UTILISING DYNAMIC EXCURSIONS OF MASS (DEM) FROM ON-BOARD MASS (OBM) SYSTEMS FOR MONITORING INFRASTRUCTURE AND TRUCK SUSPENSION CONDITIONS AND THEIR DEGRADATION RATES IN REAL TIME

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Abstract

Monitoring the effects of vehicle suspensions on the roads, and bridges over which they travel, and their complementary significance in the maintenance of these assets, can be measured through Dynamic Excursions of Mass (DEM).

DEM data is automatically generated within suspensions by road irregularities and by badly maintained suspensions so, by capturing it from across the entire road network it is possible to locate the road sections and the suspensions which require immediate or planned maintenance, to extend the life of both.

Other direct benefits are that they show how and when the mass/distance data is changing from historical to other routes as major projects are commenced and as the changing demographics of the population increase demands on roads and freight deliveries.

This paper details how this is done and the cost and safety benefits which come from the timely and effective use of DEM and related data by ensuring it is available over the internet to Infrastructure Owners, their managers and to the Road Transport Operator (RTO) so that they can be proactive rather than reactive in maintaining these assets.

This paper presents the analysis of the results and the benefits in utilising these data sets.

It further proposes that it is important to compare two different sets of data (OBM and WIM) and to combine this information to accurately inform Road Authorities and Road Transport Operators of road and suspension conditions for effective and timely management of maintenance requirements to reduce costs whilst improving safety for all road users.

Keywords: On-Board Mass, high productivity freight vehicles, mass management, mass measurement, asset sustainability, preventative maintenance

1. Background

Onboard Mass Measurement (OBM) systems have traditionally been installed on Heavy Vehicle (HVs) for purposes of, productivity, profitability, monitoring loads and deliveries, reducing the risks of fines from overloading, or penalties for non-compliance (in Australia) with other legislation/laws such as, "Chain- of-Responsibility" and "Work, Health and Safety" and other commercial considerations to ensure safe loading practices are in place every load, every time.

What has not been considered is how all the data which the correctly installed and monitored OBM system can produce and deliver at a time commensurate with the event in any time zone (i.e., in real time) to the Road Authorities and Road Transport Operators, be they state, federal or international, to monitor both infrastructure and suspension consumption rates.

This paper discusses these additional OBM system functions and their use to monitor HV suspension compliance with VSB 11 and the condition of the infrastructure assets which they use or consume (depending on your point of view) as they perform their various freight tasks.

Based on the DEMs (or instantaneous weight changes) generated by road irregularities in any Road-Friendly (air suspension) on any vehicle, this paper will show how all time-related data can be utilised for safety purposes and timely intervention in the repair of these suspensions and the infrastructure over which they travel. It does not exclude steel spring or other data collection devices as outlined in the *Rapp Trans paper of 19. 12. 2013 Study on heavy vehicle on-board weighing, Final Report.*

It addresses the opportunities for "*Co-operative Technology"* to be used in a simple and proactive way between OBM and WIM and various jurisdictions for monitoring speed, weight enforcement, functionality of vehicle suspensions, and asset degradation on a world-wide basis as vehicles traverse borders, state, federal or international. The opportunities to do so are extensive.

Teaming DEMs and GOOGLE earth with GPS co-ordinates turn asset maintenance monitoring into a desk-top operation whilst releasing trained staff for other duties such as introducing timely intervention via *"Co-operative Maintenance"* and for contemporaneously monitoring weight of load compliance everywhere.

The resulting DEM datasets are continuously recorded over several variable time intervals and are correlated with GPS readings, speed and mass limits, the serial numbers of each of the installed OBM systems, vehicle type, registration, and fleet numbers.

Analysis of the variable time intervals will determine which were the most productive in gaining maximum knowledge and benefit from the data, based on the vehicle type, speed, OBM type, types of suspension combinations and the type of infrastructure providing the data.

All DEMs exceeding a pre-set limit automatically undergo an internal self-testing regime for accuracy, tampering and several other necessary parameters for accuracy, enforcement and for comparison purposes with the captured WIM data to accurately inform Road Authorities and RTOs of road and suspension conditions, everywhere.

The RTO of the condition of their suspensions in their HV fleet in relation to VSB 11, (Vehicle Standards Bulletin 11.) and the accuracy or otherwise, of their OBM systems whilst simultaneously informing the Road Authorities of network degradations, their locations and, the efficacy of any repairs all within their jurisdictions.

The objective being to eliminate latency in the repair of the road asset, the vehicle's suspensions the OBM and, in the future any WIM unit. Asset and suspension management could be reduced to days not months with attendant efficiencies in scheduling any necessary repairs and to enhance safety for all road users e.g., imminent, or possible bridge collapse.

This paper highlights the methodology being used to fill the gap between the "current state" of data being reported from the HV fleet and when compared with WIM data to a point where accurate suspension and road network asset condition data is concurrently available.

2. Structure of this paper

This paper draws on data from previous and related papers on this subject, as well as data concurrently derived from forty-six (46) RTOs operating four hundred and sixty-seven (467) different vehicles in various Australian locations over the last two (2) decades (since 2003) all equipped with OBM systems and software designed and manufactured by the author.

The systems report the DEMs derived from potholes, bridges, culverts and their abutments and other road irregularities. The OSOM Low Loader data is typical of such DEM data.

DEM data reports suspensions which need to be re-bushed or have dampers replaced, or both. The person analysing DEM data can readily determine whether it is the road and/or the suspensions causing the problems. Data is easily categorised as it can be cross-referenced between the various DEMs being produced because, if a section of road is in good condition and any suspension/s become active it is those suspensions which need repairs, not the road.

Conversely, if the suspensions are in good condition and become active, then the damping ratio and frequency will confirm the condition or functionality of such in-service suspensions and then it is the road which needs repairs.

NOTE: The term road is used to denote any road, bridge, culvert, or any area over which motor vehicles travel for any reason.

It is also possible for WIM installations to produce DEMs in all the suspensions which travel over it – dependent on the suspension type and its condition.

Certain bridges (a WIM can be categorised as an instrumented "bridge") are known to produce DEMs and can be used as a "test track" to filter out bad from good suspensions – Refer to Krebs and Cantieni's paper – Dynamic Vehicle Bridge Effects presented at the OECD DIVINE Asia-Pacific Concluding Conference in Melbourne November 5-7, 1997.

This co-operative data sharing of the DEMs and the loaded mass on each of the axle groups enables this technology to compare calibration data between each OBM and WIM and cross-reference same for accuracy, tampering and in-service compliance of the OBM system and the vehicle's suspensions.

The dual benefits are timely and scheduled repairs for both suspensions and infrastructure assets and thus avoid catastrophic events such as the bridge collapse in Pittsburgh USA on the 28th of January 2022.

Figure 1 – Pittsburgh Bridge collapse on 28th January 2022 – see below:

https://www.9news.com.au/world/bridge-in-pittsburgh-collapses-hours-before-scheduled-biden-visit-to-talk-infrastructure/99428f71-3c6e-4ce1-86a4-fa7aa8d34d7d

3. Spray and Pray – the Infrastructure Owner's Lament

Do we keep spraying over (spot repairing) the cracks in the road network and keep praying that these temporary fixes will work or, do we ignore them because there is no organised or regulated capture of real time data on road, bridge, or culvert responses to DEM overloads from worn suspensions or, DEMs being generated by rapidly generating structural defects in the assets causing such catastrophic failures, as above.

DEM data is available almost for free as it is being generated by the assets themselves – both stationary and mobile and can be used to prioritise maintenance decisions, accordingly.

The old and un-proven broad-brush approach to maintenance expenditure of "*what was spent 4 or 5 years ago is O.K. if we add say, 5.0 – 6.0% for inflation*" – This is no longer viable due to the age of most of our roadway assets.

This paper details how effective monitoring is being done now and the cost-benefits which accompany same. There is no implementation cost to Road Authorities as the RTO does so at their expense in exchange for higher mass limits and larger vehicle combinations. This has been effective in Australia by allowing higher mass limits in exchange for TMA (Telematics Monitoring Application) and RIM (Road Infrastructure Management) data which clearly demonstrates the cost-benefits to the Road Authorities and the RTO in the effective use of this data in monitoring:

a) *road degradation rates with standard reporting back to road authorities for purposes of early remediation after OBM DEM data thresholds of detected road damage are reached,*

b) *excessive HV suspension wear with accompanying reports of any faults being made available to HV operators for timely repairs and or maintenance to reduce asset damage,*

c) *re-calibration requirements, tampering, and other OBM data as to the quality of the DEM and of the static mass data being produced (called MQRs – Mass Quality Records),*

d) *post remediation monitoring to ensure that infrastructure and suspensions repairs were done, when and, in a cost-effective manner. If the repairs to the roadworks improved the D.E.M. data, this ensures that the work was done, and the expected results have been achieved. If there is no improvement, then the repairs have not achieved the desired result and need re-doing. The same applies to all HV suspension repairs where In-Service Compliance with* VSB 11 *(Vehicle Standards Bulletin 11 for Road Friendly Suspensions) is a requirement for most HML, PBS, IAP etc permitted H.Vs., and finally and, most importantly,*

e) *real time achievable greenhouse gas reductions from less vehicles completing the daily freight task with simultaneous reductions of wear in the infrastructure and the HVs suspensions due to timely intervention to prevent catastrophic failures in both,*

(Ref Krebs and Cantieni's 1997 paper page 6 of 13, Fig. 9 to Fig. 14). Below are the current versions of Figure 9 and Figure 10 as Figure 2 and Figure 3 for ease of reference purposes only and to keep the numeric sequence of the Figures intact in this paper, as well.

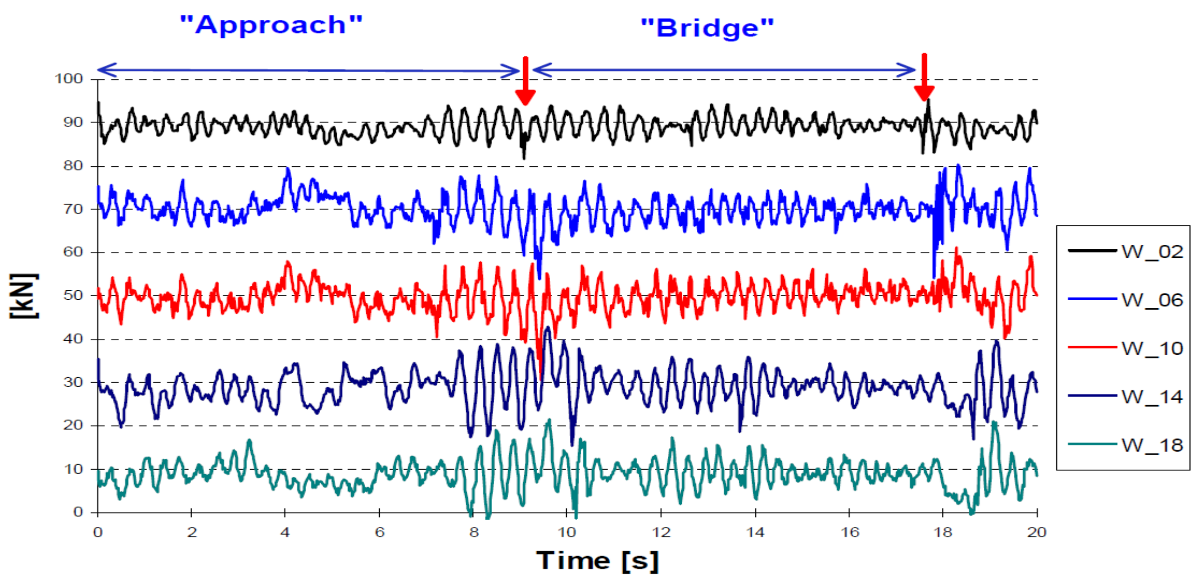

Figure 2 – current versions of Figure 9 from paper updated in 2000

Dynamic wheel load time signals recorded with the steel-suspended vehicle at v = 48 Km/Hr. over Deibuel Bridge.

These two Figures (2 and 3) demonstrate the difference between the Dynamic Wheel Loads in steel spring suspensions and air spring suspensions across the same section of instrumented roadway. The relationship is quite clear as are the amplitudes of the dynamic loads and their respective frequencies of oscillation of the axles in the two different types of suspension groups.

They are included here to show how an OBM system can capture these dynamic wheel loads in the air suspension as the Dynamic Excursions of Mass (DEMs). They have an immediate and direct correlation between the Dynamic Wheel Loads in the Deibuel Bridge but, DEMs can be captured anywhere at any time for little or no cost to the Asset/Infrastructure Owner and to the RTO.

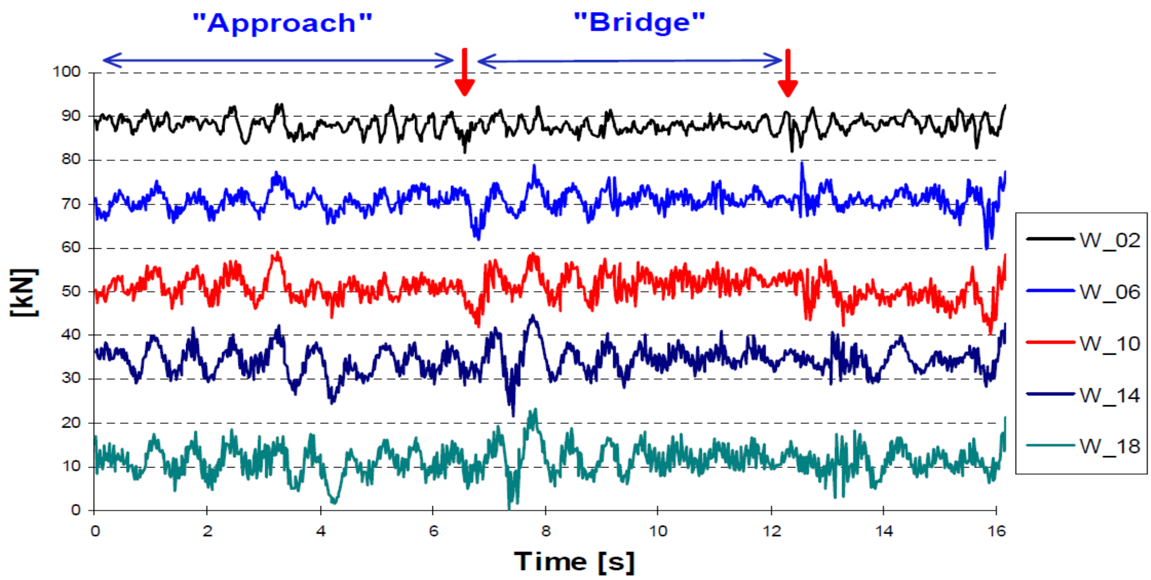

Figure 3 – current version of Figure 10 from paper updated in 2000

Dynamic wheel load time signals recorded with the Air- suspended vehicle at v = 55 Km/hr. over Deibuel Bridge. Krebs, W. and Cantieni, R. (2000).

A "road-friendly" suspension imparts lower magnitude DEMs into the roads. However, the real problem is that when worn, road friendly suspensions can quickly reach a point where they are *very unfriendly* to the road network unless they are kept maintained within the parameters set out in VSB 11. Degraded roads cause compliant suspensions to become overactive and, suspensions in need of maintenance to become excessively overactive.

See Figure 4 over the page.

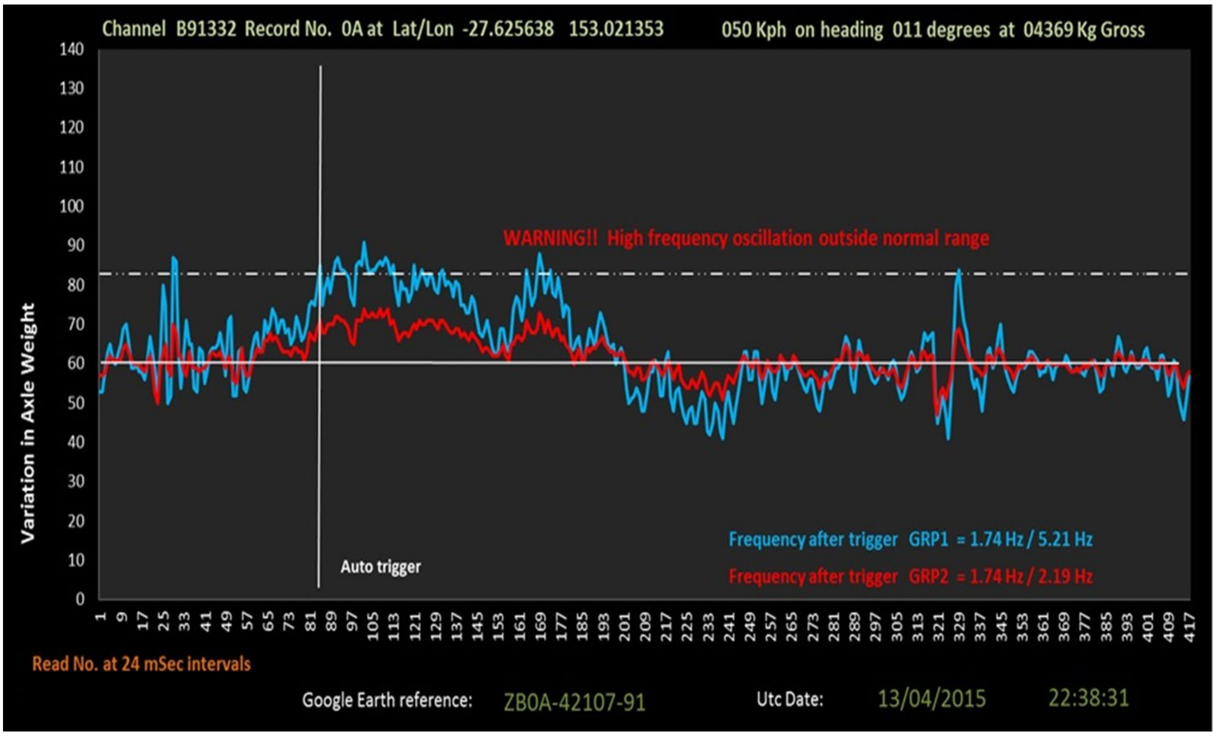

Figure 4 – Typical DEM graph of a badly worn air suspension – lightly loaded at 4,369kgs

Examples of the approach of how to identify Infrastructure Degradations.These following graphs were captured as follows:

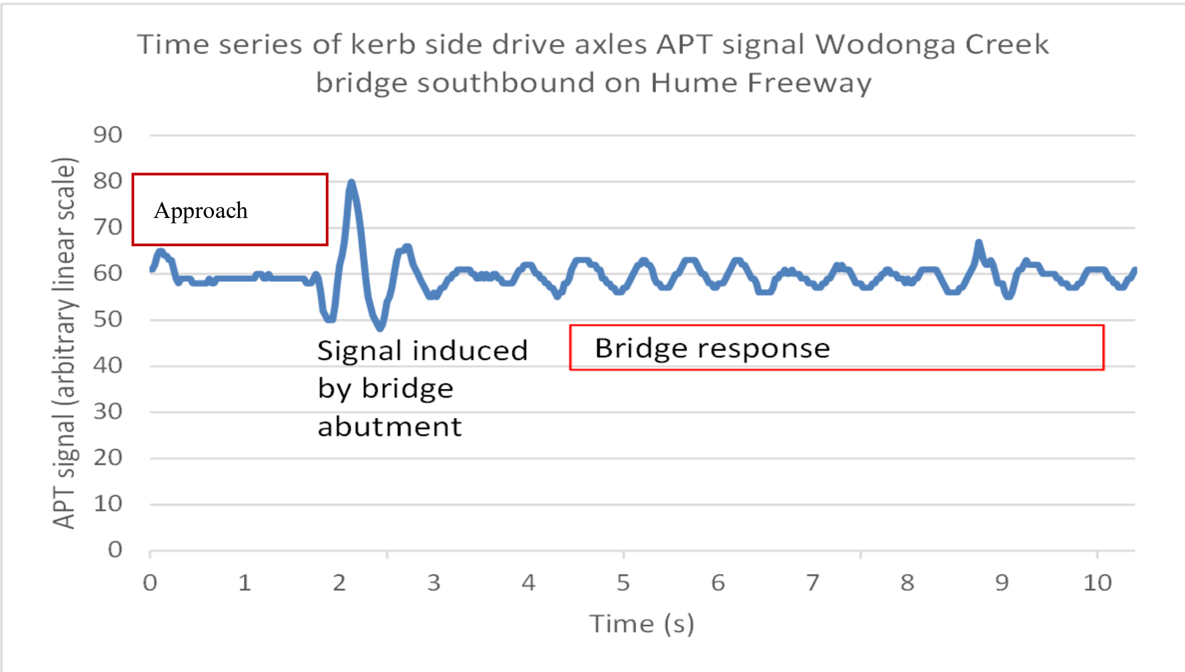

Figure 5 - A typical APT signal for a smooth pavement approach to a bridge abutment in New South Wales and subsequent HV suspension interacting with bridge resonance. Here Eigen frequencies are coming into play with the DEMs after the main impact – see Krebs and Cantineni – Frequency Coupling - Page 9 of 13

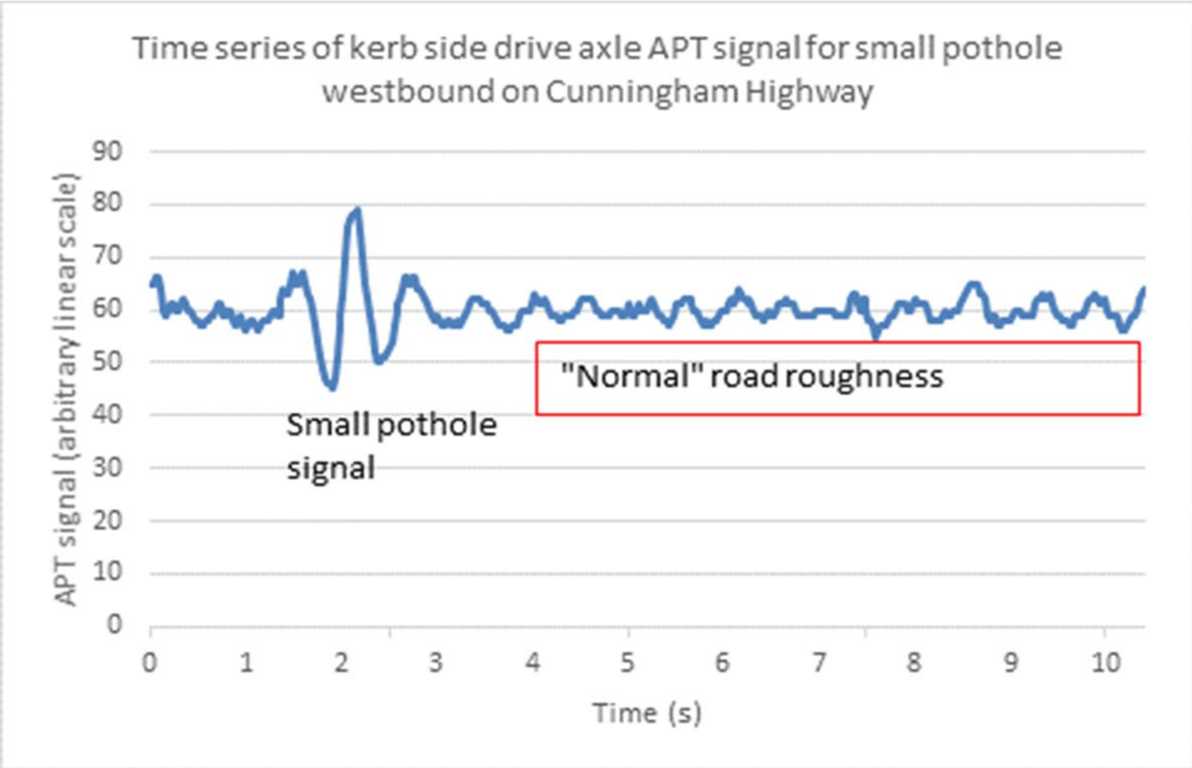

Figure 6 – Typical APT signal from a small pothole for "normal" road roughness
NOTE: An APT is an air pressure transducer whilst an HPT is an hydraulic one.

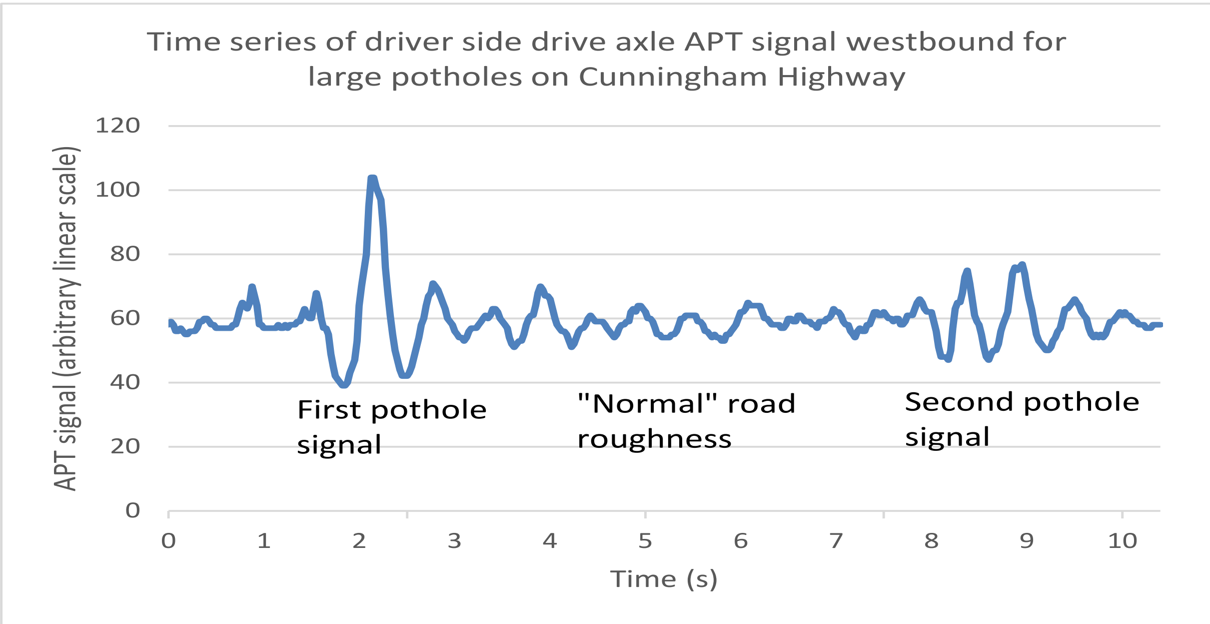

Figure 7 - A typical APT signal travelling over two (2) large potholes in Queensland and with "normal" road roughness in between both.

4. Relationship with Road Friendly Suspension (RFS)

Many papers have been produced over the years on RFS, their wear on the road networks, and regarding why they should be maintained to reduce this directly related pavement damage and wear. But not on how to monitor this in a cost-effective manner – refer to T.E.C. Cotter, D. Cebon, D.J. Cole – Assessing "Road-Friendliness": A Review July1997: page 1, costs to the British taxpayer, and page 9-10 *too expensive for practical implementation.*

For the purposes of this paper any impulse from a bridge abutment, a culvert, or any irregularity in the road network in any condition is a constant input to the HV suspension at that time, at that speed, at that load and at that position on the network.

This paper demonstrates a cost-effective methodology of using captured DEM data signals to remedy the existing problems of where, when, and how to prioritise repairs to the suspensions and to the road irregularities.

DEM signals are constrained by the fundamental laws of physics governing the way the mass of the HV bounces during travel due to the condition of the roads and of the suspensions which travel over them. Captured DEMs are then used to monitor the movement of the HV's axles in accordance with their frequency and the damping parameters of their shock absorbers/dampers. No other consistent work has been done to date using DEM signals from HV suspensions to monitor and to thus predict road network asset degradation save for that presented in this paper.

This paper shows how it is already being done in real time and by associating DEM data with WIM data can confirm the veracity of both sets of data thus making this co-operation an effective low cost, non-intrusive methodology for monitoring compliance and maintenance requirements in all their aspects and it thus becomes a simple daily reality.

For the purposes of consistency and accuracy the following typical examples of this captured DEM data and the ensuing INS-COM (In Service Compliance) graphs are from one of a widely distributed fleet of different HV truck and trailer combinations travelling over various road assets in the three eastern states of Australia of Queensland, New South Wales, and Victoria.

Most HVs are A-Doubles (see Figure 8) equipped with TCA Approved Smart-OBM hardware and software to capture and upload the data to cloud-based servers where the data provides facts on mass, distance, location, speed, etc and including the various wear rates or degradation of the network and of the vehicle's suspensions travelling over them.

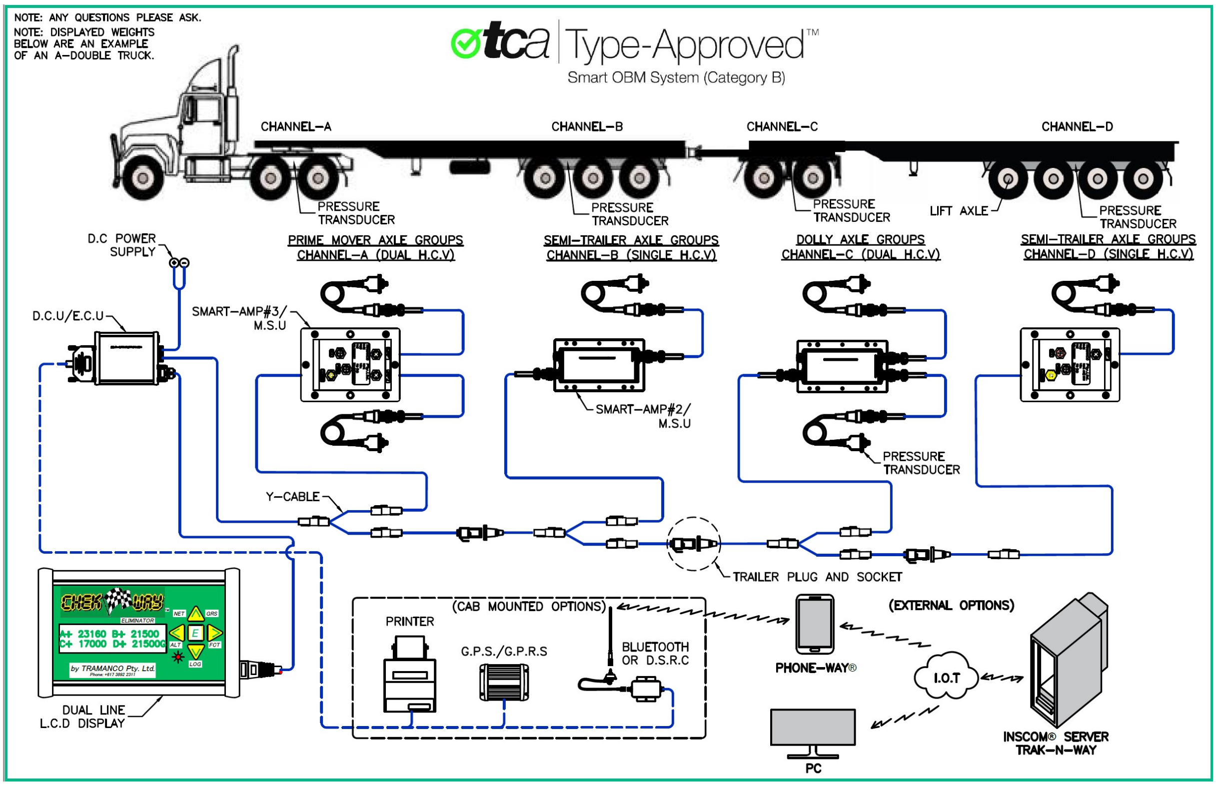

Figure 8 – A typical A-Double installation with OBM monitoring equipment and software

DEM graph Figure 9 of a culvert in New south Wales demonstrates how rapidly roadway degradation can occur. Interventional maintenance saved it from a catastrophic failure event by using the captured DEM data in a timely manner. The explanations of the NOTES pasted on to the Google Earth Shot in Figure 9 are as follows.

The note in the bottom RH corner shows significant impact levels on Feb 7th, 2017. The actual static load of 19,208kgs (captured dynamically) is used as the reference weight which now has a dynamic multiplication factor of 2.01g at the point of impact.

DEMs are referred to in (g) as they represent an equivalent static mass x 2.01 which, in this case produces an instantaneous dynamic weight impact of 38,246kg. At 95kph the now reduced initial impact weight will be first returned to the road at approximately 13.4m from the initial impact zone by the prime mover's suspension group, followed by the lead trailer, the dolly, and the rear trailer suspension group's impacts. Each DEM impact decreases exponentially every 13.4m until it falls below the variable preset value at interval 137 on the Y-Axis.

NOTE: This suspension is in good condition (ref VSB 11) as the bounce frequency is 1.81 Hz on each side of the suspension therefore it is the road/culvert causing the DEMs of this magnitude.

The note at the top RH corner on March 5th, 2017, less than a month later shows how rapidly road irregularities can degrade with sometimes catastrophic results. Here the DEM at 91kph is now 2.36g and with a static mass on the suspension of 23,412kgs this becomes an initial impulsive load of 55,252kgs being returned to the roadway at 12.6m away from the initial impact point/zone and reducing in magnitude as above. In this instance the suspension has had the repairs done to it as the ***Smart-AMP I.D.*** **A91321** on the prime mover is the same.

The bounce frequency has reduced to 1.54Hz which has also enabled the suspension to have a Damping Ratio within the VSB-11 requirements of above 20.0%.

The actual longitudinal impact zone of 13.4m to 12.6m away from the initial impact clearly proves the existence of what Potter, Cebon and Cole refer to in their 1997 paper in **3** ROAD DAMAGE ISSUES. **3.1 Spatial repeatability** as suggested on page 4 of their paper by Hahn [15]

This March 5th event was immediately reported to RFNSW (Road Freight for NSW) and just two (2) days later (7th March 2017) the culvert was being replaced/repaired.

The driver manually triggered a DEM capture at the same location on 29th March 2017 at 07:19:25 – see note at top LH corner. The impact zone had now *moved* further away along the roadway. It is probably the abutment joint between the old and the new bitumen (Macadam) roadway, which is the likely result of another not entirely successful, ***Spray and Pray*** effort.

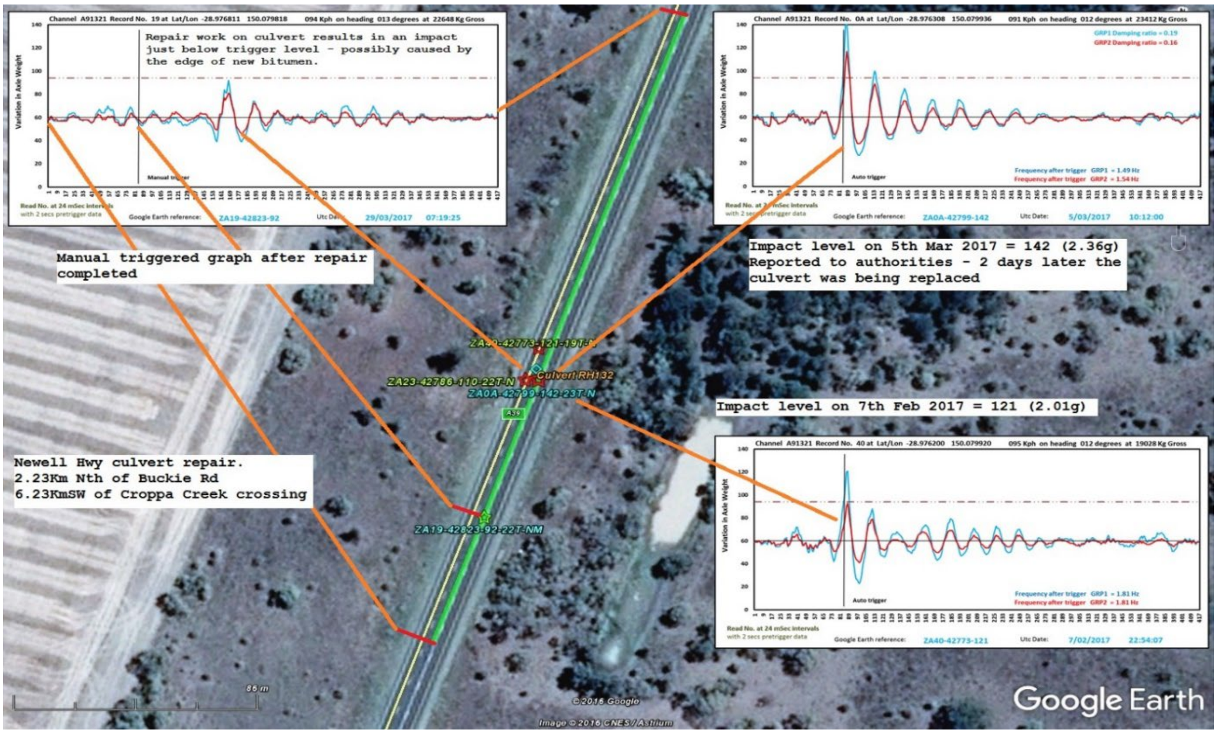

Figure 9 - Newell Highway culvert degradation and repair in New South Wales

Capturing DEMs proves the efficacy or otherwise of all road repairs and their longevity such as in 2008 when a section on the Hume Highway in Victoria was also identified by DEMs as in need of urgent repairs. An outside contractor had previously repaired the section for VicRoads and within weeks the DEMs were reported to VicRoads at much higher values than before.

A subsequent visit by a VicRoads engineer to familiarise himself with the OBM system and its software, then a physical inspection of the section of road proved the captured DEMs from the repaired section were correct. VicRoads had the contractor re-do further repairs at their cost and the DEMs saved VicRoads from another, over $300,000.00 + repair bill (in AUD 2008 $'s).

The following Figures (10 to 13) present DEM data from suspensions whose in-service compliance has failed due to on-going component failures. Therefore, this reported DEM data is incorrect. All DEM site data from every vehicle is also compared to that from other vehicles which have traversed the same road so that the data can be recognised as either derived from the road irregularity or from worn suspensions. With co-operative technology the DEM road data could now be compared to the DEM suspension data from WIM installations (if available) to act as a secondary confirmation of - ***Is it the road or, is it the suspension?***

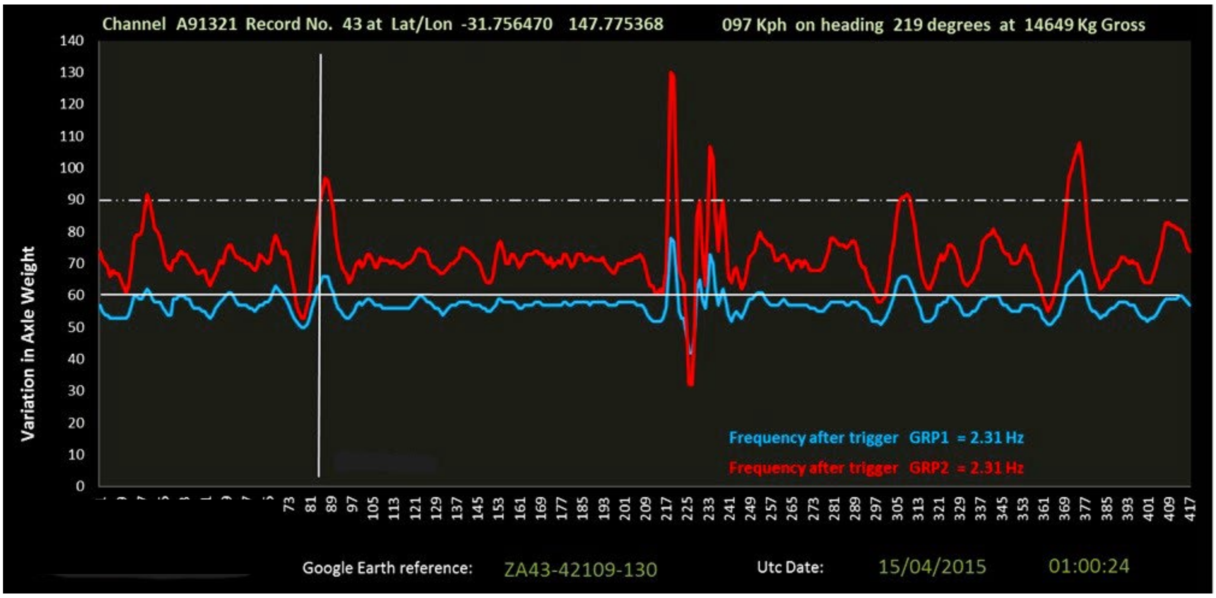

Figure 10 This prime mover's suspension (A91321) has an air leak on the LH side airbags/air springs (GRP2). It was subsequently repaired.

The following Figures 11 to 13 are from a trailer suspension in need of urgent repairs and whose data needs to be "rejected" as it is not degradation of the roadway.

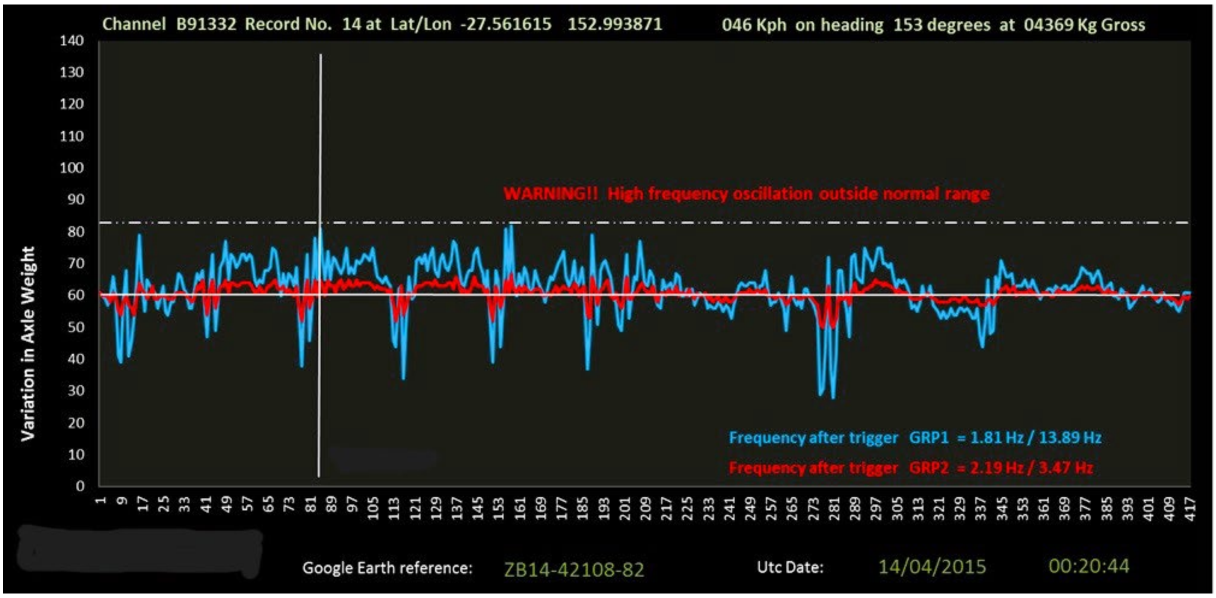

Figure 11 This trailer suspension (B91332) has faulty suspension bushes and shock absorbers and was subsequently repaired by replacing them.

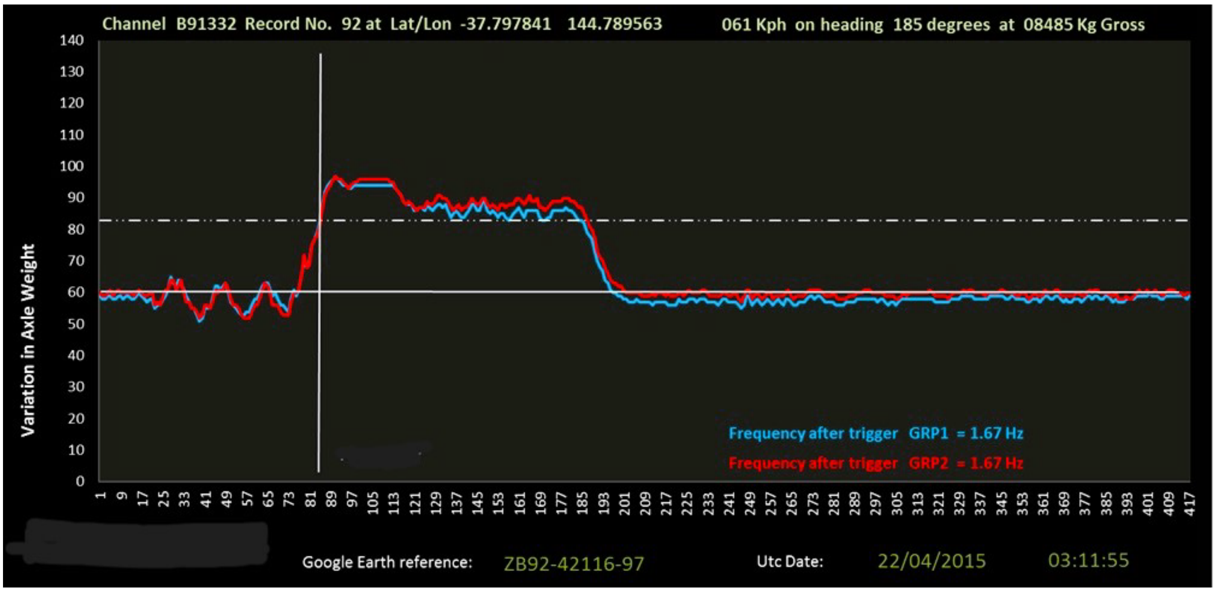

Figure 12 The same trailer suspension (eight (8) days later) now has problems with its Height Control Valve and/or its mechanical linkages which are causing (HCV) flutter.

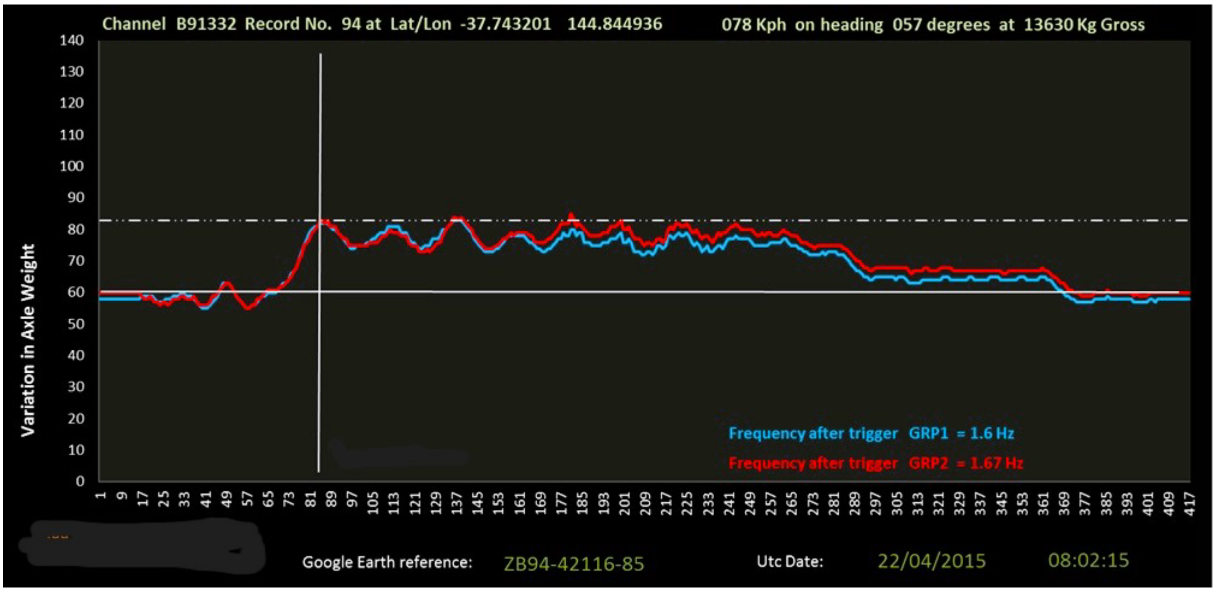

Figure 13 This same trailer suspension (5 hours later) still has Height Control Valve (HCV) issues and has now developed leaking air springs/bags, as well.

Each make of RFS exhibits different DEM properties, but all share a common denominator in the DEMs which they produce so, the TMR (Transport and Main Roads Department) in Brisbane decided to trial one of their four rows of four low loaders with a load-sharing hydraulic suspension to capture its unique DEM characteristics of road-friendliness. The prime mover has a load-sharing air suspension on the tandem drive axles.

Hydraulic suspensions are supposedly more precise, with faster load-sharing thus making them more road-friendly. This hydraulic suspension consists of four separate tandem groups per side. Each group has an HPT system down each side, with its own Smart-AMP (Smart Amplifier A-D convertor) or MSU (Mass Sensor Unit). These are interconnected and separated into separate Groups 1 and 2 to enable the collection of individual DEMs to monitor each suspension group's functionality, the weight distribution (side to side and fore and aft) and under or over-loading so that indivisible loads can be correctly distributed before leaving any loading site.

Figures 14 and 15 show the four separate hydraulic suspension groups. Explanatory notes are attached to Figure 14 similar to the annotated DEM air suspension captures on Figure 9. They separately refer to the front and rear RH and LH side suspension groups and are likewise attached to Google Earth shots of the location and of one of the road irregularities (a culvert) which is an unfinished Spray and Pray re-surfacing repair (see – Street view of the culvert)

The Left-Hand side is the near side of the road and in Australia is usually the roughest side, as well. This is shown quite clearly in these DEM captures.

Figure 14 - OSOM Low Loader with Widespread Four Rows of Four hydraulic suspensions. Installed in June 2021

Figure 15 - OSOM Prime mover and Quad Axle low loader (Four Rows of Four) – fully loaded in the depot

5. In-service HV Suspension Testing – often suggested but never implemented

Today's HV suspension metrics contain specific test provisions defined by Vehicle Standard Bulletin 11 (VSB 11: Australian Department of Transport and Regional Services, 2004) for evaluating any suspension's compliance as a "road-friendly" suspension (RFS).

It is a simple, longitudinal, fixed-in-place lift-and-drop test for all new or re-designed single axle suspensions which then extrapolates the low-speed *"type test"* results to *estimate* road and bridge infrastructure damage by HV's multi-axle suspensions operating at highway speeds.

VSB 11 mandates 2.0 Hz as the permitted suspension upper value for damped natural frequency and not less than 20% for the mean damping ratio lower value, viz:

"The frequency of the sprung mass above the axle or axle group in a free transient vertical oscillation must not be higher than 2.0 Hz.
The mean damping ratio DM must be more than 20% of critical damping (Co) for the suspension in its normal operating condition."

Road damage and HV suspension testing experiments are limited by the technology of the day and the assumptions around VSB 11 were derived from the results of last century's HV testing.

So, VSB 11 is limited to an experimental design constrained by technology dating from the last Millennium and allows compliance testing to be performed by a static lift and drop test of a single axle suspension which are then extrapolated to HV multi-axle suspension behaviours at highway speeds without any further in-service testing of these multi-axle suspension groups.

It is also noted that the term *Road-Friendly Suspension* is in one way a misnomer. Certainly, some suspensions are more so than others but, all RFS vehicle suspensions regardless of design or age are designed to be *Load-Friendly* be they transporting passengers or cargo.

When the suspension goes into service – how does any operator know when to repair them? The short answer is – they really don't, until someone notices that something has failed.

The problem is that once placed into service, Australian road authorities do not implement (require) any comprehensively enforceable in-service suspension functionality test other than a voluntary maintenance regime which may or may not involve replacing bushes and exchanging old shock absorbers (dampers) for new ones.

One of the suggestions examined for in-service compliance testing of HV dampers was to have fully loaded HVs subjected to tests by lift-and-drop devices, possibly placed at the side of the roads where loaded HVs were stopped, lifted, and then dropped to check if the damped natural frequency and damping ratio from the generated *impulse loads captured only in the lift-and-drop device* could determine if the HV's suspensions needed repairs. Actual physical tests with this lift-and-drop device in which the author was involved, took 6 men to set up the test to try to use the device. After more than 8 hours with no positive results the test was abandoned. Another abandoned idea was that vehicles were to be taken offroad and all shock absorbers removed and sent out for a pass/fail test. If they pass, they could be re-installed.

Neither idea gained industry or government acceptance (Starrs *et al* 2000); one of the factors for non-adoption was undoubtedly that the cost of labour just to test a set of dampers was greater than a new set, and the other was that the lift-and-drop device was a total failure.

Dr. D. Cebon had already recommended an international system of parametric type-testing for “road friendliness” combined with annual in-service testing (Cebon, 1999). Others (Potter, Cebon, & Cole, 1997; Woodrooffe, 1995), agreed. Even earlier, the need to test new generation HVs for characteristics which contributed to their “road-friendliness” was recognised as “probable” (Woodrooffe, LeBlanc, & Papagiannakis, 1988).

What has been ignored under various higher mass limits (HML) schemes and micro-economic reforms in Australia is that “road friendliness” is conditional upon in-service suspensions being maintained to perform within the limits for compliance in VSB 11 – see above.

The real issue was, and still is, how to maintain (or monitor) the in-service “road friendliness” of each vehicle’s suspension group/s, the codification of in-service road friendliness and enforceable testing for same as contained in each Bilateral Infrastructure Funding Agreement (BIFA) between the Australian Government and individually, the Queensland (Qld) Government and the New South Wales (NSW) Governments in 2005 (Australia Department of Transport and Regional Services 2005a & 2005b).

Using financial data from the Queensland Treasury, it was estimated that in Queensland alone, that infrastructure damage costs could be reduced by at least $59 million per year (Davis & Bunker, 2007) if effective testing of HV suspensions to ensure compliance with VSB 11 was carried out. That figure was determined from the then named Queensland Main Roads Department’s documented cost of repairing infrastructure damaged by HVs that were, through lack of suspension maintenance, non-compliant with VSB 11 (Davis & Bunker, 2007).

The RTA Marulan survey by Blanksby, George, Germanchev, Patrick, & Marsh, in 2006 showed that more than half of the HV’s suspensions inspected on the Hume Highway did not meet at least one VSB 11 suspension parameter. In-service testing of heavy vehicle suspensions – background report for the NTC project: https://eprints.qut.edu.au/19607/1/c19607.pdf

During February and March 2006, the then (RTA) Roads and Traffic Authority of New South Wales intercepted, inspected, and “tested” 150 HVs at the Marulan checking station in (NSW). One hundred and twenty-one (121) of them had air suspensions with loads ranging from 14t to full (21.0t) and:

- 54 % (65) did not meet VSB11 for damping, and
- 16 % (20) did not meet the VSB11 specification for suspension frequency.

Dr. Cebon’s modelling of these tests for the then RTA is shown below in Table 1, as to what will happen to the road network if in-service road-friendly suspensions are not maintained to comply with the parameters as specified in VSB 11.

Table 1: Effect of not maintaining RFS's on total pavement maintenance costs

Load	Share of fleet in which RFS's are maintained			
	100% well maintained shock absorbers	30-40% poorly maintained shock absorbers	50% poorly maintained shock absorbers	100% poorly maintained shock absorbers
a) Statutory mass limits	14-17% decrease	Neutral	4-5% increase	28 – 32% increase
b) Higher Mass Limits (HML)	0-5% increase	15-20% increase	20-30% increase	50 - 60% increase

By using Dr. Cebon's modelling above on the RTA's 2008 maintenance costs of AUD$90M and applied to the length or distance of the two (2) different routes, see (a) + (b) below.

(a) [20 – 30 % x [Main Roads' maintenance budget] x HML route length] plus,

(b) [4 – 5 % x [Main Roads' maintenance budget] x "as of right" mass route length].

Under the BIFA (NSW, Q' LAND & other jurisdictions) there were to be HVs carrying increased mass under HML (Higher Mass Limits) having additional access to over 5,000km of roads in Qld alone, in return for having RFS which are:

1. Subject to an enforceable in-service road friendly suspension maintenance regime
2. Based on a required an in-service suspension test for RFS which was yet to be developed, and
3. The NTC (National Transport Commission) was tasked with determining this requirement (2) for the test.

As at Close of Business on 14th August 2023, some 17.5 years later – nothing has happened.

So, in NSW alone the RTA now called Transport for NSW (Transport for New South Wales) has now spent at least $1.53B ($90M x 17, without allowing for inflation) on road maintenance.

If we now take the two (2) percentages effects of not maintaining RFSs and of the effects of HML of a 15-20% increase in costs which equals between $1.76B and $1.84B and, the 20-30% increase in costs which equals between $1.84B and $1.99B the *unadjusted maintenance cost for inflation* is almost $2.0B. (See real costs below from Infrastructure Partnerships Australia).

If a low-cost maintenance regime proposed by previous advocates and based on Dr Cebon's Effect (Table 1) had been introduced the HML extra maintenance costs of well-maintained RFSs could have only increased by 5.0% to $1.6B over the last 17 years delivering a potential saving *at no cost to the RFNSW of $0.4B = $400M.*

The link below outlines what cost savings are available by utilising various other options. by Infrastructure Partnerships Australia.

Quote: *Australian governments spend* ***more than $7 billion maintaining and renewing the road estate every year.*** *States alone invest more than $5.5 billion per annum on road maintenance and repairs, while local governments spend around $1.5 billion".*

A word search by this author did not find any mention of suspensions in this document.

Since then, millions of kilometres have been travelled over the road networks and possibly some millions of words written about road damage, and all this data (information) has been virtually ignored as a low-cost suspension test regime has not been introduced as part of the requirements for H.M.L. on any road network anywhere in Australia.

Until now all other suggested methodologies for in-service compliance have failed the "hardness" test – i.e., *it is just too hard to do these physical tests with any certainty and within any meaningful time frames.* The costs are not predictable as each vehicle must be taken offroad to be inspected, then an arbitrary decision made to test it, or not, and the time delay could be at least 8 hours based on the author's experience. One lift-and-drop device would only allow for 365 vehicle suspensions to be tested every year if the device did not itself need any maintenance and if the device worked. It did not, it was a failure. This meant that only ninety-one (91) complete A-doubles may be fully tested per annum.

Instead, monitoring all HVs with Smart OBM in conjunction with WIM units whilst performing their daily tasks means no unnecessary off-road time and minimal to limited costs all round. Generated cost savings can be used elsewhere for timely road and suspension maintenance and new capital works. Best of all the DEMs are almost "free" as they are produced automatically by the suspensions owned by the R.T.O.

6. Discussion reference the above and reduction in greenhouse gases

The TCA paper on the Port of Brisbane to Toowoomba Road corridor proved truck numbers were halved by simply converting to A-Doubles from B-Doubles with actual reductions in tyre wear, road wear, oil spillage (see link below) and emissions. Monitoring of their DEMs allows smaller, targeted, and timelier road repairs by road authorities and would thus increase safety for all road users, in that pavements, bridges, and culverts would be better maintained.

7. Acknowledgements

There are forty-six RTOs using this Smart OBM system on four hundred and sixty-seven (67) different vehicles capable of capturing DEM data for monitoring road and suspension wear across a range of road conditions and locations in Australia. The rest of the fleets/vehicles are not proactive in this endeavour due to lack of enforcement of compliance testing of in-service RFS being implemented, at this time.

Mr Rod Pilon, owner of Rod Pilon Transport has, since 2005, provided a B-double trailer combination with a Kenworth prime mover for such purposes. Special mention goes to Mr Rod Hannifey who drives this B-Double combination and has been pro-active in reporting of road conditions to various asset/infrastructure owners. Both gentlemen and the other road transport operators whose DEMs have been used in this and other papers are owed a great debt of thanks as they have provided their HV vehicle combinations and their time and vehicles without direct reward of any kind to develop these tests for the greater good.

8. References

Infrastructure Partnerships Australia https://infrastructure.org.au/wp-content/uploads/2016/12/Road- maintenance-Options-for-Reform.pdf

Reto Cantieni and Walter Krebs, EMPA Dubendorf, Switzerland and Rob Heywood, QUT Brisbane, Australia.

EMPA Dynamic Interaction Between Vehicle and Infrastructure Experiment: OECD IR 6 DIVINE PROJECT Element 6, Bridge Research - Final Report / Test Report No 53'031/ 2000.

Reto Cantieni and Walter Krebs, EMPA Dubendorf, Switzerland. Dynamic Vehicle/Bridge Effects OECD DIVINE Asia-Pacific Concluding Conference, November 5-7, 1997, Melbourne, Australia.

Blanksby, C George, R Germanchev, A Patrick, S and Marsh, F (2006) *In-service survey of heavy vehicle suspensions VC71235-01-01 08/2006* ARRB Group; Roads and Traffic Authority: Sydney

Davis, L (2010) *Heavy vehicle Suspensions – Testing and Analysis*. PhD thesis. Brisbane: QUT

Davis, L and Bunker, J (2007) *Heavy Vehicle Suspensions – Testing and Analysis. A literature review*, Brisbane: Department of Main Roads and QUT.

Davis, L and Sack, R (2004) Analysis of heavy vehicle suspension dynamics using an on- board mass measurement system, CD-ROM paper 11 of *Papers of the 27th Australasian Transport Research Forum* Canberra: ATRF.

Bruzsa Laszlo (Les), Sack, R, Shephard, G. (2006) Smart Technologies for the Effective Management of Heavy Vehicles. 9th International Symposium on Heavy Vehicle Weights and Dimensions, the Nittany Lion Inn, State College, Pennsylvania, USA.

Davis, L and Sack, R (2015) Dynamic on-board mass used for monitoring road condition and truck suspensions - Big Data from a widely distributed fleet of trucks Australasian Transport Research Forum 2015 Proceedings 30 September - 2 October 2015, Sydney, Australia Publication website: http://www.atrf.info/papers/index.aspx

de Pont, J J (1999) Suspensions or whole vehicles? Rating road-friendliness, *International Journal of vehicle design 6 (1-4)*, 23

de Pont, J J (2004) Modelling the dynamic wheel forces of the heavy vehicle fleet, *Papers of the International Symposium on Heavy Vehicle Weights and Dimensions, 8* Muldersdrift: IHVTT

de Pont, J J and Steven, B (1999) Suspension dynamics and pavement wear, *Papers of the Conference on Vehicle-Infrastructure Interaction 4*, Zakopane: Institute of Fundamental Technological Research

Karl, C Davis, L Cai, D Blanksby, C Germanchev, A Eady, P *et al* (2009) *On-board mass monitoring test report (final)* Melbourne: Transport Certification Australia Ltd

Starrs, M M Wright, I and Associates (2000) *Evaluation of in-service compliance of road friendly suspensions: final report* Melbourne: National Road Transport Commission

Sweatman, P F Macfarlane, S Komadina, J Cebon, D (2000) *In-service Assessment of Road-friendly Suspensions* Melbourne: National Road Transport Commission

Sweatman, P F (1976) *A pilot study of truck suspension performance. (Internal report No. AIR 1019-2)* Vermont South: ARRB

Sweatman, P F (1983) *A study of dynamic wheel forces in axle group suspensions of heavy vehicles (Special report No. 27)* Vermont South: ARRB

Woodrooffe, J H F (1995) Evaluating suspension road-friendliness *Papers of the Dynamic loading of heavy vehicles and road wear, mid-term seminar* Sydney: Roads and Traffic Authority

Woodrooffe, J H F, LeBlanc, P A, & Papagiannakis, A T (1988) *Suspension dynamics - experimental findings and regulatory implications* In Society of Automotive Engineers (SAE) (Ed), Special publication 765, Warrendale: Society of Automotive Engineers.