow of the test programme tasks, their precedents and overall requirements.

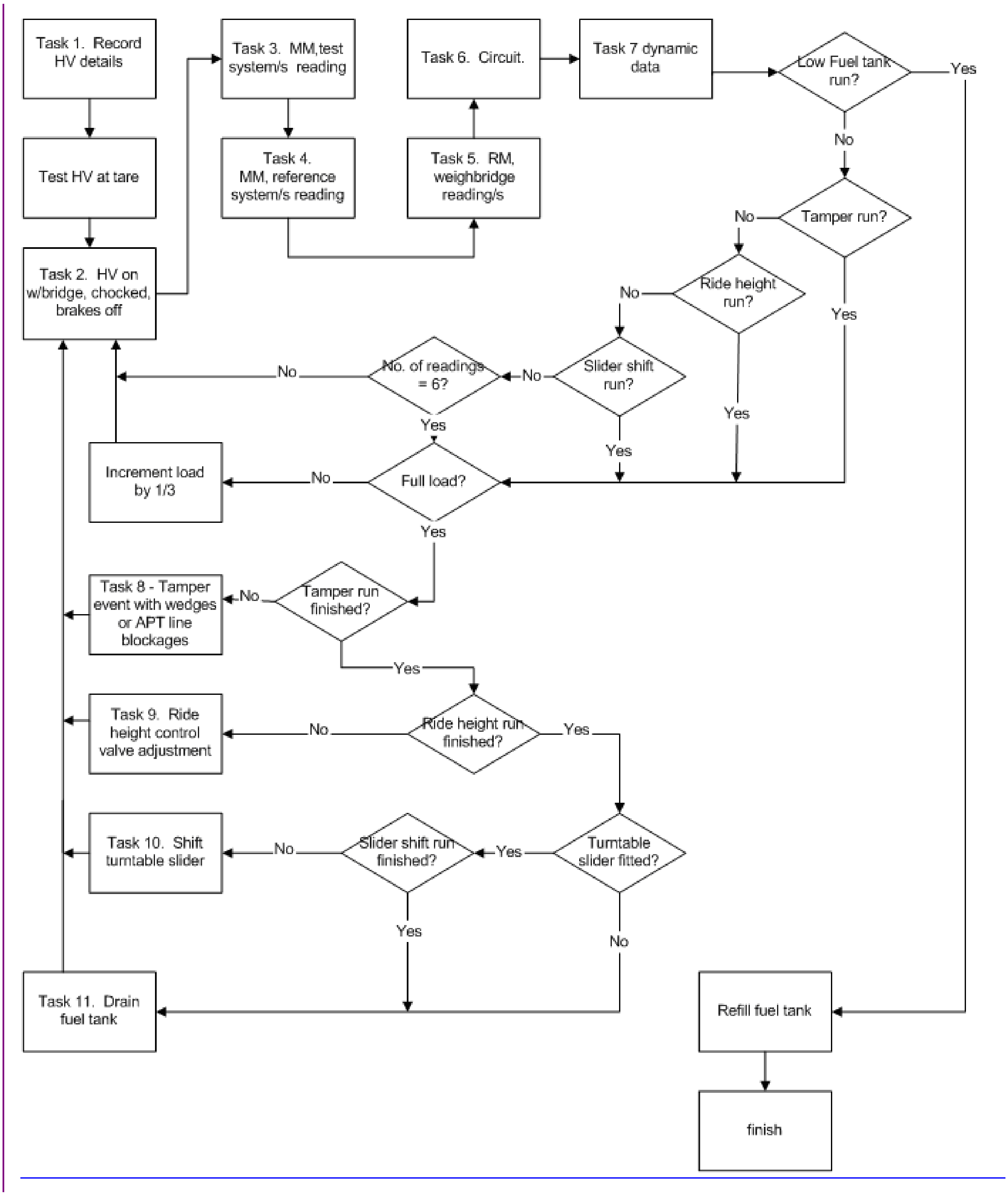

Figure 3. Flowchart of tasks for test programme.

6.3. Summary of this section

The procedures in this section will allow the following analysis to be made:

- Differences in the RM over time to ensure that compensation may be made for any drift or inaccuracy in:
    - the calibration of jurisdictional scales; and
    - the OBM readings due to fuel tank empty *vs*. full.
- Alterations to the dynamics of the signals from the OBM due to:
    - rudimentary tampering;
    - shifting the 5th wheel (if turntable sliders are fitted); and
    - air-spring ride height adjustment.

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the OBM readings due to fuel use

Cross-validation of the manufacturer's VSB11 characteristics against measured frequencies in the test HV suspension will augment investigations into in-service HV suspension testing under the auspices of the joint QUT/Main Roads project *Heavy vehicle suspensions – testing and analysis* currently underway at QUT.

TCA's testing contractor is to formulate such a report as agreed under separate documentation.

7. Societal obligations

7.1. Workplace health & safety

QUT has a workplace health and safety system. TCA has its own workplace health and safety system in place. Any testing contractors used will have their own workplace health and safety system in place. The testing will be done across at least 3 road transport jurisdictions. Each jurisdiction has its own workplace health and safety system in place. When working in any particular jurisdiction, team members will abide by the provisions of that jurisdiction's workplace health and safety system and be guided by the knowledge provided by team members to whom that jurisdiction is their "home" jurisdiction. To the extent that QUT can control a project involving other jurisdictional activities *via* the TCA overarching project, a risk analysis has been performed. This has been defined previously (Davis *et al*., 2008) in the pilot test plan documentation and will be applied, given the above, to this programme.

7.2. Ethics

This has been explored previously (Davis *et al*., 2008) in the pilot test plan documentation and will be applied to this programme.

8. Conclusion

The issue of on-board mass (OBM) measurement for HVs is now prominently on the national agenda of Australian transport jurisdictions.

A project entitled *Technical Feasibility Assessment of On-Board Mass-Monitoring (OBM) Devices* under the aegis of TCA is underway to determine the feasibility of OBM for HVs under the IAP. The results of the programme as outlined in this test plan will inform that project with regard to accuracy, robustness, use of data from other on-board electronic systems and tamper evidence.

Further investigations and analysis of dynamic data will be undertaken to enhance the joint QUT/Main Roads project *Heavy vehicle suspensions – testing and analysis* currently underway at QUT, particularly the previously defined investigations into in-service HV suspension testing.

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Appendix 1 - Test data recording form

Vehicle details			Odometer reading (km):				Comments (e.g. type of OBM system, how many load cells or APTs)
Reg. number	Make	Model	Axle configuration[4]				
			Steer (S)	Drive (D)	Trailer 1 (T1)	Trailer 2 (T2)	

Tare load test	Reading 1								Reading 2								Reading 3								Reading 4								Reading 5							
(tonnes)	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2
Flat, brakes off.																																								
	Reading 6								Reading 7								Reading 8								Reading 9								Reading 10							
(tonnes)	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2
Flat, brakes off.																																								

1/3 load test	Reading 1								Reading 2								Reading 3								Reading 4								Reading 5							
(tonnes)	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2
Flat, brakes off.																																								
	Reading 6								Reading 7								Reading 8								Reading 9								Reading 10							
(tonnes)	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2
Flat, brakes off.																																								

2/3 load test	Reading 1								Reading 2								Reading 3								Reading 4								Reading 5							
(tonnes)	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2
Flat, brakes off.																																								
	Reading 6								Reading 7								Reading 8								Reading 9								Reading 10							
(tonnes)	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2
Flat, brakes off.																																								

[4] e.g. tri-axle semi with single drive axle and single steer axle on the prime-mover will be 113, two tri axle trailers on a B-Double with tandem drive and single steer axle on the prime-mover will be 1233; an 8x4 rigid will be 22. Note: if desired, the form may be amended so that details of individual units in combination can be recorded, as well as individual axle group masses, if the original intent of the data to be recorded is not altered.

Full load test	Reading 1								Reading 2								Reading 3								Reading 4								Reading 5							
(tonnes)	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2
Flat, brakes off.																																								
	Reading 6								Reading 7								Reading 8								Reading 9								Reading 10							
(tonnes)	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2	RM S	MM S	RM D	MM D	RM T1	MM T1	RM T2	MM T2
Flat, brakes off.																																								

Appendix 2 Definitions, Abbreviations & Glossary

Terms, abbreviations and acronyms	Meaning
Accuracy	Accuracy is the relationship between a measured value and a reference. Increasing system accuracy comes from the measured value approaching the reference. See Figure 4.
APT	Air pressure transducer. A device for emitting an electrical signal as a proportional surrogate of input air pressure.
ARRB	Australian Road Research Board – now privatised, has changed its name to ARRB Group Limited.
ARTSA	Australian Road Transport Suppliers Association.
ATC	Australian Transport Council. "The Australian Transport Council (ATC) is a Ministerial forum for Commonwealth, State and Territory consultations and provides advice to governments on the coordination and integration of all transport and road policy issues at a national level." http://www.atcouncil.gov.au
ATRF	Australasian Transport Research Forum. A conference for presentation of papers and colloquia on matters of transport planning, policy and research.
BIFA	Bilateral Infrastructure Funding Agreement. Also known as the Auslink agreement. An agreement between individual States of Australia and the Commonwealth which "covers arrangements applying to funding made available by the Australian Government to Queensland under the first five-year AusLink investment programme (2004-05 to 2008-09) and any agreed subsequent changes to, and extensions of, the programme. It also covers agreed arrangements for infrastructure planning, identification of investment priorities, development and assessment of project proposals and evaluation of completed projects." (Australia Department of Transport and Regional Services, 2005b).

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Body bounce	Movement of the sprung mass of a truck as measured between the axles and the chassis. Results in truck body dynamic forces being transmitted to the road *via* the axles & wheels. Usually manifests in the frequency range 1 – 4Hz.
CoG	Centre of gravity. The point at which a body's mass may be said be concentrated for purposes of determining forces on that body.
Damping ratio	How much the shock absorbers reduce suspension bounce after the truck hits a bump. The damping ratio, zeta (ζ) is given as a value under 1 (e.g. 0.3) or a percentage (e.g. 30%).
Δ	Greek letter "delta" – denoting increment.
DIVINE	Dynamic Interaction between heavy Vehicles and INfrastructurE.
DoTaRS	Department of Transport and Regional Services. An Australian Government department.
Eigenfrequency	Frequency of a body at one of its vibrational resonance modes.
FFT	Fast Fourier transform. A method whereby the Fourier transform is found using discretisation and conversion into a frequency spectrum.

Fourier transform	A method whereby the relative magnitudes of the frequency components of a time-series signal are converted to, and displayed as, a frequency series. If the integrable function is h(t), then the Fourier transform is: $\phi(\omega) = \int_{-\infty}^{+\infty} h(t) e^{-i\omega t} dt$ Where: ϕ is the Fourier series; ω is the frequency in radians/s; and $i = \sqrt{-1}$ (Jacob & Dolcemascolo, 1998).
GVM	Gross vehicle mass.
HML	Higher mass limits. Under the HML schemes in Australia, heavy vehicles are allowed to carry more mass (payload) in return for their suspension configuration being “road friendly”. See VSB 11.
HV	Heavy vehicle.
Hz	Hertz. Unit of vibration denoting cycles *per* second.
IAP	Intelligent Access Programme. The Intelligent Access Program (IAP) is defined by the TCA as third generation HV access to the Australian network. This approach is intended to complement ‘general’ and ‘restricted’ access with a further layer of ‘intelligent’ access. The IAP voluntary programme provides HVs with improved access to the Australian network. This with the proviso that HVs thus benefited are monitored using GPS tracking or other forms of vehicle telematics to ensure compliance with improved access conditions. (Transport Certification Australia, 2005).

MCV	Multi-combination vehicle. HVs with general arrangement or GVM greater than that of a semi-trailer.
MM	Measured mass. Three MM readings will be taken *per* test, one reading from each of the reference OBM systems and one from the test OBM system.
NHVAS	National Heavy Vehicle Accreditation Scheme. A voluntary scheme that certifies transport operators against a set of industry-specific quality assurance requirements. Membership of this scheme is a pre-requisite for HML.
NRTC	National Road Transport Commission. A national body set up by the States of Australia to facilitate economic reform of the road transport industry. Became the NTC earlier this decade.
NSW	New South Wales.
NTC	See NRTC
MRWA	Main Roads Western Australia.
OBM	On-board mass. A generic term describing the systems used to monitor a HV for its mass using on-board telematics.
OECD	Organisation for Economic Co-operation and Development
Participants	On-board mass suppliers or their representatives in Australia.
PBS	Performance-based standards http://www.ntc.gov.au/viewpage.aspx?page=A023114004005800200
Precision	Repeatability in measurement data. Precision is an assessment of the variation in measurement of the same value. The more precise measurements are, the closer together their measured values. See Figure 4.
QDMR	Queensland Department of Main Roads
QT	Queensland Transport

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QUT	Queensland University of Technology
Reference system	An OBM system supplied by TCA and installed on all test HVs to provide a consistent set of data across all test HVs for the purposes of comparing the MM of the reference system to the MM of the test system and the RM. Note that there will be three MM readings *per* test, one from each of the reference OBM systems and one from the test OBM system.
RFS	"Road-friendly" suspension. A HV suspension conforming to certain limits of performance parameters defined by VSB 11. (Australia Department of Transport and Regional Services, 2004)
RM	Reference mass. The mass reading from the certified scales. See measured mass (MM).
RTA	Roads and Traffic Authority, NSW
SPV	Special purpose vehicle (e.g. cranes or low-loaders)
TCA	Transport Certification Australia Limited. Established in 2005 as a public company. TCA members are the road authorities of the Australian, State, and Territory governments. TCA supports the development and implementation of the IAP and administers the IAP including legislative, policy and administrative issues. (Transport Certification Australia Ltd, 2007).
Test OBM system	The OBM system under test.
TSA	Transport South Australia
VSB 11	Vehicle Standards Bulletin 11. A document issued by DoTaRS that defines the performance parameters of "road-friendly" HV suspensions.
WiM	Weigh-in-motion. Technology that uses sensors in the road to measure the wheel-force of vehicles.

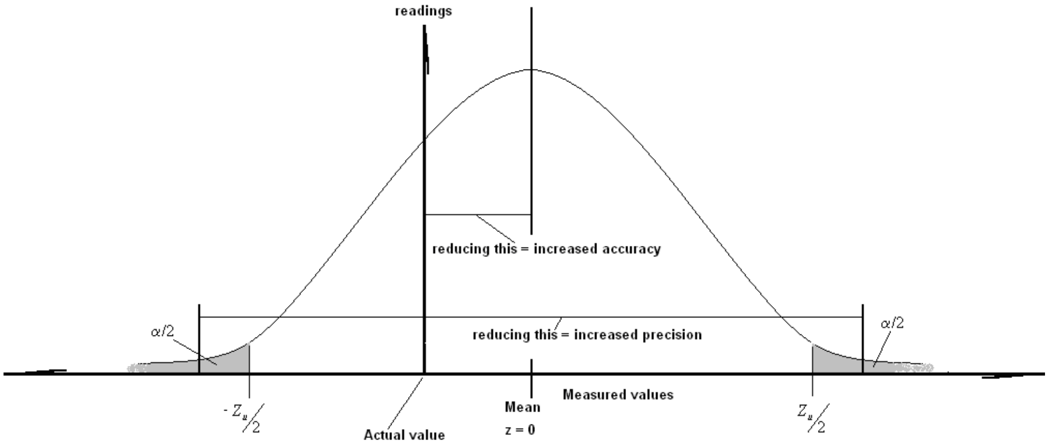

Figure 4. Visual interpretation of accuracy, precision and tails used to derive critical values for degrees of confidence.

Appendix 3 Sample size

Assuming that the spread of the readings from the test cases in the proposed testing, *viz*: tare, 1/3, 2/3 and full load; will have a normal distribution around a mean value, an appropriate sample size (number of readings *per* load condition) may be found for a desired accuracy value and level of confidence that the mean of the population of OBM systems, as a whole, will not differ from the measured mean of the OBM system under test.

The process of determining sample size requires input values such as the expected (or known from previous trials) standard deviation of the experimental measured values, desired accuracy of the data and level of confidence regarding that accuracy.

The number (n) of samples (readings) may then be determined from the following formula (Snedecor & Cochran, 1967):

$$n = \left[\frac{\left(Z_{u} / 2 \right) \sigma}{E} \right]^2$$

Equation 1

Where:

n = sample size (number of readings);

$Z_{u}/2$ = the critical value of the standardised normal (z) distribution used to determine the level of confidence;

σ = is the standard deviation of the population data; and

E = the desired accuracy (specified error) of the test. This is the pre-defined acceptable difference between the mean of the experimental data and the mean of the total population[e].

The value of $Z_{u/2}$ is determined by the choice of the level of significance known as α which is, in turn, used to derive the level of confidence. The level of confidence is usually denoted as a percentage that can be visualised as being bounded by the critical values of +/- $Z_{u/2}$ under the normal population distribution curve in Figure 4 and related to half of the level of significance (α/2) therein. The level of confidence is a value (or percentage) of certainty that the mean of the sample data will be within the specified error of the mean of the entire population.

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The level of confidence is denoted:

1 - α as a value; or

(1 - α) x 100 as a percentage.

For instance, a value of α = 0.1 provides a level of confidence of 0.90 or 90% that the mean value in the sample readings will be equal to or smaller than the desired error of the population mean (Snedecor & Cochran, 1967).

The OBM pilot test plan used an initial value for standard deviation σ of 350 kg (Davis, 2006). Early in the pilot testing a maximum value for σ for OBM readings of 130 kg for loads approximating 22 t was observed. These results and choosing a maximum value of E as 140 kg for loads of approximately 22 t led to the following calculations to choose the number of readings.

To find the number of readings required to determine the mean accuracy of OBM systems for:

- a level of confidence of 95%; and
- a standard deviation σ of 130 kg[f]; with

[e] In this case, the total population will be the total population of OBM systems.

- a desired maximum error E of 140 kg between the test data mean accuracy and the population mean accuracy;

let:

α = .05 (i.e. a 95% level of confidence);

σ = 0.13; and

E = 0.14

=> the area in the region to the left of $Z_{u/2}$ and to the right of z = 0 in Figure 4 is:

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0.5 – (0.05/2) = 0.475;

the table of the standardised normal (*z*) distribution (CTQ Media LLC, 2008) gives a $Z_{u/2}$ value of 1.96;

Substituting into Equation 1:

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$$n = \left[\frac{1.96 * 0.13}{0.14}\right]^2$$

=> n = 3.3

∴ the number of readings for these experimental parameters for each load condition, *viz*: tare, 1/3, 2/3 and full load; will be:

n (rounded up) = 4.

Allowing for a conservative approach to surety, given that 4 is a low number, by adding a margin of (say) 50% to 4; this makes the number of readings 4 + 2 = 6. This

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[f] *i.e.* assuming here that 95% of the population of OBM systems return a mass reading within a maximum range of 260kg either side of the mean. This is a deliberately conservative assumption. *n.b.* this 95% is not the same 95% that was chosen for the degree of confidence in this exercise but relates to the fact that 95% of a normally distributed population will lie between a range two standard deviates either side of the mean.

means 6 repeated readings *per* test load condition without changing any other variables.

This choice of 6 readings was validated in the middle and latter stages of the pilot testing where the values of σ (standard deviation of the test and reference system population data) were about or below 140 kg after anomalous data were removed.

It is noted that the conservative approach of 6 readings will increase the level of confidence and reduce the value of E to approximately 100 kg if the maximum value for σ drops below 90 kg, which was indicated in some of the pilot tests.

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