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A Review of Brake Performance Monitoring Systems

Authors
M. McCarthy, M. Edwards, A. Deans, F. Amadhe

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Executive Summary

This research investigated the extent to which brake performance monitoring systems (BPMS) can be used for current, conventionally driven vehicles and future automated vehicles to assure their roadworthiness. For current BPMS, the feasibility of improving inspection efficiency and reducing industry costs by substituting their use for roller brake tests carried out as part of safety inspections and at periodic technical inspection (PTI) was investigated. For future automated vehicles, the longer-term outlook and implications for BPMS was considered.

A market review found nine separate BPMS that are available only for semi-trailers and trailers, which measure only service braking efficiency. One further system was found fitted to DAF trucks as part of the electronic braking system, but this did not report service braking efficiency remotely and provided only a driver warning light in the case of reduced service brake efficiency.

Stakeholder engagement comprised tailored questionnaires and interviews covering a range of stakeholder categories and resulted in responses from 22 and 9 organisations respectively. Information from a number of ADS developers was sought, but even after several attempts, no engagement was made with the project. Future research should engage with several stakeholders in this category to validate the conclusions made on this topic.

The current BPMS are only available for trailers. They are not suitable for replacement of the Roller Brake Test (RBT) in the MOT for several reasons, the main ones being that only service brake efficiency is measured, whereas the RBT in the MOT assesses a much greater scope of brake deficiencies, and the service braking efficiency of the trailer cannot be disaggregated from that of the truck. However, for operators using these systems, it is typical that they are used in some safety inspections in place of directly measuring service brake efficiency via a RBT. Among the benefits identified are that BPMSs:

- provide monitoring of service brake efficiency over time, facilitating predictive maintenance and realising the associated operational and safety benefits.
- negate the time, resource, and cost with activities associated with performing a laden RBT such as getting vehicle to test facility and loading / unloading it for test:
    - Note: nature of activity will vary depending on operator circumstances, for example, the operator may have a test facility on site or have to travel a distance to access one.
- as estimated by industry (Logistics UK, 2024), (Axscend, 2025), could result in a benefit of approximately £100 per trailer per year if they are used as a substitute for 3 laden roller brake trailer tests as part of the safety inspection regime for commercial goods and large passenger vehicles.

Substantial variability was found between current BPMSs, particularly with respect to system inputs and how valid brake events are determined. There was also variability in system outputs, a lack of consistent verification/validation of function and no third-party check of compliance of the systems with the standard. Revised technical requirements for the existing Electronic Brake Performance Monitoring Systems (EBPMS) standard (DVSA,

2024) are recommended to ensure an improved minimum standard for current and near future systems on trailers and semi-trailers. Revised requirements for both system outputs and verification/validation procedures against a laden, graduated RBT with controlled brake delivery pressure are specific areas of the standard that could be revised without impinging on intellectual property rights. Improved minimum performance levels would likely increase industry confidence in the systems.

In the near-term future, technical developments may include wheel end / brake temperature and additional wheel speed sensors to provide an indication of location of service braking efficiency deficiencies. Temperature measured by tyre pressure monitoring systems (TPMS) could also be utilised as indicative information for location of issues. This may allow some items to be assessed that are not possible for current systems.

In the longer term, the three major trends of connectivity, automation, and electrification will affect the future of the automotive industry and introduce both new challenges and new opportunities for vehicle braking systems.

For vehicle connectivity, the industry (ACEA[1]) propose a model called the 'Extended Vehicle' (ISO 20077, 2017), which is already deployed by some OEMs[2] (also see Section 6.1.2 for information on the Extended Vehicle model). To assure cybersecurity, OEMs are likely to introduce more security measures which could make access to vehicle data by third parties more restricted, in particular in regard to fitment of third-party devices, such as current electronic BPMSs. This could prevent these devices accessing vehicle data in the future. Precisely how this issue may be addressed in the future is unknown at present, but several potential options can be envisaged, including a potential regulatory route.

Full vehicle automation will likely drive a change to more electronic based roadworthiness testing of vehicles, because at full automation (i.e. SAE level 4 and 5[3]), the automated driving system (ADS) will require verification that the vehicle is in a roadworthy state before (and while) the self-driving functionality is activated, and this will need to be achieved in a cost-effective manner. For the braking system, as well as continuous remote performance monitoring, a self-test performed by the ADS could be a key part of an electronic test suite because it offers greater opportunity for roadworthiness assurance. For example, it could brake individual axles and wheels and thus assess performance at axle / wheel level which is not possible currently for remote performance monitoring systems. However, braking of a vehicle for self-diagnostic purposes on public road would need to be assured to be safe and the enhanced diagnostic capability gained justified before this approach could be implemented.

Electrification is considered likely to exacerbate an existing problem with 'sleeping brakes' because of greater use of regenerative braking rather than traditional friction brakes.

[1] ACEA: European Automobile Manufacturers' Association, see https://www.acea.auto/about-acea/

[2] Original Equipment Manufacturer

[3] Defined in SAE J3016 as 'Level 4 means that the vehicle can perform all driving tasks under certain conditions, without human intervention. Level 5 means that the vehicle can perform all driving tasks under all conditions, without human intervention or a steering wheel.'

However, manufacturers have braking strategies to reduce the risk of sleeping brakes developing. For example, if the friction braking force requirement was low, instead of braking all axles at a low force, which would develop sleeping brakes, one axle could be braked at a higher force to exercise individual axle brakes more and reduce the risk.

While further research is required to understand how to assure and validate the roadworthiness of fully automated vehicles, a potential option is to develop regulation that includes specific technical requirements. These could be incorporated into secondary legislation developed for the self-driving test which the vehicle must pass to be granted authorisation for use. The self-driving test is enabled via the ‘power to authorise’ in Section 3(1) of the Automated Vehicles Act (2024). Specific requirements for the ADS to check the vehicle’s roadworthiness state to permit its use could be included, along with requirements for data availability so that inspection authorities, such as the Driver & Vehicle Standards Agency, could perform independent validation of the vehicle’s roadworthiness.

1 Introduction

The correct performance of the braking system is crucial for vehicle safety and therefore assurance is needed that it, and other safety critical systems, are maintained in a roadworthy condition. Currently, for private vehicles not operated under a licensed scheme, the registered vehicle keeper and vehicle driver are responsible for maintaining the vehicle in a roadworthy condition. Independent assurance that this is done is provided by the MOT. The MOT is a mandatory Periodic Technical Inspection (PTI) performed annually after the vehicle reaches a defined age, which checks that the vehicle's safety and environmental protection systems meet defined minimum standards. For vehicles such as large commercial and passenger vehicles which are generally operated under a licensed scheme, the vehicle operator and vehicle driver are responsible for the maintenance and roadworthiness of the vehicle[4]. As for private vehicles, assurance that this is done is provided by the annual MOT. However, because of the greater safety risks associated with heavy commercial vehicles (greater mileages and increased collision consequences) more assurance is demanded and provided through additional safety inspections which are required to be performed at defined intervals between the annual MOTs.

In recent years, advancements in technology have offered the possibility of monitoring vehicle braking performance while it is in use. These monitoring systems can provide information to help assure the roadworthiness of the braking systems in a more continuous, and potentially more cost-effective manner. This may allow more effective scheduled maintenance of the vehicle which could also help reduce costs.

For fully automated vehicles of the future, there will be no driver in the vehicle - known as no user in charge (NUiC) - to determine that something is not functioning correctly while in use. Furthermore, as vehicles become more technically complex, the safety and control of the vehicle, including the braking system, will be increasingly reliant on electronically controlled systems. Therefore, the need for in-use monitoring will increase because the potential risks will be greater unless they are appropriately managed.

This research is investigating the extent to which in-use monitoring of braking systems can be used for both current, conventionally-driven vehicles, and future automated vehicles to better assure their safety. This includes assessment of potentially improving efficiency and reducing vehicle operating costs by substituting their use for roller brake tests performed in safety inspections and at PTI.

This report details the results of this investigation. It is structured as follows:

- Background
- Objectives
- Task 1 – Technical review of existing electronic brake monitoring systems
- Task 2– Stakeholder engagement
- Task 3 – Analysis and discussion

[4] For the purposes of this document, references to a vehicle also apply to trailers

- Conclusions
- Recommendations

2 Background

2.1 Roadworthiness inspection

According to the Road Traffic Act (1988), a vehicle must be maintained in a roadworthy condition, meaning it should not be driven if it is considered unsafe due to its condition, and it is an offence to drive or allow to be driven a vehicle that does not meet these standards. Many of the requirements for a vehicle to be considered roadworthy are detailed in the 'in-use' regulations which include:

- The road vehicles construction and use regulations 1986
- The road vehicles lighting regulations 1989
- The road vehicles authorisation of special types general order 2003

To help enforce that vehicles are maintained in a roadworthy condition, the following types of scheduled and unscheduled inspection are required:

- Periodic Technical Inspection (PTI) known as the MOT test in the UK (scheduled)
- Roadside inspections[5] (unscheduled)

And for commercially operated vehicles:

- Safety inspections / Intermediate safety inspections (scheduled)
- Daily walkaround check by the driver (scheduled)

2.2 Periodic Technical Inspection (PTI) / MOT test

An MOT test involves a wide-ranging inspection of a vehicle to ensure it meets minimum road safety and environmental standards. The inspection includes brake components and efficiency.

A more detailed description of the scope of the MOT inspection can be found in Appendix A. The main method for inspection is visual, with operation when necessary; for example, the condition of brake friction components such as pads and discs are visually assessed, whereas components such as the compressor, reservoirs and air lines are operated to check them. However, special equipment is used to check some key safety aspects, for example, a Roller Brake Tester (RBT) which is the preferred method, Plate Brake Tester (PBT) or decelerometer, are used to check the performance and efficiency of the braking system.

The frequency of the MOT test is annual; the age of the vehicle from which tests have to be performed varies from 1-3 years old, depending on the vehicle class and is detailed in Appendix A.

[5] Note that all vehicles can be subject to roadside enforcement, but the focus is on commercial vehicles

2.2.1 Braking system

The MOT test of the braking system consists of two main parts:

1. Assessment of the mechanical and electrical condition plus operation of braking system components using visual inspection and/or operation as necessary.
   - Virtually all braking system components are assessed in some manner from those used by the driver to control the brakes, e.g. the brake pedal, to those that physically decelerate the vehicle, e.g. the disc / pad or drum / shoe and components in-between, e.g. compressor and reservoir, air and control lines, connections, valves, actuators, etc.
   - Anti-lock braking system (ABS) and Electronic Brake System (EBS) are assessed using visual inspection of parts (e.g. wiring and sensors) and check of warning devices.
2. Assessment of brake performance and efficiency using a roller brake tester (RBT) or by exception a decelerometer.
   - Assessment includes:
     - Service brake performance and efficiency,
     - Secondary (emergency) braking performance and efficiency (if met by separate system)
     - Parking braking performance and efficiency
     - Endurance braking system (retarder) function where possible.

     Note: Unlike RBT, decelerometer cannot assess performance of individual wheel brakes
   - RBT Performance assessment for service brake includes:
     - Bind (service brake only) - check if brake effort recorded when brakes not applied
       - Failure if brake bind > 4% measured axle weight.
     - Time lag - check to ensure brake mechanism not sticking indicated by abnormal time lag before increased reading obtained. Note: can also be indicated by abnormal variation in brake effort (grabbing)
       - Failure judged by vehicle inspector
     - Ovality – for steered axles only, check for excessive fluctuation in braking effort as each wheel rotated.
       - Failure if difference > 70% between highest and lowest brake reading at steady pedal pressure
     - Imbalance - check on percentage variation of brake effort for brakes on same axle
       - Failure if brake imbalance > 30%
     - Max force (wheel brake effort) - check meets minimum

- Failure if maximum force recorded < 5% of measured axle weight

- Efficiency - calculated from maximum brake effort measurements expressed as a percentage of the vehicle's gross weight. The performance limits are:
  - Motor vehicles >= 50% Design Gross Vehicle Weight (DGVW)
  - Semi-trailers >= 45% Design Total Axle Weight (DTAW)
  - Draw-bar trailers >= 50% DTAW

For accurate measurement of service brake efficiency, a major issue is the vehicle's wheels locking which limits the maximum brake effort recorded. Since January 2023, to help prevent this problem, the MOT test for commercial goods and passenger carrying vehicles (with some exceptions), must be laden, ideally to at least 65% and not less than 50% of its design axle weight to each axle. This does not include vehicle front axles. It can only be tested unladen if it cannot be loaded due to design limitations or the type of load it normally carries; for example, coaches and furniture HGVs which don't have sufficient floor strength unless the load is distributed.

For testing of unladen vehicles concessions based on wheel locking can be applied. These include:

- Front wheel lock allowance: this considers the weight transfer to the front axle(s) that occurs when the vehicle is on the road.

- Passing on locks (locked wheels): if more than half the wheels on a system lock, then the vehicle will pass on locks, unless there is another reason for failure.

- For unladen tri-axle semi-trailer the minimum total brake force that the service brake must achieve depending on the number of wheels that lock during the test (see Table 2.1):

Table 2.1: Number of wheels locking and minimum brake force required

Number of wheels locking	Minimum total brake force required
6	3,000 kg
5	3,600 kg
4	4,200 kg
3 or fewer	Normal; laden trailer requirements apply

2.2.1.1 *Analysis of MOT test data*

To help understand better the potential of brake performance monitoring systems (BPMSs) to substitute for brake items within an MOT test, DVSA supplied TRL with an extract of data that identified braking defects from MOT tests for commercial vehicles (HGVs, trailers and PSVs) for the period of March 2023 to January 2025 inclusive. The data was supplied in an excel spreadsheet with a separate row for each deficiency and columns containing information about the inspection manual deficiency reference, the test date, the vehicle type, and a unique test reference so that the volume of deficiencies could be associated a specific test record.

Using the HGV and PSV MOT manuals (DVSA, 2024b; DVSA, 2024c), the following braking system deficiencies were identified and associated with either Part 1 assessment (visual inspection and operation) or Part 2 assessment (using a brake tester) of the MOT brake assessment as defined in the Section 2.2 above (see Table 2.2).

Points to note:

- It was assumed that deficiency 71.1.d.v ‘specified brake effort is not met’ was in fact the specified brake **efficiency** not met.
- Realistically, current brake performance monitoring systems can only check for service brake efficiency (71.1.d.v). However, it should be noted that if a single brake is not functioning (or if there are other braking defects) to the extent that the overall brake efficiency is lowered, then this will be detected by current BPMS. In the example of a single brake not working correctly, this may be detected in the overall braking efficiency, but current BPMS cannot locate the issue to the wheel or axle level, or diagnose the cause to a specific defect type.

Table 2.2: MOT brake deficiencies reference number and description as defined in HGV and PSV inspection manuals

Ref. No.	Description of MOT brake deficiencies	MOT part association	Can a current BPMS inform on this item?
12	Trailer parking and Emergency Brake and Air Line connections	Part 1 (visual …)	No
36	Hand Lever Operating Mechanical Brakes and Electronic Park Brake Controls	Part 1 (visual …)	No
37	Service Brake Pedal	Part 1 (visual …)	No
38	Service Brake Operation	Part 1 (visual …)	No
39	Hand Operated Brake Control Valves	Part 1 (visual …)	No
59	Brake System and Components	Part 1 (visual …)	No
71	Service Brake Performance	Part 2 (RBT)	Partly (see below)
71.1.a	Binding	Part 2 (RBT)	No
71.1.b	Lag	Part 2 (RBT)	No
71.1.c	Ovality	Part 2 (RBT)	No
71.1.d. ii	Little brake effort at wheel	Part 2 (RBT)	No
71.1.d. i	No brake effort at wheel	Part 2 (RBT)	No
71.1.d.iii	Imbalance	Part 2 (RBT)	No
71.1.d.iv	Imbalance steered axle	Part 2 (RBT)	No
71.1.d.v	Specified brake effort (efficiency) is not met	Part 2 (RBT)	Yes
71.2.a	Decelerometer test – brake efficiency is not met	Part 2 (RBT)	Yes
71.2.b	Decelerometer test – vehicle deviates from straight line	Part 2 (RBT) alternative	No
72	Secondary Brake Performance	Part 2 (RBT)	No
73	Parking Brake Performance	Part 2 (RBT)	No

The data analysis was performed as follows:

- The deficiencies listed were filtered to remove ones categorised as minor and advisories, i.e. remove deficiencies that did not result in an MOT fail.
- For trailers, HGVs, and PSVs, the remaining deficiencies were counted and the proportion of those which were 'service brake performance (71)', and 'service brake efficiency' (71.1.d.v) related were calculated.

- For trailers, HGVs and PSVs, the number of tests was counted and the proportion of those in which there was a 'service brake efficiency' related deficiency was calculated.

The results of this analysis are shown in Table 2.3, below. It is seen that the proportion of tests with brake deficiencies in which one of those deficiencies was a 'service brake efficiency', which current brake performance monitoring systems (BPMSs) detect, was 45% for trailers, 20% for HGVs, and 4% for PSVs.

This illustrates that for vehicles fitted with a current BPMS, complementary methods are needed to detect vehicles with brake deficiencies which do not include a service brake efficiency deficiency because these are the majority of vehicles with brake deficiencies, specifically 55% of trailers, 80% of HGVs and 96% of PSVs. It also illustrates that, ideally, future BPMSs will need to assess many more brake deficiencies in addition to service brake efficiency in order to better substitute for an MOT style safety inspection, even though they have the advantage of continually monitoring the vehicle as compared to the MOT annual assessment.

Table 2.3: MOT brake failure analysis results showing number and percentage of braking deficiencies that were 'service brake performance (71)' and 'service brake efficiency' related and number and percentage of tests in which there was a 'service brake efficiency' related deficiency

Vehicle scheme	No. and % of deficiencies All	No. and % of deficiencies Service brake performance (71)	No. and % of deficiencies Service brake efficiency (71.1.d.v)	No. and % of tests All	No. and % of tests Service brake efficiency (71.1.d.v)
Trailer	37,052 (100%)	17,046 (46%)	13,275 (36%)	29,479 (100%)	13,275 (45%)
HGV	35,879 (100%)	11,258 (31%)	5,564 (16%)	27,765 (100%)	5,564 (20%)
PSV	3,720 (100%)	750 (20%)	111 (3%)	3,035 (100%)	111 (4%)
ALL	76,651 (100%)	29,054 (38%)	18,950 (25%)	60,279 (100%)	18,950 (31%)

2.2.2 Roller Brake Test (RBT) issues

For heavy trailers (O4 category), UNECE Regulation No. 13 Annex 4, para 3.1.3. requires the efficiency performance limits of >= 45% for semi-trailers and >= 50% for drawbar trailers shall be achieved without the signal in the control line exceeding 650 kPa. This requirement is important for RBTs because if a signal exceeding 650 kPa is supplied it will potentially result in higher braking forces and an over-estimate of the service braking efficiency or potentially premature locking of wheels, if higher braking force is applied quickly.

Stakeholders have stated that sometimes this pressure is exceeded in RBTs and up to circa 850 kPa seen into the brake actuators when the vehicle's Brake Assist System (BAS) is activated when the brake pedal is fully depressed, or due to the manner in which the brake pedal is depressed. BAS supports the driver during full brake applications by detecting intense braking and supplying the full braking pressure (~850 kPa) into the brake actuators, regardless of the brake pedal being fully applied or not. When the driver releases the brake pedal, the brake assist system terminates the braking process.

Note that whilst the rapid application of a high brake force may also prematurely lock the trailer wheels, even in a laden RBT, in a real-world situation where the vehicle speed is greater, the EBS/ABS will be operational and prevent wheel locking.

2.2.3 Electronic Braking System (EBS) warnings

UN Regulation No. 13 requires the fitment of optical warnings for the driver for electronic braking system (EBS) failures, which include electrical control line defects and transmission line defects, such as low reservoir energy levels. These warnings are available remotely and can be used to complement information from a BPMS to give a fuller assessment of the roadworthiness of a vehicle's braking system. A full list of the warnings is provided in Appendix B.

2.3 Roadside inspections

For commercial vehicles, i.e. HGVs, trailers, buses and coaches, the DVSA stop and carry out checks which include:

- Check of authorised load weights and type of load permitted
- Check of vehicle for roadworthiness and mechanical faults
- Check of tachograph records
- Check driver has a valid vocational driving licence and that it is being operated legally (i.e. with the correct licence).

The aim is to keep unsafe vehicles off the road and check that they are not breaking any rules and regulations. Therefore, vehicles are chosen to be stopped without notice to the driver or operator, not on a random basis, but on the basis that they are more likely to be unsafe and fail the checks.

The check of the vehicle's roadworthiness is essentially the same as for its Periodic Technical Inspection (i.e. MOT), subject to test location / facilities / equipment available, and can be carried out at the roadside or at a dedicated test site.

2.4 Operator licensing

The DVSA supports the statutory duties of the traffic commissioners in terms of licensing and compliance to ensure the safe and proper use of commercial goods vehicles and Public Service Vehicles (PSVs), protect the environment, and promote fair competition through a consistent application of the rules.

A goods vehicle operator's license is required to use a goods vehicle of over 3.5 tonnes gross plated weight or (where there is no plated weight) an unladen weight of more than 1,525kg, to transport goods for hire or reward or in connection with a trade or business. Also, a license is required to carry goods for hire or reward on international journeys when using a vehicle (or a vehicle combination) with a maximum laden weight of more than 2.5 tonnes. A PSV operator's license is required to transport passengers for payment in vehicles designed or adapted to carry nine or more passengers.

The DVSA[6] supports the statutory duty of the traffic commissioners for ensuring that operators of goods and passenger vehicles are compliant with legislation relating to matters including drivers' hours, roadworthiness, operator licensing and the safe loading of vehicles.

There are various types of operator licences depending on the type of vehicle used and what is being transported. For example, for goods vehicles there are three main types of license:

- Standard international licence which allows transport of your own goods, and goods for other people for hire or reward, both in the United Kingdom and on international journeys.
- Standard national licence which allows transport of your own goods on your own account in the United Kingdom or abroad, or other people's goods for hire or reward only in the United Kingdom.
- Restricted licence which usually only allows transport of your own goods within the UK and EU.

Goods licences can authorise the use of different classes of vehicles. For example, a license authorising vehicles over 3.5 tonnes is called a 'heavy goods vehicle license', whereas a license which only authorises vehicles 3.5 tonnes or less is called a 'light goods vehicle license'.

The requirements to hold an operator license include:

- Be fit to hold a licence, considering any relevant convictions and activities.
- Have sufficient financial resources or to be of the appropriate financial standing.
- Have satisfactory facilities and arrangements for maintaining vehicles in a fit and serviceable condition.
- Have ability to obey all the rules:
    - Satisfactory arrangements for securing compliance with drivers' hours rules.
    - Satisfactory arrangements for ensuring vehicles are not overloaded.
    - Ensure drivers have the correct licence and training to drive a goods vehicle.
    - For heavy goods vehicle licences, specify a suitable operating centre at which there is sufficient capacity for heavy goods vehicles used under the licence.

[6] Driver & Vehicle Standards Agency

And in addition, for standard and international licenses:

- Effective and stable establishment – premises in which core business documents are kept.
- Good repute.
- Financial standing.
- Professional competence – effectively a professionally qualified transport manager responsible for managing operations.

To help operators assure that they comply with legal requirements and maintain high standards of operation, it is recommended that they have independent audits performed. A framework for these audits is provided by the Traffic Commissioners (Traffic Commissioners for Great Britian , 2024). Key aspects of the audit include:

- Operational Audit which reviews overall compliance with the terms of the operator licence.
- Driver's Hours Compliance Audit which assesses adherence to regulations governing drivers' working hours.
- Maintenance Audit: which focuses on vehicle upkeep and safety.

2.4.1 Guide to maintaining roadworthiness

Roadworthiness means complying with the appropriate vehicle construction, road safety, environmental and operating standards required by the law in the UK. For a driver and/or operator, it is a criminal offence to use an unroadworthy vehicle on the road.

The 'Guide to maintaining roadworthiness: commercial goods and passenger carrying vehicles', is a document produced by the DVSA in collaboration with key industry stakeholders (DVSA, 2024a). It explains best practice for maintaining vehicles in a roadworthy condition in terms of the responsibilities for roadworthiness, the different types of inspections, inspection intervals, records and data storage, inspection facilities, planner updates and essential reviews. The best practices described contains both mandatory and recommended requirements which are denoted clearly. Although the recommended requirements are not direct legal requirements and hence operators do not legally have to fulfil them, it is strongly recommended that they do unless they can demonstrate that an alternative approach provides a similar level of compliance.

To ensure vehicle roadworthiness the guide requires two main types of safety inspections in addition to the monitoring of in-use performance to identify and report any defects:

- Daily walkaround checks, usually performed by the driver
    - This includes visual checks inside the vehicle such as the view (mirrors, cameras, and glass), wipers and washers, dashboard warning lights, steering, horn, brakes and air build-up; and checks outside the vehicle such as lights and indicators, fuel and oil leaks, tyres and wheel fixings, and security of load.
        - For brake inspection the driver cannot make any assessment of their performance and efficiency, but a BPMS can be used to provide this

type of assessment. However, a driver can check many items related to the brake's mechanical and electrical operation which a BPMS may not be able to do. This can be achieved by visual inspection of components (e.g. twisted and/or chaffed airlines), listening for air leaks, noticing unusual air pressure build-up times, and checking warning lights.

  - If defects are found, they should be reported, and the driver should not commence or restart a journey until they are assessed and rectified if deemed necessary.

- Safety inspections, which include first use and intermediate inspections.
  - Safety inspections are performed at appropriate intervals, depending on the vehicle's use, in-between the annual MOT tests. The maximum interval recommended for safety inspections, which includes the annual MOT, is every 10-13 weeks for lightly loaded vehicles with easy operating conditions. This means that as a minimum, 4 safety inspections are required each year (one of which could coincide with the annual MOT frequency).
    - For brake inspection, with some limited exceptions, at each safety inspection the guide recommends that either a laden roller brake test is performed, or an Electronic Brake Performance Monitoring System is fitted – see Section 4.1.

All safety inspections (including intermediate safety inspections for high wear items) should be undertaken independently from routine servicing and repair so that, as well as providing the operator with the means to determine individual vehicle roadworthiness, they can also be used to assess the overall effectiveness of their maintenance systems. The MOT inspection manuals represent the minimum legal standards for roadworthiness and, together with manufacturers' recommended tolerances for wear limits, can be used as a guide for the scope of and requirements for any safety inspections.

The guide provides recommendations for intervals for safety inspections based on vehicle use, but these can be tailored to suit the operation, both in terms of frequency and scope, if they are effective in maintaining roadworthiness.

2.4.1.1 Safety inspections for braking and electronic BPMSs

Because a high percentage of MOT braking defects are only found during a braking performance test, every safety inspection must assess the braking performance of the vehicle or trailer.

From April 2025, there is an expectation that every safety inspection will include a brake performance assessment using either a RBT, a suitable brake performance monitoring system, or a decelerometer with brake temperature readings.

If an electronic brake monitoring system is not used, it is expected there is a minimum of 4 laden brake tests spread evenly across the year, which can include the annual test.

An electronic BPMS monitors the vehicle's braking performance (specifically the efficiency of the service brakes) whilst it is being used. A compliant report would contain:

- Vehicle identification
- Braking performance value (BPV) expressed as a percentage and its validity
- Data range to which BPV applies
- Graphical report of BPV over period of report illustrating any trend occurring

This information can be used as a substitute for a RBT in a safety inspection. The electronic BPMSs used are expected to meet the industry standard (DVSA, 2024). The main requirements of this standard include:

- Accuracy of BPV reported – margin of error of < 3% and reported with a statistical 95% confidence interval.
- Calculation of BPV – should not use inappropriate braking event data, e.g. events in which the ABS is intervening, but should compensate for the effect of gravity (incline).
- Functionality:
    - to alert the vehicle operator by appropriate means (email or SMS) when vehicle braking performance below minimum prescribed and/or when ABS/EBS reports a fault.
    - to produce a braking performance report for use in safety inspections and store reports for at least 36 months[7].
- Verification - produce an information document verified by a competent person or body which:
        - Details the electronic brake performance monitoring system manufacturer, system name, units used, system variants, software version and explains basic function of system.
        - Details vehicle types on which the system may be installed and any limitations in application or installation.
        - Confirms that the BPMSs can detect underperforming braking system in compliance with requirements defined in standard.

2.4.2 Earned recognition

The DVSA earned recognition scheme is a voluntary scheme to prove that a licensed operator is compliant with legal requirements and maintains high standards of operation. The main requirement is for the operator to use a DVSA-validated IT system for vehicle maintenance and drivers' hours, which monitors a set of key performance indicators (KPIs) and every 4 weeks reports to DVSA if any KPIs are missed. If this happens, DVSA will work with the operator to fix any problems.

[7] Note that this requirement has been questioned by Industry and 18 months may be more realistic

Aspects that are relevant to braking performance include fulfilling the ‘guide to maintaining roadworthiness’ requirements for performing laden roller brake tests at each safety inspection or fitting an Electronic Brake Performance Monitoring System; this is assessed at audit – see Section 4.1. Further details about the earned recognition scheme can be found in Appendix C.

3 Objectives

The project has investigated electronic brake performance monitoring systems (BPMSs) to better understand current and future capabilities, benefits and disbenefits, high-level costs, and feasibility with respect to predictive maintenance, roadworthiness/safety, and periodic technical inspection (MOT). The objectives of the project were as follows:

1. Identify and document the broad range of electronic BPMSs fitted to current vehicles and trailers and investigate future technical developments.
2. An analysis of how vehicle braking data is used today by manufacturers and telematic businesses.
3. A view on the viability for brake performance monitoring systems as an alternative to driver in-use monitoring, safety inspections and the statutory PTI.
4. Identification of the benefits and disbenefits of brake performance monitoring systems compared to the existing methods.
5. A high-level cost quantification of brake performance monitoring systems as an alternative to driver in-use monitoring, safety inspections and the statutory PTI.
6. Information on the feasibility of developing a recognised standard for remotely monitored braking performance systems.
7. Information to inform the future requirements for in-use monitoring for Connected and Autonomous Vehicles (CAVs)

4 Task 1: Technical review of existing brake performance monitoring systems (BPMSs)

4.1 Electronic braking performance monitoring system (EBPMS): Industry standard specification

Vehicle operators and drivers must ensure that their vehicles are roadworthy when used on the public road (see Sections 2.1 to 2.4). An electronic brake performance monitoring system monitors the braking performance of the vehicle combination (specifically the efficiency of the service brakes) and provides a report which is used as a substitute for a RBT in a safety inspection of the trailer (see Section 2.4.1.1) and can also be used for predictive maintenance. The systems used are expected to meet the EBPMS industry standard published by the DVSA. This has been developed as guidance to confirm that an Electronic Brake Performance Monitoring System (EBPMS) can detect an underperforming brake system (DVSA, 2024).

The standard states that *"In providing a system defined within this document as an EBPMS, it is recommended that appropriate elements should, where possible, employ at least the same, similar or equivalent methodologies as those described in ISO 21069"*. ISO 21069 is a standard that specifies a roller brake test for determining the service braking efficiency of road vehicles.

The standard requires the Brake Performance Value (BPV) to be reported and the resulting EBPMS report shall include:

- *a means of identifying the vehicle it relates to*
- *the braking performance value (expressed as a percentage)*
- *the date range to which the braking performance value applies*
- *a graphical report of the brake performance value over the period of the report illustrating any trend occurring*

The braking performance report shall also indicate if the data does not enable a valid braking performance value to be produced.

The requirements specification section contains brief outline guidance on the braking events that should be included in the assessment of the BPV:

The braking performance value shall be derived using a repeatable algorithm and the results shall utilise braking event data in a manner that minimises the effect of braking events, which includes braking event data that could have a negative influence on the validity of the braking performance value

Furthermore, the BPV value shall compensate for the effect of gravity on the braking event data when a braking event occurs on an incline.

The requirements specification section also contains brief outline guidance on the braking events that should be excluded in the assessment of the BPV:

The braking performance value shall not utilise inappropriate braking event data, including but not limited to that generated during ABS cycling, or which includes inappropriate demand pressures or speeds or changes in speed

The standard could be applied to all vehicles, but the guidance has only been developed for semi-trailers and trailers, and aimed at providing a potential alternative method to the RBT to measure brake efficiency.

4.2 Market review

This section of the report presents the findings from the market review of current electronic BPMSs, their capabilities, and provides an overview of these systems.

4.2.1 Methodology

A market review was conducted to collate current electronic BPMSs that are available. This activity focussed on current systems and identified that the available systems were fitted to trailers.

The project team devised a list of relevant and tiered keyword search terms that we determined would produce the most fruitful search and the greatest number of relevant results to analyse and review. Tier 1 were the most relevant terms, which formed the main points of the search. Tier 2 gave more detail and were used to identify further information about BPMS we required. Tier 3 were tertiary terms that were included to produce additional search results from supplementary sources that may not appear in other searches. The search terms identified and used were as follows:

Table 4.1: Keyword search terms

Tier 1	Tier 2	Tier 3
Remote brake performance monitoring & BPM / (S)	Product/s	Market
Electronic brake performance monitoring system & EBPMS	Manual/s	Sales
Brake performance monitoring	Description/s	Guide/s
Electronic braking system	System/s	Example/s
HGV EBPMS	Manufacturer/s	ABS
Trailer EBPMS	Operator/s	List
HGV EBS	Function/s	News
Trailer EBS	Data	Update/s
Trailer EBS	Use/usage	Software
Trailer EBS	Analysis	Diagram
Trailer EBS	Development	Future
Trailer EBS	Full axle	Check/s
Trailer EBS	Wheels/individual wheels	
Trailer EBS	Test/s	

These search terms produced a substantial number of results on the Google search engine, which were reviewed in turn and checked for duplication of reviewed sites and documents. The search yielded a variety of different sources of information on systems on the market and electronic brake performance system function/use. This included but was not limited to; news pieces describing new releases or updates, product descriptions on manufacturer websites, manuals or tool guide for electronic brake performance monitoring products, testimonials on their function, guides/explanations as to how electronic BPMSs work, and lists of products on offer by manufacturers.

From this list of sources, we removed duplicates and reviewed each source to determine its general usefulness and content. Those deemed to be circumstantial, lacking in detail, or irrelevant were eliminated from the list so that the time for a full review could be focused on the most important information.

4.2.2 *Findings*

The literature/market review identified nine separate current BPMSs available on the market, although some of these systems are supplied under different tradenames and/or as part of different fleet management system packages. (see Table 4.2). It should be noted that:

- BPMSs are typically provided as integral components of fleet management systems (FMS). Three distinct BPMS are offered under different tradenames as part of more than one FMS.
- All systems that were identified are designed to be equipped to trailers. The providers state that all these systems are compliant with the electronic braking performance monitoring system (EBPMS) industry standard referenced in the DVSA guide to maintaining roadworthiness document.
- For all the systems identified the suppliers state that they are compatible with the main EBS systems fitted to trailers, namely those from ZF, Haldex, and Knorr-Bremse.

Only one brake performance monitoring system for vehicles other than trailers was identified. This was a brake performance monitoring system which is fitted to the truck, i.e. HGV rigids and tractors, by DAF (SAF Holland). This system is built into the Electronic Braking System (EBS). It works by the (EBS) ECU checking the deceleration of the vehicle during braking and if the deceleration falls below an expected prescribed level, it warns the driver directly by displaying a low brake performance warning on the driver instrument panel. This differs from the other systems identified for trailers in that it measures the braking performance of the vehicle and, if appropriate, warns the driver, rather than measuring the brake efficiency and using telematics communication to report this information primarily towards fleet managers. It is not compliant with the EBPMS industry standard.

Table 4.2: Current brake performance monitoring systems identified in market review

Supplier or trailer manufacturer/ leasing company	System name	System supplied by	Reported compliance with EBPMS industry standard? Yes / No
Axscend	TrailerMaster	Axscend	Yes
BPW	Cargofleet/idem telematics	BPW	Yes
Donbur	Cargofleet	BPW	Yes
Jost-world	Asgard	Vanguarder	Yes
Michelin/ Masternaut	eBPMS or Smart Brakes	Michelin	Yes
Microlise	Trailer Brake Performance Monitoring	Microlise	Yes
Montracon	BPW Cargofleet or Axscend Trailermaster	Supplied by BPW and others dependent on customer preference	Yes
Orbcomm	Fleet Manager/ Transportation Platform	Orbcomm	Yes
Samsara	Part of Smart Trailer	Samsara	Yes
TIP	BrakePlus	ZF	Yes
Vanguarder	Asgard	Vanguarder	Yes
Wielton Group	ABERG Connect (not commercially available currently)	Wielton Group	Yes
ZF	Scalar (Evo pulse)	ZF	Yes

4.3 Current electronic brake performance monitoring systems and how they work

This section contains three sub-sections. The first describes the parts of UNECE Regulation No. 13 which are relevant for understanding how current BPMSs for trailers work. The second sub-section details how the systems work, specifically the main steps taken to calculate the brake performance value (BPV), the outputs provided and their verification / validation. The final sub-section lists the advantages and disadvantages of a brake monitoring system compared with a roller brake test.

4.3.1 Relevant parts of UN Regulation No. 13

The relevant parts of UN Regulation No. 13 to help understand how current BPMSs for trailers calculate the efficiency of the service brake include:

- Provisions for the periodic technical inspection (MOT) of braking systems: Paragraph 5.1.4.
- Braking tests and performance of braking systems – vehicles of category O: Annex 4, paragraph 3.
- Requirements or compatibility between towing vehicles and trailers – requirements for semi-trailers: Annex 10, para 4.

4.3.1.1 Provisions for the periodic technical inspection (MOT) of braking systems

The main relevant provisions are related to the RBT, namely the requirement that, '*It shall be possible to generate maximum braking forces under static conditions on a rolling road or roller brake tester*' (Para 5.1.4.4) and the requirement for reference braking forces (para 5.1.4.6).

Reference braking forces are the braking forces of each axle generated at the circumference of the tyre on a roller brake tester, relative to brake actuator pressure. They shall be determined for a brake actuator pressure range from 100 kPa to the pressure generated under type-0 test[8] conditions for each axle. They shall be declared such that the vehicle is capable of generating a braking rate equivalent to that required for the relevant vehicle (50 per cent in the case of vehicles of category M2, M3, N2, N3, O3 and O4, except semi-trailers, 45 per cent in the case of semi-trailers), whenever the measured roller braking force, for each axle irrespective of load, is not less than the reference braking force for a given brake actuator pressure within the declared operating pressure range.

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[8] A type-0 test is an ordinary performance test on a test track with the brakes cold. It is performed with the vehicle laden at prescribed initial speeds with the engine connected and disconnected. The main performance requirements for the service brake are that a minimum mean fully developed deceleration performance is achieved (≥ 5.0 m/s2 engine disconnected, ≥ 4.0 m/s2 engine connected) and a maximum stopping distance, which is dependent on the initial test speed, is achieved. Trailers also must meet these requirements (engine disconnected) and meet compatibility requirements to ensure that the trailer brakes decelerate its own weight and puts minimal load through the coupling to the tractor unit.

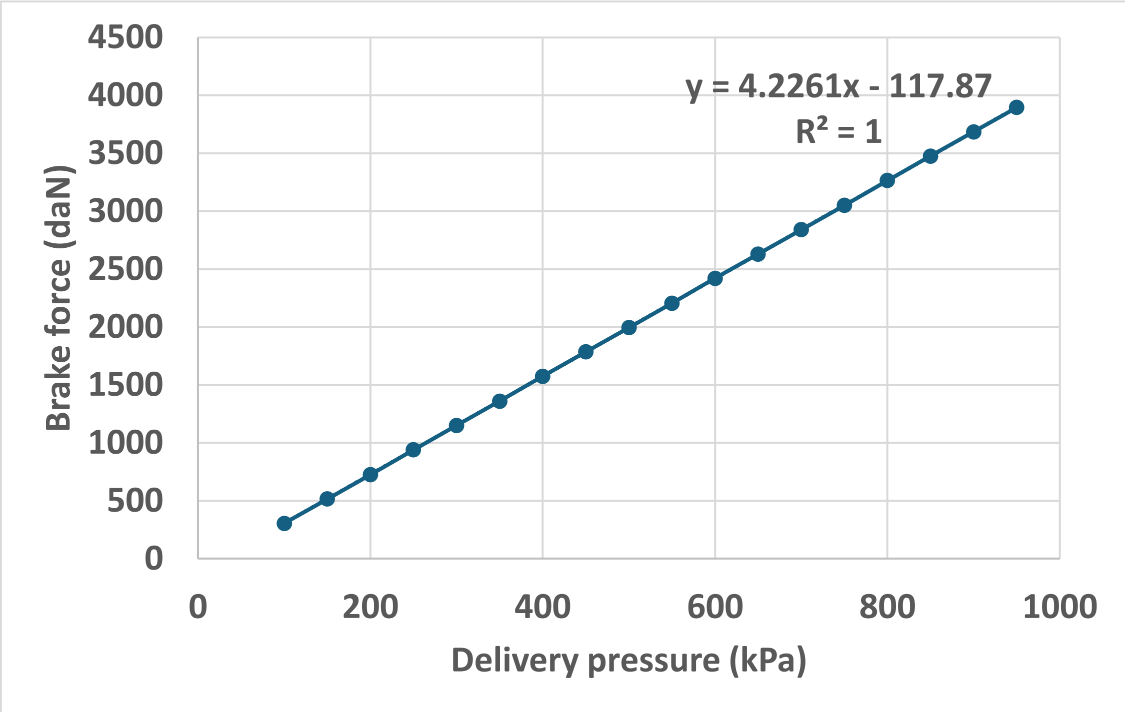

Figure 4.1: Example of reference brake forces for MAN Knorr SN5 disc brake showing linear relationship between brake delivery (actuator) pressure and brake force at wheel circumference

Reference braking forces can be used to calculate[9] the minimum brake forces required in a RBT at lower actuator pressures than those seen in a type-0 test and hence allow valid roller brake tests with less chance of wheel locking. The disadvantages of this approach are that the brake actuator pressure must be measured and reference braking forces for each of the vehicle's axles made available to perform the relevant calculations.

4.3.1.2 Braking tests and performance of braking systems – vehicles of category O

The main relevant provisions are related to the minimum efficiency of the trailer service braking system and the maximum demand pressure at which this efficiency shall be obtained.

Annex 3, paragraph 3 specifies tests and associated requirements for the braking performance of category O vehicles (trailers).

Type 0 tests shall be performed for category O (trailer) vehicles, with the braking performance of the trailer calculated either from the braking rate of the towing vehicle plus the trailer and the measured thrust on the coupling or, from the braking rate of the towing vehicle plus the trailer with only the trailer being braked. The engine of the towing vehicle shall be disconnected during the braking test.

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[9] BS ISO 21995-2008 details the method for performing the calculations

For the service braking system of O_4 trailers it is required that (paragraph 3.1.3.):

- The sum of the forces exerted on the periphery of the braked wheels shall be at least x per cent of the maximum stationary wheel load, x having the following values

	x [per cent]
Full trailer, laden and unladen	50
Semi-trailer, laden and unladen	45
Centre-axle trailer, laden and unladen	50

- If the trailer is fitted with a compressed-air braking system, the pressure in the supply line shall not exceed 700 kPa during the brake test and the signal value in the control line shall not exceed the following values, depending on the installation:
  (a) 650 kPa in the pneumatic control line;
  (b) A digital demand value corresponding to 650 kPa (as defined in ISO 11992:2003 including ISO 11992-2:2003/Amd.1:2007) in the electric control line.

4.3.1.3 Requirements or compatibility between towing vehicles and trailers – requirements for semi-trailers

For a towing vehicle and its trailer to be compatible, ideally the towing vehicle and the trailer should both brake their own weights. To help achieve this, Annex 10, paragraph 4 defines a permissible relationship between the braking rate T_R/P_R and the coupling head (demand) pressure p_m for trailers, which shall lie within two areas derived from diagrams 4A and 4B for all pressures between 20 and 750 kPa, in both the laden and unladen states of load. This requirement shall be met for all permissible load conditions of the semi-trailer axles.

An example of the area derived for a 24-tonne laden trailer with a centre of gravity height of 1.8 m and a length (distance between king pin and centre axle) of 6 m is shown below where:

T_R is 'sum of braking force at periphery of all wheels of trailer'

P_R is 'total normal static reaction of road surface on all wheels of trailer'

p_m is 'coupling head pressure', i.e. demand pressure

T_R/P_R equates to deceleration in units of g

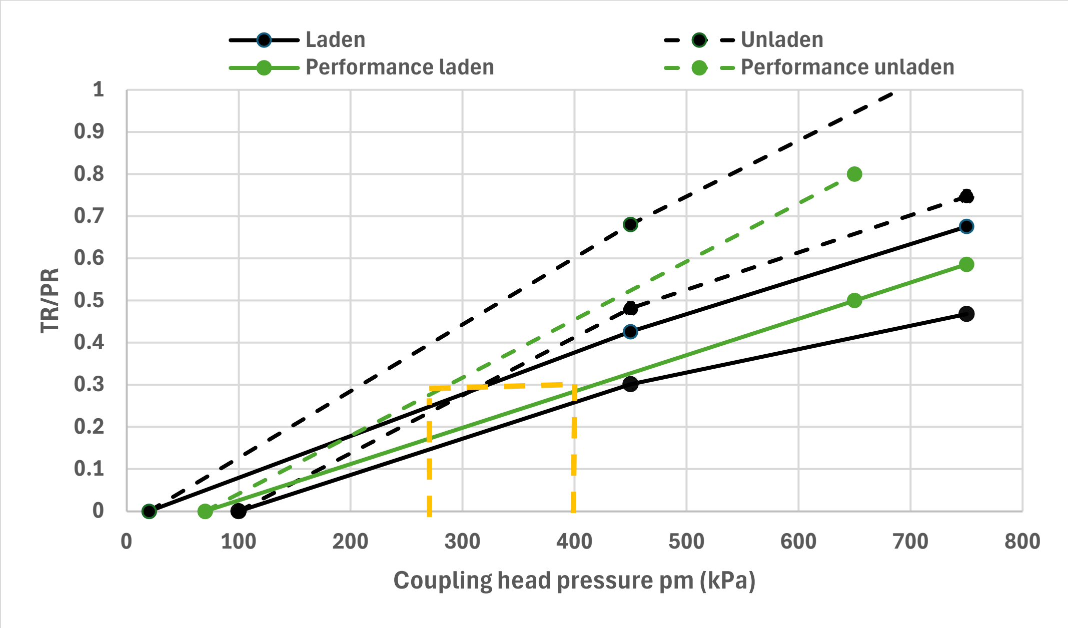

Figure 4.2. Example of braking rate (T_R/P_R) against coupling head pressure (p_m) trailer compatibility requirements for laden and unladen 24 tonne trailer with c. of g. height of 1.6 m. Adjustment of brake delivery pressure by EBS for unladen trailer shown by orange dashed line

It should be noted that the trailer Electronic Braking System (EBS) will adjust the brake actuator delivery pressure to obtain the braking rate (deceleration) associated with a laden trailer for a given coupling head (demand) pressure. The EBS calculates the weight of the trailer from the pressure in the suspension airbags. For example, (see Figure 4.2 dashed orange line) a coupling head (demand) pressure of 400 kPa will be delivered on 1 to 1 basis to brake actuator (delivery pressure) for laden trailer to result in a braking rate (deceleration) of ~0.3 g, whereas for an unladen trailer, the EBS will reduce the brake actuator delivery pressure to ~260 – 270 kPa to result in an equivalent braking rate of ~0.3 g. For trailers without EBS, the load sensing valve will reduce the pressure to the brake actuators for unladen trailers.

4.3.2 Calculation steps

In this sub-section, the main steps that current BPMSs for trailers follow to calculate and output a Braking Performance Value (BPV) are described. Also described are differences and similarities between systems, most of which were discovered during stakeholder engagement.

The braking performance value (BPV) is defined as a value, based upon continuous sampling of data whilst the vehicle is in operation, indicative of the service braking performance of the vehicle and expressed as a braking rate relative to the maximum static axle/bogie load for a given demand pressure

Step 1: Record braking events and other associated data

For the duration of each braking event the following are recorded:

- Time.

- Driver / tractor braking demand pressure to EBS modulator
    - T-CAN, ISO 7638 pins 6 and 7, ISO 11992-2:2023; interchange of digital information on electrical connections between towing and towed vehicles – application layer for brakes and running gear.
- Vehicle speed change, i.e. deceleration.
- Other associated data as appropriate such as:
    - Activation of ABS, and / or vehicle stability control functions.
    - Information to calculate road gradient.

The following are points to note:

- All current systems will record similar braking event data from the T-CAN (or for some systems directly from the EBS trailer unit), but the associated data information recorded, for example that to calculate road gradient, may vary depending on the supplier.

<u>Step 2: Filter recorded braking events</u>

- Delete braking events which are unsuitable for the calculation of a braking performance value (BPV). These include:
    - Events where ABS and /or vehicle stability controls are active
    - Events where it is not possible to calculate a meaningful deceleration value, i.e. a mean fully developed deceleration.
    - Events where demand pressure is not valid, for example too low (< ~ 70 – 100 kPa), or too variable throughout braking event
- If appropriate select relevant part of braking event for calculation of BPV
    - For example, it may be necessary to filter part of braking event where vehicle comes to a stop because decelerations in this part of the event may not be representative. Note that in regulatory braking tests to measure the Mean Fully Developed Deceleration (MFDD) the start and finish of braking events are removed from the data used to calculate it.

The following are points to note:

- During a braking event the demand pressure and the associated vehicle deceleration may change as the driver increases or decreases the pedal pressure to increase or decrease the vehicle's braking. If these changes are within defined limits, i.e. not too large and variable, both the demand pressure and associated vehicle deceleration can be averaged to calculate single meaningful values for calculation of a BPV. However, if changes fall outside the limits the braking event must be deleted.
- All current BPMSs will filter braking events but although some filters, such as deleting events where ABS is active, will be similar, how events are filtered in terms of if a meaningful deceleration value can be calculated may vary between systems from different suppliers. Indeed, this filtering is key to how well the brake monitoring system performs and is part of the supplier's intellectual property.

Step 3: Calculate Brake Performance Value (BPV)

- For each filtered part of a braking event:
    - Calculate BPV as a percentage of g correcting for items such as road gradient if necessary.
    - Record BPV against associated braking demand pressure

The following are points to note:

- The braking rate (deceleration) is calculated from the vehicle speed change measured from the wheel speed sensors and represents the vehicle deceleration.
- As mentioned above in Section 4.3.1.3, the EBS is programmed according to the UN Regulation No. 13 Annex 10 trailer compatibility requirements so that, for a given braking demand, depending on the vehicle loading condition, it will automatically decrease the brake cylinder delivery pressure to provide a braking deceleration equivalent to that for a fully laden trailer, e.g. for a trailer half the weight of a fully laden one, assuming a linear relationship between brake delivery pressure and brake force (see Figure 4.1), the EBS will decrease the delivery pressure by about half. The suspension airbag pressure is used by the EBS to calculate the vehicle loading condition.
- Theoretically, provided the braking rate is expressed as a percentage of g, road gradient can be considered by subtracting for positive (up) gradient or subtracting for negative (down) gradient, if gradient expressed as a percentage, e.g. 1 in 10 is 10% (HSE, 2007).

The following are points to note:

- There is much variation in how road gradient is accounted for between the available BPMSs, both in terms of how road gradient is measured and how it is addressed. For example, while many systems measure the road gradient and correct the BPV estimated to account for it, some systems do not correct the BPV to account for road gradient and simply filter out brake events for which the road gradient is above a prescribed limit.

Step 4: Average and extrapolate

When enough braking events have been gathered over an appropriate range average and extrapolate to estimate BPV at a demand pressure of 650 kPa.

- This is achieved using statistical techniques such as a least squares linear regression analysis
    - Confidence intervals for this can be calculated to ensure that the BPV is within 95% confidence interval DVSA standard requirement.

The following are points to note:

- All current BPMSs average and extrapolate, but the technique used may vary for different systems, or if the same technique is used, because the input data may be different, the extrapolated result could differ depending on the system used.

Step 5: provide outputs for operators

As required by the EBPMS standard, all electronic BPMSs generate a braking performance report for the operator which consists of a:

- trailer identifier;
- brake performance value (BPV) - expressed as percentage;
- date range to which the BPV applies;
- graphical report of BPV over time illustrating any trend occurring; and
- if appropriate, an indication that the data does not enable a valid BPV to be calculated.

There is one exception to this, in that one brake monitoring system presents the BPV using a normalised traffic light approach on a scale of 0 to 1, with satisfactory (green) values defined as > 0.3, not > 45% as one would expect if BPV expressed as a percentage and relatable to the service brake efficiency measured in a RBT. Furthermore, not all manufacturers provide a graphical report of BPV over time. This highlights a question of how compliance with the standard is controlled because in stakeholder engagement it was stated that this system was compliant with the standard, whereas strictly it is not. From stakeholder engagement it was found that compliance with the standard is self-policed with system suppliers providing an information document which demonstrate compliance. Currently, there are no independent checks or validation processes in place to verify that systems meet the standard.

The standard also requires that the brake monitoring system alert the vehicle operator if the braking rate falls below the minimum prescribed, i.e. 45% for semi-trailers. All BPMSs do this on the basis that a valid BPV has been calculated. However, given that most BPMSs require braking data collected over at least a few days to calculate a valid BPV (usually the values are averaged), some systems also provide an alert, on the basis of braking data collected over a much shorter time period, that it is most likely that the BPV is below the minimum prescribed, but has not yet been validated.

The following are points to note:

- The number of braking events required to calculate a valid BPV varies for different electronic brake monitoring systems, ranging from ~ 100 to ~1,000.
- Electronic BPMSs that alert the operator of a potential BPV issue on the basis of an unvalidated BPV, do so in a variety of different ways; some have a definite flag in their standard interface, whilst others allow operators to customise the interface to interrogate the trend data in detail and set a flag.
- Some electronic BPMSs have an option to re-start BPV calculations following trailer maintenance, whereas others do not. For systems that do not, any difference that the maintenance makes to the service brake efficiency will be seen in the trend line over a period as the influence of the BPV values prior to maintenance on the value post maintenance becomes less.

4.3.3 General points to note about use of electronic brake monitoring systems

This sub-section notes some important general points to remember related to the use of current electric brake monitoring systems:

- They assess the efficiency of the service braking system only, so they do not assess the performance of the parking brake or the influence of retarders and exhaust brakes.
- The results are for the combined tractor / trailer unit so a reduction in the braking performance value (BPV) may be because of a deficiency with the trailer, the tractor or both. Because of this:
    - If a service braking efficiency issue is flagged by the trailer brake monitoring system, the operator will usually bring the trailer in for a safety inspection which includes a roller brake test to determine if the trailer has a brake deficiency and the exact nature of the deficiency, i.e. which wheel / axle related to.
    - Changing tractor / trailer combinations will affect the trailer BPV measured if there is a difference in the service braking efficiency between the tractors.
- EBS trailer brake ECU / modulator is programmed using UNECE R13 specific brake calculation values (Annex 10 compatibility, see section 4.3.1.3). This needs to be correct for electronic BPMSs to work because its dependent on items that can change such as:
    - Tyre sizes
    - Suspension geometry and airbag type
    - Air chamber type and sizes
    - Slack adjuster lever length

4.3.4 Electronic brake performance monitoring systems verification / validation

The EBPMS industry standard requires that brake monitoring system suppliers provide an information document which includes confirmation that the brake monitoring system can detect an underperforming braking system.

The level of verification / validation provided varies between suppliers. Whilst all suppliers, at least mention, that they have correlated detection of an underperforming system with a similar finding from a RBT, a few provide additional verification from track tests such as a comparison of the deceleration values measured for braking events with all brakes working and with brakes on one axle disabled (by blanking brake chambers on one axle).

To help address this issue, the EBPMS working group made an initial proposal for a proving procedure to verify / validate BPMSs in March 2024. The procedure consists of six steps as follows:

1. Load trailer to as close as fully laden as possible

2. Perform two brake roller tests, a standard MOT one and a graduated one which can be used to plot the brake response curve, with readings taken every ½ bar (0.5 kPa) from 0 to 6.5 bar (650 kPa).
3. Check for tractor compatibility by performing braking events and checking brake temperatures.
4. Perform enough appropriate brake events to allow brake monitoring system to calculate the BPV.
5. Disconnect the brake chambers on one axle (of the triaxle semi-trailer) and repeat step 4.
6. Carry out UN Regulation No 13 type 0 test to measure performance of trailer brakes without any influence of tractor.

The proposal then states that the graduated roller brake test results (step 2), the data recorded in Steps 3 and 4 and the data from step 6 can be plotted (after processing) and will give an indication of accuracy of the brake monitoring system in terms of its brake performance value prediction. However, the proposal does not provide a method for performing this comparison or any proposal for acceptance criteria.

Also, comments from group members highlight the issues with the procedure, the main ones being:

- The cost of the procedure could be high, especially if tests need to be performed by an independent body.
- The graduated roller brake test may be difficult to perform because it is not usually performed and involves some risk of damage to the RBT equipment if care is not taken.

Even though it may be difficult to achieve, the authors believe that the best approach to verify / validate the BPMSs is by comparison with roller brake tester (RBT) results which the suggested procedure aims to do.

The reason why the comparison may be difficult to perform is because of the fundamental differences between brake efficiency measured by a brake monitoring system and a RBT. BPMSs measure brake efficiency over a time and with the trailer under different/dynamic loading while in real-world use, and with the braking contribution of the tractor unit. In contrast, the RBT measures trailer brake efficiency at a specific point in time at low wheel speeds, potentially with brakes below optimum operating temperatures. For a meaningful comparison, the brake efficiency in the RBT will need to be measured in a graduated manner as proposed by the EBPMS working group. If wheel lock occurs, then the brake efficiency should be extrapolated to the same delivery pressure used by a brake monitoring system to compare the brake efficiency values as fairly as possible.

It is recommended that their work is continued to develop this procedure with focus on how the comparison may be performed, potential acceptance criteria, and streamlining the procedure. Note that some stakeholders have commented that step 6, and indeed step 5, may not be needed provided that an appropriate method and criteria to compare RBT and electronic brake performance monitoring system results can be developed.

4.3.5 *Comparison to Roller Brake Test (RBT)*

The main advantages and disadvantages of electronic BPMSs compared with traditional roller brake testing are:

- Advantages:
    - More continuous – The RBT carried out as part of the MOT is only done once a year and, although safety inspection RBTs may be every six to eight weeks (if trailer used heavily), this is still not close to continuous.
    - Measured while trailer is in use, so could save operational downtime of trailer (and resource) required to undertake RBT if the 14 day concession to carry out the RBT when the trailer is not in use does not apply.
- Disadvantages:
    - Can only detect service brake efficiency deficiencies directly and not the other brake deficiencies that can be detected by a RBT, namely:
        - Parking brake performance and efficiency.
        - Service brake[10]:
            - Fluctuation / ovality,
            - Binding / grabbing,
            - Braking imbalance on axle,
            - Braking efficiency of individual axles and wheels.
    - Measures service brake efficiency of truck and trailer combination and is subject to variability brought about by the use of different trucks if the trailer is swapped in operation.
    - In terms of implementation of BPMS to the market, the technical requirements are such that current systems differ in terms of their data inputs and outputs (see Section 6.1.1.2), meaning that some current systems may report a BPV that aligns closer to a RBT than others.

[10] As described in Section 2.2.1.1, current BPMSs can indirectly detect other brake defects if they lower the overall braking efficiency, but they cannot locate the defect to a wheel or axle level or diagnose the type of defect.

5 Task 2: Stakeholder engagement

5.1 Background

Stakeholder engagement was crucial to achieving the project's objectives. Gathering these insights was essential to developing a comprehensive understanding of existing systems and anticipated future advancements.

5.2 Engagement methodology

Stakeholders were identified through multiple sources. The DVSA highlighted an existing electronic BPMSs working group and provided some further recommendations. TRL also identified stakeholders through industry contacts and from conducting a technical review of existing brake performance monitoring technology which supplemented the list.

5.2.1 Stakeholder categorisation

The list of candidate stakeholders was assigned to categories according to the following groups:

- Autonomous vehicle manufacturers.
- Brake manufacturers.
- Trailer manufacturers/leasing.
- Brake performance monitoring manufacturers/suppliers.
- Operators.
- Roadworthiness experts.
- Trade associations.
- Truck OEMs.

5.2.2 Stakeholder questionnaire

The objective of Task 1 was to document and understand how current systems function. Therefore, an efficient approach was devised which involved a questionnaire which was sent to the EBPMS working group in addition to brake manufacturers, operators and truck OEMs to gather a wide range of information rapidly on current systems, but also on the anticipated future developments. Brake and brake performance monitoring suppliers were targeted to gain insights into both existing systems and future advancements, while operators were targeted to better understand current systems and their implementation

A questionnaire was sent to these stakeholders, totalling 34 individual stakeholders across 23 organisations (Table 5.1). The category-specific questions are presented in Appendix E. A topic guide providing background information and outlining the project objectives was developed and shared alongside the questionnaire (Appendix B). The questionnaire covered all areas of the project objectives but focussed more on the Task 1 objective of understanding the existing BPMSs available on the market.

Three sets of email reminders were sent after initial contact and in several cases this was followed up by a phone call and assistance from DVSA to solicit engagement with the project.

5.2.3 Stakeholder interviews

The interviews were used to clarify or discuss in greater detail the answers provided by the questionnaire, and also to focus to a greater extent on the future developments that might be anticipated with the development of braking system technology, increasing vehicle automation and the implications for BPMSs.

A smaller subset of stakeholders was selected with the aim of achieving a representative sample and practical considerations regarding how proactive specific stakeholders were to the topic. Stakeholders were invited to participate in one-hour interviews conducted via Microsoft Teams. Interview invitations were sent to 26 individual stakeholders across 19 organisations (Table 5.1).

Table 5.1: Number of stakeholders and organisations contacted via questionnaires and interview invitations

Stakeholder category	Number of questionnaires sent	Number of organisations invited to interview
Autonomous vehicle manufacturers	0	1
Brake manufacturers	8	5
Trailer manufacturers/leasing	11	2
Brake performance monitoring manufacturers/suppliers	10	3
Operators	3	3
Roadworthiness experts	1	2
Trade associations	0	1
Truck OEMs	1	2
Total	**34**	**19**

In addition to the aforementioned information, informal discussions and initial engagement for participation were made with three autonomous vehicle manufacturers. However, these stakeholders did not respond to engagement with the questionnaire or interview tasks.

5.3 Engagement results

The project received 29 completed questionnaires from 22 different organisations, including six additional Operators that responded after the questionnaire was forwarded on by a Roadworthiness stakeholder. Interviews with 9 organisations were held (Table 5.2:).

Brake manufacturers and Brake performance monitoring manufacturers/suppliers contributed the majority of responses across both the questionnaires and interviews (Figure 5.1 and Figure 5.2). These are key technical stakeholders with direct knowledge of system capabilities, limitations, and future developments. Operators also provided a good level of response for the questionnaires, offering insights into technology implementation and operational considerations (Figure 5.1).

However, there were no responses from some important stakeholder categories, including Autonomous vehicle manufacturers and Trade associations and engagement with Truck OEMs was limited to a single interview. This limits the breadth of perspectives, particularly in relation to how BPMSs might integrate with future vehicle technologies. Also, while operators and trailer manufacturers were well represented in the questionnaire responses (Figure 5.1), the limited number of interviews with these groups restricted opportunities to explore their responses in depth.

Table 5.2: Number of stakeholders and organisations who responded

Stakeholder category	Number of questionnaires returned	Number of organisations who participated in interviews
Autonomous vehicle manufacturers	0	0
Brake manufacturers	8	2
Trailer manufacturers	4	1
Brake performance monitoring manufacturers/suppliers	10	3
Operators	7	0
Roadworthiness experts	0	2
Trade associations	0	0
Truck OEMs	0	1
Total	**29**	**9**

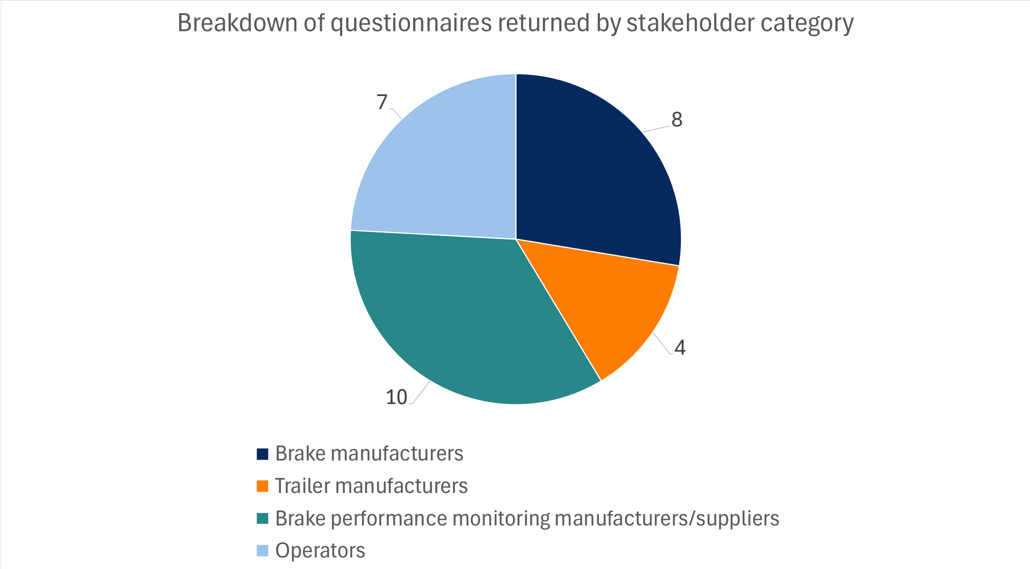

Figure 5.1: Breakdown of questionnaires returned by stakeholder category

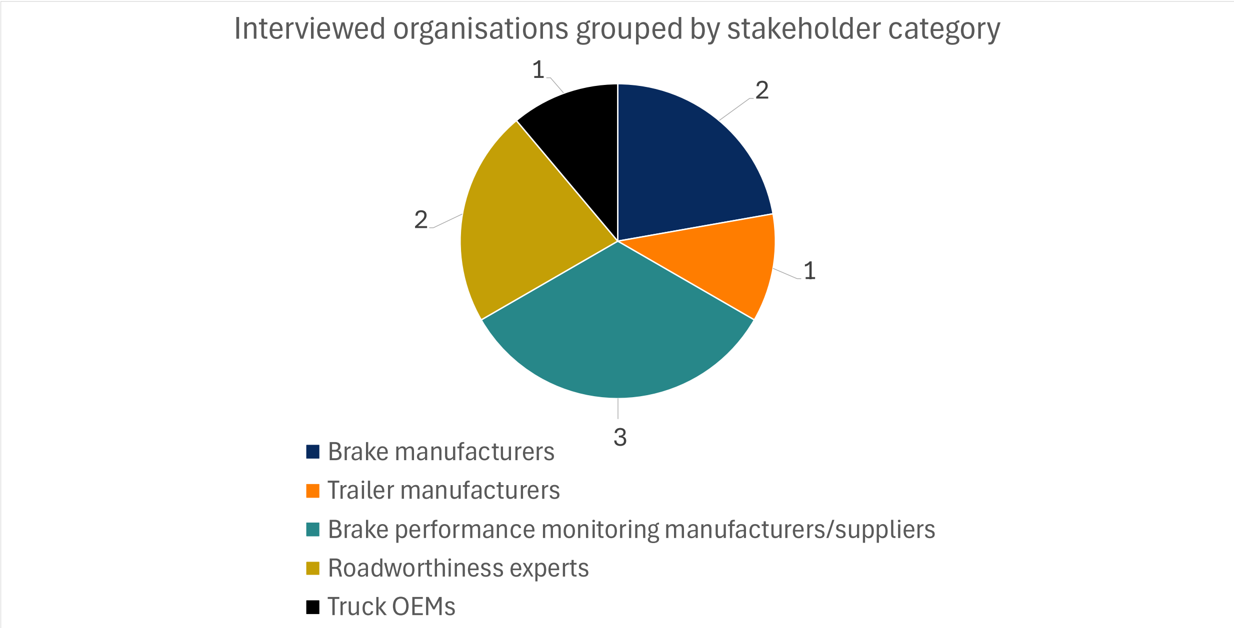

Figure 5.2: Breakdown of organisations interviewed by stakeholder category

5.4 Challenges faced

The key challenges during the stakeholder engagement were obtaining the required participation and commercially sensitive information. The former challenge was mitigated to a certain extent in the selection of stakeholders for both the questionnaire and interview, but despite this, not all stakeholders responded. The overall short timeline for the project was a factor, but overall, the project gathered a selection of views and information from a range of stakeholder groups.

Information from automated vehicle developers was sought in the stakeholder consultation task, but only one stakeholder was contacted who did not engage with the project. Future research on this topic should aim to engage with a number of stakeholders in this category.

The stakeholder engagement timeline for the project also crossed into the Christmas period, and this particularly affected stakeholders in the Operators group, since this was their busiest time of year. The project mitigated this by using the questionnaire for these stakeholders to gather information, as this was more efficient compared with the logistics and time required for an interview.

To address the issues protecting intellectual property, non-disclosure agreements were arranged as part of this process.

An identified way to improve stakeholder response in future projects of this nature is to establish direct contact with key stakeholders earlier in the engagement process so there is a lower risk of a poor response from stakeholders from a particular category.

6 Task 3: Findings, analysis and discussion

This section details the key findings from the review of existing systems and stakeholder engagement for current and future brake performance monitoring systems. Following this, considering the research objectives of this project, the key findings are analysed and discussed further to help develop conclusions and recommendations.

6.1 Findings

6.1.1 Current brake performance monitoring systems

6.1.1.1 General

Brake performance monitoring systems are currently only available for trailers with one exception which is detailed below. All the current trailer electronic braking performance monitoring systems state that they meet the industry standard specification (DVSA, 2024) and report service braking efficiency of the tractor and trailer combination.

This exception is a brake performance monitoring system fitted by one vehicle manufacturer to their HGV rigids and tractors. During braking, the Electronic Braking System (EBS) ECU checks the braking performance of the vehicle and if the performance falls below a prescribed level it warns the driver by displaying a low brake performance warning on the driver instrument panel. The braking performance is checked by comparing the actual deceleration of the vehicle with the expected nominal deceleration calculated by the EBS ECU, considering factors such as use of the retarder. Low brake performance can be caused by factors such as brake fade (overheated brakes) or worn-out disc brakes.

This system does not meet the EBPMS industry standard because it only provides a warning to the driver and does not provide an alert to the vehicle operator or provide the operator the ability to produce a braking performance report. It should be noted that, in principle, this system could be developed further so that it would meet the EBPMS industry standard. However, during stakeholder engagement with this vehicle manufacturer it was mentioned that to undertake this development, the general need for the development would require good justification because, due to the way their organisation operated, it would need to be fitted across their vehicle range. Also, a robust standard for the system would be required for its development to reduce the risk of developing an inappropriate system. The authors' understanding of these comments was that future system development would, require a regulatory mandate, or at least a strong demand across the industry.

The reasons that brake performance monitoring systems are currently mainly available for trailers only, are that:

- The level of standardisation for trailers (ISO 11992) is much higher than for other vehicle types which allows third party suppliers to provide systems.
- A greater proportion of service brake efficiency type deficiencies was found for trailers compared to other vehicle types, i.e. there is a bigger issue with trailers relating to service brake efficiency; see Section 6.1.1.1 below.

- The benefit that arises from their use compared to the testing regime is greater compared to some other vehicle types. For example, passenger cars only have an annual assessment of brake performance at the MOT once over the age threshold.

6.1.1.2 Limitations and variation

The limitations of current brake performance monitoring systems for trailers include:

- Electronic BPMSs measure performance of service brake (efficiency) only, i.e. they do not measure other deficiencies that are assessed by a Roller Brake Tester (RBT) such as imbalance, bind, time lag / grabbing, ovality and maximum force. Also, they do not measure parking brake performance in any way.
- Deceleration can only be measured for whole vehicle, which includes tractor unit, so service brake efficiency also only measured for whole vehicle, 'tractor and trailer'. This means that changing the tractor / trailer combination during operations can affect the measurement of the service brake efficiency. Also, if a service brake efficiency performance reduction is detected, it may be related to the trailer or tractor or both. Therefore, additional diagnostics are required to determine whether the defect is related to the trailer or tractor, and following this, which axles / wheels the defect is related to. This is done by assessing the vehicle on a RBT.

Current systems are also variable in terms of how they work, their outputs for operators and the level of verification / validation. The main variations are:

- How they work:
    - Sampling and filtering of brake events which are used to calculate a Braking Performance Value (BPV).
        - To calculate a BPV for a braking event, a single value of deceleration and brake demand pressure is usually assigned to each event. The brake demand pressure requested by the driver (and thus the vehicle deceleration) may vary during a braking event because the driver may adjust the brake pedal position to increase or decrease vehicle braking to respond to the road situation. If this occurs, single representative values of demand and acceleration can be estimated by averaging to an extent; however, for some events this may lead to non-representative values and hence these braking events need to be filtered out.
    - How they measure and account for road gradient.
        - There is substantial variation in how this is performed, ranging from measuring the road gradient and adjusting the estimated vehicle deceleration to compensate for the road gradient to filtering out brake events where the road gradient has a significant effect on the vehicle's braking.
    - How they compensate for vehicle load.

        - Some assume that the EBS correctly alters the brake delivery pressure to account for vehicle load, whilst others adjust the BPV calculated to account for vehicle load.

- Operator outputs:
    - The number of qualified braking events used to provide a Braking Performance Value with confidence.
        - This varies between systems with number of events varying from order of a hundred to the order of a thousand.
    - The provision of an immediate (amber) warning of reduced service brake efficiency, i.e. an option to alert when the BPV is below an acceptable value before enough brake events processed to give full confidence that it is below, for example based on a defined number of low values being recorded in series.
        - Some provide these and others do not.
    - The provision of a reset following trailer maintenance by the operator.
        - Some provide these and others do not, although for some of those that do not, it is possible to examine the step change in the BPV following maintenance by using the trend reports.
- Level of verification / verification
    - Whilst all suppliers, at least mention, that they have correlated detection of an underperforming system with a similar finding from a RBT, a few provide additional verification such as data from track tests which show differences measured from disabling brakes on a single axle.
    - The EBPMS working group have made an initial proposal for a proving procedure to verify / validate BPMSs by comparison of its results with RBT results. However, this procedure requires further work to develop a method to compare the results, acceptance criteria, and streamlining of the procedure.

6.1.1.3 MOT data analysis

Analysis of brake deficiency data supplied to the project by the DVSA showed that the proportion of tests with brake deficiencies in which one of those deficiencies was ‘service brake efficiency’, which current BPMSs detect, was 45% for trailers, 20% for HGVs and 4% for PSVs.

This illustrates that for tests with brake deficiencies, the proportion of tests with service brake efficiency deficiencies is greater for trailers than for other large vehicles. It also shows that, for tests with service brake deficiencies, the majority of tests have brake defects that cannot be detected by current BPMSs, specifically 55% for trailers, 80% for HGVs, and 96% for PSVs. It also illustrates that, ideally, future BPMS will need to assess many more brake deficiencies in addition to service brake efficiency to better substitute for an MOT style safety inspection, even though they have the advantage of continually monitoring the vehicle as compared to the MOT annual assessment.

Note that a detailed description of the MOT data analysis and results can be found in Section 2.2.1.1.

6.1.1.4 High-level cost benefit information

The DVSA 'Guide to maintaining roadworthiness: commercial goods and passenger carrying vehicles' (DVSA, 2024a) states that for the assessment of brake performance from April 2025:

To follow best practice and comply with legislation there is an expectation that every safety inspection will include a brake performance assessment using either a RBT, a suitable electronic brake performance monitoring system (EBPMS) or a decelerometer with temperature readings.

If EBPMS is not used it is expected there is a minimum of 4 laden brake tests spread evenly across the year, this can include the annual (MOT) test.

Where a laden brake test is not carried out a risk assessment detailing the reasons, must be completed by a competent person who understands braking systems and components.

Little information could be found related to costs and benefits of current brake performance monitoring systems, laden roller brake tests and the DVSA guide to maintaining roadworthiness requirements for three laden roller brake tests in addition to the annual MOT[11]. However, the following information was gathered from stakeholder engagement and a document prepared by industry (Logistics UK, 2024), which investigated the cost of implementation of the DVSA laden RBT operator requirement.

- Cost of laden RBT:
    - ~£100 mid cost with variation from £50 to £150 depending on issues such as whether the test was scheduled, and effort required to load the trailer.
- Cost of electronic BPMSs (for trailer):
    - ~£200 per year per trailer, with some information that this could be approximately £300 per trailer along with a small monthly subscription as part of a wider telematics offering.

Logistics UK estimates the cost of the DVSA guide to maintaining roadworthiness requirement for laden roller brake tests on the basis that many operators perform one per year at present and so an additional two laden RBTs will be required. The cost estimated for the HGV and trailer fleets was:

[11] Note: There are exemptions for some vehicles to be presented for test in a laden condition due to design limitations or restrictions caused by the type of cargo they carry. Examples of such vehicles are those which carry obnoxious loads, those which carry livestock and furniture removal vehicles with a low load bearing ability or false floors.

746,226 (vehicles/trailers) X 2 (additional laden brake tests per year) X £100 (cost of laden roller brake test) = £149,245,200, which approximates to £150 million.

The Logistics UK document states that, even if the additional cost of the laden brake tests was half that estimated (£75 million), the additional cost burden on the industry, for a MOT fail rate of service brake performance for HGVs of 2.3% and trailers of 3.17%, is disproportionate. However, it should be noted that the potential costs associated with a fatal or serious collision are significant. For example, discounting any legal fines relating to the outcome of commercial or passenger vehicle collisions, the 2023 valuation of a single fatal and serious casualty is £2.41 million and £271,000 respectively[12].

It should be noted that the use of electronic BPMSs could reduce the additional cost for trailers on the following basis. For the industry calculation, it was assumed that operators already perform two laden brake tests per year, one for the MOT and one mid-year, thus an additional two would be required, making four in total. The laden brake test for the MOT cannot be replaced by use of a BPMS, but the other three can. The cost of these three laden tests is 3 x £100 = £300. The cost of an electronic brake monitoring system is ~£200 per year which gives a cost reduction of £100 per trailer per year. This agrees well with the cost saving of £136 per trailer per year estimated by an online calculator from the Axscend website (Axscend, 2025).

This effectively halves the additional cost burden for trailers initially estimated above, but electronic BPMSs are not available for HGVs (so these costs cannot be halved) and the industry argues that even at half the initial cost estimated, the burden is still disproportionate. However, it should be noted that an independent assessment on this has not been made.

6.1.2 Future brake performance monitoring systems

This section describes the key findings from literature review and stakeholder engagement related to future brake performance monitoring systems. It is divided into two subsections. The first describes near-term developments of current BPMSs for trailers. The second subsection considers the longer term with focus on relevant trends and associated changes to standards and regulation and their influence on the development of braking performance monitoring systems in the future.

6.1.2.1 Near term

Most BPMS suppliers are thinking about measuring and using other parameters, such as wheel end / brake temperature and additional wheel speed sensors to detect service braking performance deficiencies other than efficiency, and to provide indication of the location of service braking efficiency deficiencies, whilst some suppliers are actively performing research in this area. For example, there is a possibility that wheel temperature, potentially measured by the data already recorded by the Tyre Pressure Monitoring System (TPMS), could be used to detect imbalance and / or binding from measurement of

[12] https://assets.publishing.service.gov.uk/media/66f44bd730536cb927482738/ras4001.ods

temperature differences between wheels. Additional wheel speed sensors could provide information to potentially detect time lag / grabbing and additional information to help detect imbalance and binding.

However, it should be noted that this research is in its early stages and there are many details to be considered. For example, if wheel speed data was to be used to help detect imbalance it would need to be known that the vehicle was braking in a straight line and to know this, vehicle lateral acceleration, steering, projected and actual path data could also be required.

6.1.2.2 Longer term

There are three major trends affecting the future of the automotive industry: electrification, automation, and connectivity. These are reshaping the design, function, and regulatory requirements for all vehicles. The transition towards electric vehicles (EVs) and automated vehicles (AVs) are introducing both new challenges and new opportunities for vehicle braking systems.

Electrification refers to the adoption of electric powertrains, replacing traditional internal combustion engine (ICE) systems. This transition is influencing braking technologies for all vehicle types in several ways. Electric vehicles typically have heavier unladen weights, low centres of gravity, higher performance than internal combustion engine (ICE) vehicles and employ regenerative braking, which recovers energy during braking and feeds it back into the battery, reducing wear on traditional friction components. This element may be proportionately more important for larger, heavier vehicles. Use of regenerative braking means that most braking events may be met, with conventional friction braking only required in instances where the braking demanded is more than the deceleration that can be delivered via regenerative braking. This is likely to require advancements in the design of both regenerative and conventional braking systems to ensure that the materials and overall system design can deliver the appropriate braking performance in all situations, including situations where conventional braking systems may have been largely dormant which is likely to exacerbate the problem of sleeping brakes.

Sleeping brakes occur when brake pads and linings do not reach a temperature that is needed for the development of optimum brake performance, the friction coefficient of their surfaces lowers resulting in a loss of performance, i.e. they fall asleep, and they need to be replaced although they are not worn out. However, if detected at an early stage, sleeping brakes can be revived through substantial braking application. Current BPMSs can detect sleeping brakes, but if this could be detected at early stage, an opportunity exists to inform the operator so that action could be taken to revive them. Alternatively, the likelihood of sleeping brakes developing in the first place could be reduced. For example, assuming that the Electronic Braking System (EBS) has control over brake delivery pressure for individual axles, it could be programmed such that if the friction braking force requirement was low, instead of braking all axles at a low force, which would likely develop sleeping brakes, it could brake one axle at a higher force to reduce the likelihood of developing sleeping brakes. It is interesting to note that some current EBS effectively do this already. If wear measurement sensors are fitted, current EBS already change axle braking distribution in low/medium deceleration events to even pad wear across the vehicle.

Sleeping brakes is currently becoming more of an issue with trailers because of a variety of factors including the increased running of trailers at low weights and that the number of HGV tractors with strong endurance brakes is increasing[13]; thus the trailer brakes are used less. To help address this issue, the UN Working Party on Automated/Autonomous and Connected Vehicles (GRVA) have endorsed a proposal from an industry stakeholder (CLEPA[14]) to amend UN Regulation 13 Annex 10 'compatibility between towing vehicles and trailers' to allow higher brake forces to be applied to trailer brakes.[15]

In summary, because of electrification leading to less use of the friction brakes, sleeping brakes will become more of a problem if braking systems continue to operate as they do now, i.e. each axle brakes its own weight, even for low deceleration braking events. However, the authors believe that manufacturers will not allow this to happen and will alter the design of their braking systems to minimise the potential future problem of sleeping brakes. For example, they could change axle braking distribution in low/medium deceleration events so that brakes on some axles were not used at all and brakes on other axles were exercised to reach proper operating temperatures, thus help prevent sleeping brakes.

Automation, particularly the development of partially and fully automated vehicles, is another transformative trend that has major implications for vehicle braking systems. For automated driving systems (ADS) the designs of underlying safety critical systems, such as the brakes, will require sufficient redundancy to continue full operation after the detection of a fault to enable the vehicle to perform a minimum risk manoeuvre (MRM) and reach a safe state. With fail-operational architectures, a high level of safety integrity and a high level of availability is necessary — typically through independent hardware. To help enable implementation of the types of redundant architecture required and electro-mechanical braking (EMB) systems, standards and regulations are being revised as detailed in Appendix F. The main revisions are to UN Regulations No. 13 and 13H by the GRVA 'Automated/Autonomous and connected vehicles' working party in Geneva and ISO 26262 by expert working groups. It is interesting to note that revisions being developed to UN Regulation No. 13 to permit approval of a safety concept for braking of an automated vehicle, namely control transmission redundancy consisting of two electric circuits and brake controllers, are being implemented by Daimler Truck North America in their truck

[13] Note that towing vehicles and trailers fitted with ABS do not need to fulfil the Regulation No. 13 unladen compatibility bands (see Annex 10). Therefore stronger regenerative braking on the tractor can be used to substitute for trailer braking for when vehicles and trailers fitted with ABS not fully loaded.

[14] European Association of Automotive Suppliers https://www.clepa.eu/

[15] Working document ECE-TRANS-WP.29-GRVA-2025-16e_0.pdf: https://unece.org/sites/default/files/2024-11/ECE-TRANS-WP.29-GRVA-2025-16e_0.pdf

Informal document GRVA-21-59: https://unece.org/sites/default/files/2025-01/GRVA-21-59e.pdf

Note that, during the meeting an error was found in the working document compatibility diagrams. To address this, a correction was issued post the meeting in informal document GRVA-21-59.

prototypes[16]. These prototypes are part of a development programme aimed at targeting market entry for SAE Level 4 automated trucks in a hub-to-hub use case in the US by 2027.

Also, for fully automated vehicles, i.e. SAE L4+, to assure safe operation, ideally before it is activated, the ADS will require information that the vehicle (including the foundation braking system) is in a roadworthy state. This could be achieved in several ways ranging from frequent physical safety inspections which include a RBT to an electronic based safety inspection which for example, includes brake performance monitoring. In principle an electronic based approach should offer better cost effectiveness because it should result in less need to take the vehicle off the road for inspection. However, this assumes that all safety related items can be inspected electronically which is unlikely to be the case when one considers the items in the current MOT that are checked by visual inspection and operation (see Section 2.2.1). Therefore, the assurance of roadworthiness for automated vehicles is likely to consist of a mixture of the two approaches with a preference for electronic based testing where feasible because it is likely to be more cost effective.

The electronic based roadworthiness testing of vehicles, including automated ones, could be influenced by the following in the future:

- Introduction of electro-mechanical braking systems
    - EMB systems should offer more opportunity to sense deficiencies compared to current pneumatic and hydraulic systems given their electronic / electrical (E/E) nature. For example, air pressure or hydraulic pressure sensors will not be required so saving their associated cost. However, some form of physical visual inspection will still be required, for example, to check that wiring is correctly secured and not damaged.
- Vehicle self-testing
    - A self-test of the braking system offers more opportunity to assure its roadworthiness compared to continuous brake performance monitoring because can brake individual axles and wheels and thus assess performance at axle / wheel level which is generally not easily possible for continuous monitoring because all brakes applied, and deceleration of whole vehicle measured. However, braking of vehicle for self-diagnostic purposes on public road would need to be assured to be safe and the enhanced diagnostic capability gained justified. Therefore, before implementation of self-testing, further work is required to assure it is implemented in a safe manner and can be justified.

Connectivity

For future vehicle connectivity, the industry (ACEA) propose a model called the ‘Extended Vehicle’ (ISO 20077, 2017), which is already deployed by some OEMs and being implemented by others currently (ACEA, 2021). They believe that the ‘Extended Vehicle’

[16] Daimler Truck North America – Innovation – Autonomous Driving: https://northamerica.daimlertruck.com/innovation

model reflects best practices in the industry for sharing of in-vehicle data and resources[17] underpinned by the key principles of safety and security of the driver.

The extended vehicle model allows access to vehicle data through several interfaces that can be used depending on the purpose for which access is sought:

- On-board Diagnostics (OBD) interface for regulated emissions control, diagnosis, repair and maintenance.
- Web interface for all other third-party services (e.g. remote diagnostic support).
- Ad hoc communication interface under the responsibility of the vehicle manufacturer (e.g. remote fleet management services (rFMS) or applications in the field of cooperative intelligent transport systems).

The customer determines whether they wish to share their personal data. Each vehicle manufacturer then determines which technology will be used to make that data available to third parties on a non-discriminatory basis. In principle, vehicle data for brake performance monitoring could be accessed via either an ad hoc communication interface, e.g. as part of rFMS, or the web interface.

A key consideration for future vehicle connectivity is cybersecurity. To assure cybersecurity OEMs are likely to introduce more security measures which could make access to vehicle data by third parties more restricted, in particular in regard to fitment of third party devices, such as current electronic brake monitoring systems, which could create a possible attack route because they access CAN data, in theory could write to it and have a connection to the outside world.

Precisely how this issue may be addressed in the future is unknown at present. However, the authors can envisage several potential options which include:

1. Future electronic brake monitoring devices are connected to an FMS type port on the vehicle which provides access to data required and necessary security to prevent attack.
    - Potential challenges with this option include the availability of the necessary data on the FMS port, in particular data such as that needed to estimate road gradient.
2. Future electronic brake monitoring suppliers access data required via web interface, process it as required and do not fit device to the vehicle.
    - Potential challenges with this option are related to the necessary data being available especially given the high frequency of some data elements required such as wheel speed for calculation of vehicle deceleration. Also, given that data may not be available as standard, another challenge could be the cost of providing it.

[17] Vehicle resources are, for example, a function to allow the display of messages on a human machine interface (HMI) display or a function to activate a vehicle compartment preheating system or to open the boot remotely.

3. Future electronic brake monitoring capability provided as a built-in function of vehicle braking system
    - Potential challenges with this option include definition of the required function and method of ensuring that function available on all relevant vehicles. However, one way of ensuring availability on all relevant vehicles could be to regulate its fitment. A potential benefit of this option could be to ensure fitment of a standardised function to all relevant vehicles.

6.2 Discussion of project findings with respect to the research objectives

6.2.1 Identify and document the broad range of electronic brake performance monitoring systems fitted to current vehicles and trailers.

The BPMSs that are currently available, which report a service brake efficiency value, are for trailers and semi-trailers, with one exception which is described below. These systems have developed because the required vehicle data is available and standardised on the trailer CAN, and because there is a market need for brake performance monitoring systems which can substitute for roller brake tests in safety inspections.

For other vehicle types, vehicle data on the CAN[18] is not standardised as much, meaning that significant additional cost would be necessary to develop solutions that would be able to decode the data from the CAN even if it is available. Also, service brake efficiency deficiencies are a greater issue for trailers than other vehicle types. MOT data analysis shows that the proportion of tests with brake deficiencies in which one of those deficiencies was ‘service brake efficiency’ was 45% for trailers, 20% for HGVs and 4% for PSVs.

The exception is a brake performance monitoring system fitted by one vehicle prime mover manufacturer to their HGV rigids and tractors. During braking, the Electronic Braking System (EBS) ECU checks the braking performance of the vehicle and if the performance falls below a prescribed level warns the driver by displaying a low brake performance warning on the driver instrument panel. It is quite different to the systems available for trailers in that it does not produce reports related to the service braking efficiency over a defined period for the operator. Indeed, from stakeholder engagement with the manufacturer it was understood that its main purpose was to warn the driver of brake fade so that they could take appropriate action although it would also warn the driver of reduced service braking efficiency caused by worn linings.

In theory, this ‘driver warning’ system could be developed further to report service brake efficiency to the operator, meet the EBPMS standard and become more equivalent to current electronic BPMSs for trailers. One major advantage of doing this would be that it would avoid issues related to decoding CAN data and potential issues with cybersecurity because it would be an OEM fitted system and hence the manufacturer would resolve these issues. However, when this was mentioned to the manufacturer during a stakeholder interview, they responded that whilst all this was feasible in theory, in practice the main issues would be the development cost which would have to be justified by a need for fitment across their product range. Also to ensure costs were minimised a detailed specification for the system would be required to ensure no ambiguity in the system design requirements, i.e. the current industry standard specification would not be sufficient.

[18] Controller Area Network

6.2.2 *An analysis of how vehicle braking data is used today by manufacturers and telematic businesses.*

There are two main ways in which vehicle braking data is used today by manufacturers and telematic businesses. The first is to help ensure the roadworthiness of the braking system. This is driven by the DVSA operator licensing requirements detailed in the DVSA 'Guide to maintaining roadworthiness' document (DVSA, 2024a). The second is that vehicle deceleration data is used in conjunction with other vehicle data to monitor driver driving behaviour and help encourage safe and economical driving.

6.2.3 *A view on the viability for brake performance monitoring systems as an alternative to driver in-use monitoring, safety inspections and the statutory PTI.*

Driver in-use monitoring

With current EBS, the driver foot pedal input is somewhat disconnected from brake performance because the foot pedal input is the same whether braking a fully laden vehicle or a half laden vehicle. This is because the EBS adjusts the brake actuator delivery pressure to account for the vehicle load. However, EBS will not adjust the actuator delivery pressure to account for a reduction in the wheel end lining friction efficiency, so the driver will need to apply more braking by depressing the pedal further to compensate for this. But unless the lining friction efficiency decreases substantially on a number of axles, the driver will probably not notice this.

Safety inspections and statutory PTI

Safety inspections and the statutory PTI (MOT) includes both an assessment of the mechanical condition and operation of braking system components and an assessment of its performance and efficiency using a RBT (see Section 2.2.1).

Whilst current brake performance monitoring systems can act as an alternative for some aspects of the assessment of its performance and efficiency which use a RBT, they cannot substitute for any of the assessment of their mechanical condition, although if severe enough the EBS may warn for some aspects of the mechanical condition. However, in the future, if electro-mechanical brakes are adopted, this should offer more opportunity for assessment of the mechanical condition of the brakes.

6.2.4 *Identification of the benefits and disbenefits of brake performance monitoring compared to the existing methods.*

The main benefits are the continuous assessment of safety critical performance compared with discrete testing and cost effectiveness because, if implemented well, should help enable predictive maintenance. This reduces operational down time and improves operational efficiency.

The main disbenefit is that it is not possible to use brake performance monitoring to replace many parts of the safety inspections / PTI, so these still need to be performed using existing methods. However, in the future opportunity is likely to arise to use brake performance monitoring to substitute more parts of safety inspections / PTI, although not all.

Another disadvantage of current systems is that they measure the braking performance of the whole vehicle. For tractors and trailers this means that if the system reports a braking performance deficiency it could be related to the trailer or tractor or indeed both. Therefore, further diagnostics is required, usually a roller brake test, to determine which unit (tractor or trailer) has the deficiency and which axles / wheels it relates to. This issue is further complicated by 'drop and swap' operations in which the tractor / trailer combination changes because tractor units pick up and drop off trailer units which can be picked up by another tractor unit. Clearly, the tractor / trailer combination needs to be known to help interpret the braking performance data.

6.2.5 *A high-level cost quantification of brake performance monitoring systems as an alternative to driver in-use monitoring, safety inspections and the statutory PTI.*

Cost information was only found for current brake performance monitoring systems, the details of which are described in Section 6.1.1.4.

To understand the financial benefit of current BPMSs compared with traditional testing methods, it is necessary to clearly understand the baseline for comparison with fitment of these systems and whether they are intended to replace laden or unladen RBTs. From 1 January 2023, vehicles and trailers for annual test must be appropriately laden when presented for MOT, and for safety inspections a laden RBT is required to satisfy Regulation 18.4 of the Construction and Use Regulations[19], and there is therefore an expectation that every safety inspection will include a laden RBT (DVSA, 2024a).

Based on using brake performance monitoring systems to substitute three laden roller brake tests, a year using information provided by industry (Logistics UK, 2024) a cost saving of ~£100 per trailer per year was estimated. This agreed well with the cost saving of £136 per trailer per year estimated by an online calculator from the Axscend website (Axscend, 2025).

6.2.6 *Information on the feasibility of developing a recognised standard for remotely monitored braking performance systems.*

For current remotely monitored braking performance systems, an industry standard has already been developed but, as detailed in Section 4.3, it requires further development to reduce the large variability in how current systems work, some differences in their outputs and how compliance to the standard is controlled. Suggestions for this development which focus on improving verification / validation of the systems currently available are described in Section 4.3.4.

For future fully automated vehicles it is currently uncertain how the roadworthiness of the braking system may be assured and therefore the need and content of a standard for remotely monitored braking performance systems. This is because:

- Rather than monitor the braking system performance, a self-test approach (i.e. the vehicle has self-diagnostic capability to assess roadworthiness) may be implemented

[19] https://www.legislation.gov.uk/uksi/1986/1078/regulation/18/made

because, provided it can be achieved safely, it offers more opportunity to assure its roadworthiness because a self-test could brake individual axles and wheels, therefore assessing performance at the axle / wheel level. This is not possible for continuous monitoring because all the brakes are applied, and the deceleration of the whole vehicle measured. A self-test type approach could be implemented either by itself, or in conjunction with a continuous monitoring system. The need and content of a standard would depend on which option was chosen.

- Even if it was decided that a brake performance monitoring system was required, connectivity will be limited to assure cybersecurity. Potential options include:
  - Future electronic brake monitoring devices are connected to an FMS type port on the vehicle which provides access to data required and necessary security to prevent attack.
    - Potential challenges with this option include the availability of the necessary data on the FMS port, in particular data such as that needed to estimate road gradient.
  - Future electronic brake monitoring suppliers access data required via web interface, process it as required and do not fit device to the vehicle.
    - Potential challenges with this option are related to the necessary data being available especially given the high frequency of some data elements required, such as wheel speed for calculation of vehicle deceleration. Also, given that data may not be available as standard, another challenge could be the cost of providing it.
  - Future electronic brake monitoring capability provided as a built-in function of vehicle braking system.
    - Potential challenges with this option include definition of the required function and method of ensuring that function available on all relevant vehicles. However, one way of ensuring availability on all relevant vehicles could be to regulate its fitment. A potential benefit of this option could be to ensure fitment of a standardised function to all relevant vehicles.

Given these uncertainties in the way forward, a potential solution could be to regulate at a high level that for fully automated vehicles manufacturers are required to develop a system that assures the roadworthiness of safety critical systems such as braking to allow the Automated Driving System (ADS) to be used.

Section 3(1) of the Automated Vehicles Act (2024) prescribes a self-driving test that must be satisfied as part of the authorisation process for an automated vehicle to be driven on the road. Secondary regulation for the self-driving test itself could include specific requirements for the ADS to check and ensure the continuous roadworthiness for the authorisation of autonomous functionality. It could also include requirements to make the necessary data freely available for inspection authorities to validate the roadworthiness of the vehicle. This could include details on the data specification and data availability, and, for example, specify that data is available via the extended vehicle (see Section 6.1.2.2). The advantages of this solution include that it would give the manufacturer more freedom over what system they implement. Also, detailed requirements could be included to ensure inspection bodies, such as DVSA, could perform third party validation of the vehicle's roadworthiness system.

7 Conclusions

In response to the project objectives (see Section 3), the following key conclusions can be made:

7.1 Current systems

- Current electronic BPMSs are available for semi-trailers and trailers and measure only service brake efficiency. A market review identified 9 unique systems, although some of these were supplied as part of more than one fleet management system, sometimes under a different tradename. The exception to this was one system found which is fitted to DAF 'prime movers', i.e. rigid HGVs and tractors, as part of the electronic braking system. This system provides a driver warning when the service braking efficiency is reduced below a prescribed value, due to, for example, brake fade or worn brake linings.
- In relation to brake performance monitoring, current systems are used to measure service brake efficiency in normal operation. This is achieved by sampling braking events as they occur while driving, along with the subsequent brake pressure demand and the resulting deceleration. For operators using these systems it is typical that they are used in some safety inspections in place of directly measuring service brake efficiency via a RBT and as a predictive maintenance tool where it is used to monitor brake performance over time and flag brake efficiency issues. Once an issue has been identified, it is typical practice to carry out a RBT to confirm and diagnose the issue further to identify the specific maintenance required to remedy the issue.
- Substantial variability was found in how current systems work, particularly with respect to system inputs and how valid brake events are determined. There was also variability in system outputs, a lack of consistent verification/validation of function and no third-party check of compliance of the systems with the standard.
- The EBPMS working group have made an initial proposal for a proving procedure to verify / validate BPMSs by comparison of its results with roller brake tester (RBT) results. However, this requires further work to develop a method to compare the results, acceptance criteria, and streamlining of the procedure.
- The systems for heavy trailers (O4 category) have developed because of the availability of data via the standardised ISO 11992 CAN interface and because of a market need, both because service brake efficiency deficiencies account for a substantial proportion of trailer brake defects at MOT, and there is an opportunity to utilise the systems in place of carrying out safety inspections using a roller brake test (RBT).
    - These market drivers do not apply to other vehicle types, mainly because the required vehicle data is not standardised, but also because, for M_1 and N_1 category vehicles (passenger cars and vans) which account for the majority of vehicles, the same benefits do not exist as the brakes are only assessed annually at PTI.

- Current brake performance monitoring systems are not suitable for PTI (MOT) replacement for several reasons because they have the following disbenefits compared with the RBT:
    - Deceleration can only be measured for the whole vehicle, and therefore the service braking efficiency measured by the system is a combination of the tractor and trailer unit.
    - Brake events recorded from a trailer used in "drop and swap" type operations may be confounded by the variation in efficiency between the brakes on the different tractor units.
    - Systems do not assess imbalance, bind, time lag / grabbing, ovality and maximum brake force which are assessed by the RBT and assessed at MOT. Parking brake performance is also not assessed.
    - In principle, current BPMSs provide a brake performance average (trend), rather than an absolute point measurement and there is insufficient current data available that fully validates brake performance monitoring with RBT measured brake efficiency.
- The benefits of current brake performance monitoring compared with traditional methods have been identified as follows:
    - They provide high sample rate monitoring of the service brake efficiency over time and during operation. This allows changes in service brake efficiency to be tracked facilitating predictive maintenance which brings operational benefits in terms of efficiency (trailer taken out of service only when necessary) and timescale planning (when the trailer is maintained).
    - They can be used instead of time/resource required to laden the vehicle for a RBT test, the cost of which varies depending on the operator.
    - If it is assumed that electronic BPMSs can substitute for 3 laden roller brake trailer tests per year, using the mid-estimates, this results in a benefit of about £100 per trailer per year for the fitment of a brake monitoring system.

7.2 Future systems

- In the near-term, development of brake performance monitoring systems may include wheel end / brake temperature and additional wheel speed sensors to provide an indication of location of service braking efficiency deficiencies, and potentially other deficiencies assessed by a RBT. Temperature measured by tyre pressure monitoring systems (TPMS) could also be utilised as indicative information for location of issues. This may allow some items to be assessed that are not possible for current systems.
- In the longer term, the three major trends of connectivity, automation, and electrification will affect the future of the automotive industry and introduce both new challenges and new opportunities for vehicle braking systems.

- For future vehicle connectivity, the industry (ACEA) propose a model called the 'Extended Vehicle', detailed in ISO 20077, which is already deployed by some OEMs and being implemented by others currently (ACEA, 2021). They believe that the 'Extended Vehicle' model reflects best practices in the industry for sharing of in-vehicle data and resources[20] underpinned by the key principles of safety and security of the driver.
- A key consideration for future vehicle connectivity is cybersecurity. To assure cybersecurity OEMs are likely to introduce more security measures which could make access to vehicle data by third parties more restricted, in particular in regard to fitment of third-party devices, such as current electronic brake monitoring systems, which could create a possible attack route. Precisely how this issue may be addressed in the future is unknown at present. However, several potential options can be envisaged which are detailed in Section 6.1.2.2 and include a potential regulatory route to include specific requirements for roadworthiness checks by the ADS and data availability to authorities in the self-driving test, which is enabled by the 'power to authorise' in Section 3(1) of the Automated Vehicles Act (2024).
- Full automation will likely drive a change to more electronic based roadworthiness testing of vehicles because at full automation (i.e. SAE level 4 and 5[21]), the automated driving system (ADS) will require verification that the vehicle is in a roadworthy state before (and while) the self-driving functionality is activated, and this will need to be achieved in a cost effective manner. For the braking system, as well as continuous remote performance monitoring, a self-test performed by the ADS could be a key part of an electronic test suite because it offers greater opportunity for roadworthiness assurance. For example, it could brake individual axles and wheels and thus assess performance at axle / wheel level which is not possible currently for remote performance monitoring systems. However, braking of a vehicle for self-diagnostic purposes on public road would need to be assured to be safe and the enhanced diagnostic capability gained justified before this approach could be implemented.
- Access to the ADS self-check information could be envisaged to be available on the vehicle back-end server (as in the currently implemented Extended Vehicle model used by many vehicle manufacturers) for verification by roadworthiness inspection authorities. This would allow the performance data to be available to third parties while ensuring vehicle cyber-security.

[20] Vehicle resources are, for example, a function to allow the display of messages on a human machine interface (HMI) display or a function to activate a vehicle compartment preheating system or to open the boot remotely.

[21] Defined in SAE J3016 as 'Level 4 means that the vehicle can perform all driving tasks under certain conditions, without human intervention. Level 5 means that the vehicle can perform all driving tasks under all conditions, without human intervention or a steering wheel.'

However, this is likely to effectively close the market for third-party assessment of brake performance as the data on the server will not be real time.

  - To achieve roadworthiness assessment in a cost-effective manner will require that a large proportion of the safety inspection is performed in an electronic manner remotely, although some element of traditional visual inspection will likely still be needed alongside the electronic inspection.
  - Electrification may exacerbate an existing problem with ‘sleeping brakes’ because of greater use of regenerative braking rather than traditional friction brakes. Brake performance monitoring systems will be able to identify sleeping brakes for near term scenarios. Also, for the future given that braking systems have control over brake delivery pressure for individual axles manufacturers will likely develop braking strategies to reduce the risk of sleeping brakes developing. For example, if the friction braking force requirement was low, instead of braking all axles at a low force, which would develop sleeping brakes, one axle could be braked at a higher force to exercise individual axle brakes more and reduce the risk of sleeping brakes.

- Information from automated vehicle developers was sought in the stakeholder consultation task, but stakeholders did not engage with the project. Future research should engage with several stakeholders in this category to validate the conclusions made on this topic.

8 Recommendations

8.1 Current systems

1. Revised technical requirements for the existing EBPMS standard are recommended to ensure an improved minimum standard for current systems on trailers and semi-trailers. Revised requirements for system outputs and verification/validation procedures are specific areas of the standard that could be revised without impinging on IPR. Specific revisions recommended include:
    a. Improving requirements for **system outputs** which place appropriate requirements for:
        - An 'amber' alert for a potential service brake efficiency deficiency before the brake performance value (BPV) is confirmed as valid because BPV validity can take a significant time to confirm.
        - Re-baselining of the BPV average after maintenance activities, using a method that allows the historical record to still be referenced.

    b. Improving requirements for **system verification/validation** by:
        - Continuing to develop the 'Suggestion for a proving procedure for EBPMS' made by the EBPMS working group in March 2024. The procedure compares brake performance monitoring system results with roller brake tester results. Areas to focus on include how the comparison may be performed, potential acceptance criteria and streamlining the procedure to reduce costs while still achieving a meaningful comparison.
2. The RBT procedure would benefit by either ensuring that delivery brake pressure for the trailer is controlled to be 650 kPa or less during the RBT, or delivery pressure is measured and recorded. This would aid comparison with other methods of assessment and allow improvements to be made using evidence. Placing pressure gauges to measure delivery pressure may be logistically difficult because of health and safety issues involved with accessing the necessary components and the time required to connect and disconnect the gauges safely before and after the RBT. An efficient solution to this issue would be if delivery pressure was made available on the vehicle CAN so that it can be read by a diagnostic tool via the OBD port. CITA have made a proposal to GRVA to amend UN Regulation No. 13 to mandate this for electrical transmission braking systems [22], but it has not been adopted at present because the industry have concerns about the cybersecurity implications of this action[23].

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[22] Working document ECE/TRANS/WP.29/GRVA/2025/18: Retrieved March 2025 from: https://unece.org/info/events/event/396013

[23] Informal document GRVA-21-52: Retrieved March from: https://unece.org/info/events/event/396013

8.2 Future systems

3. Further research is needed to understand the requirements and potential opportunities for 'down-stream' benefits that could be attained by future regulation or other mechanisms (e.g. voluntary industry standards). This research could include options for how the roadworthiness for fully automated vehicles could be assured and verified by inspection authorities.
4. The current project suggests that a potential solution to assure the roadworthiness of braking systems for future fully automated vehicles of all vehicle types could be to regulate. Requirements could be incorporated in secondary legislation developed for the self-driving test which the vehicle must pass to be granted authorisation for use. The self-driving test is enabled via the 'power to authorise' in Section 3(1) of the Automated Vehicles Act (2024). Specific requirements for the ADS to check the vehicle's roadworthiness state to permit its use could be included, along with requirements for data availability so that authorities can validate the vehicle's roadworthiness. It is recommended that this is investigated further. The advantages of this potential solution include that it would give the manufacturer more freedom over what system they implement. Also, detailed requirements could be included to ensure that inspection bodies, such as DVSA, could perform independent validation of the vehicle's roadworthiness.

9 References

ACEA. (2021). *Access to in-vehicle data*. Retrieved March 2025, from https://www.acea.auto/files/ACEA_position_paper-Access_to_in-vehicle_data.pdf

Automated Vehicles Act. (2024). Automated Vehicles Act. Retrieved May 2025, from https://www.legislation.gov.uk/ukpga/2024/10

Axscend. (2025). *Axscend EBPMS savings calculator*. Retrieved March 2025, from https://axscend.com/ebpms

DVSA. (2024, September 10). Electronic braking performance monitoring system (EBPMS): industry standard specification. https://www.gov.uk/government/publications/electronic-braking-performance-monitoring-systems/electronic-braking-performance-monitoring-system-ebpms-industry-standard-specification#requirements-specification

DVSA. (2024a). *Guide to maintaining roadworthiness: commercial vehicles and passenger carrying vehicles.* Retrieved March 2025, from https://assets.publishing.service.gov.uk/media/6751b5d044885d072cecbd62/guide-to-maintaining-roadworthiness-commercial-goods-and-public-service-vehicles.pdf

DVSA. (2024b). *Heavy goods vehiclke (HGV) inspection manual.* Retrieved March 2025, from https://assets.publishing.service.gov.uk/media/665840b0d470e3279dd333a4/hgv-inspection-manual.pdf

DVSA. (2024c). Public Service Vehicle (PSV) Inspection Manual. Retrieved March 2025, from https://assets.publishing.service.gov.uk/media/67e295bb148bef6fa4cfdaa2/psv-inspection-manual.pdf

HSE. (2007). Guidance on brake testing for rubber-tyred vehicles operating in quarries, open cast coal sites and mines. Retrieved March 2025, from https://www.hse.gov.uk/quarries/assets/docs/braketesting.pdf

ISO 20077. (2017). Road Vehicles — Extended vehicle (ExVe) methodology. Retrieved March 2025, from https://www.iso.org/standard/66975.html

Logistics UK. (2024). *Brake Testing – Financial impact (revised March 2024).*

Road Traffic Act. (1988). https://www.legislation.gov.uk/ukpga/1988/52/contents

Traffic Commissioners for Great Britian . (2024, November). Guidance – Operator compliance audits. Retrieved March 2025, from https://www.gov.uk/government/publications/operator-compliance-audits/operator-compliance-audits#operator-compliance-audits

10 Glossary

ABS	Anti-lock Braking System
ACEA	European Automobile Manufacturers' Association, see https://www.acea.auto/about-acea/
ADS	Automated Driving System
ASDE	Automated Self Driving Entity: Related to the Automated Vehicles Act 2024, a legal actor initially defined by the Law Commissions. 'It is the entity that puts an Automated Vehicle forward for authorisation as having self-driving features. It may be the vehicle manufacturer, or a software designer, or a joint venture between the two'.
BAS	Brake Assist System
BPMS	Brake Performance Monitoring System
BPV	Brake Performance Value, see EBPMS standard for definition
DVSA	Driver & Vehicle Standards Agency
EBPMS	Electronic Braking Performance Monitoring System: A type of brake performance monitoring system trademarked by the industry, see EBPMS standard: https://www.gov.uk/government/publications/electronic-braking-performance-monitoring-systems/electronic-braking-performance-monitoring-system-ebpms-industry-standard-specification
EBS	Electronic Brake System
HGV	Heavy Goods Vehicle
MOT	Ministry of Transport test, name of periodic technical inspection (PTI) test in the UK
NUiCO	No User In-Charge Operator: Related to the Automated Vehicles Act 2024, a legal actor initially defined by the Law Commissions. 'Some features will be authorised for use without a user-in-charge. We refer to these as "No User-In-Charge" (NUiC) features. It is understood that when a NUiC feature is engaged on a road or other public place, the vehicle's roadworthiness is overseen by a licensed NUiC Operator (NUiCO)'.
OEM	Original Equipment Manufacturer
PSV	Public Service Vehicle
PTI	Periodic Technical Inspection
RBT	Roller Brake Test(er)

Appendix A Scope of MOT test and description of vehicle MOT classes / related information

A.1 Scope of MOT test

- Identification of the vehicle

  Registration plate (number plate) and vehicle identification number.

  - Vehicle registration mark
  - Vehicle identification number

- Braking equipment

  Brake condition and operation, service brakes, secondary brakes, parking brakes, anti-lock braking system (ABS), electronic braking system (EBS) and brake fluid.

  - Mechanical condition and operation
  - Performance and efficiency

- Steering

  Mechanical condition, steering wheel and column or handlebar, forks and yokes, steering play and electronic power steering (EPS).

  - Mechanical condition
  - Steering wheel, column and handlebar
  - Steering play
  - Electronic Power Steering

- Visibility

  Field of vision, bonnet catches, condition of the glass, the view to the rear, windscreen wipers and windscreen washer.

  - Field of vision
  - Condition of glass
  - Rear-view mirrors / devices
  - Windscreen wipers / washers,
  - Demisting system

- Lamps, reflectors and electrical equipment

  Headlamp, position lamps, daytime running lamps, stop lamps, indicators, hazard warning lamps, fog lamps, reversing lamps, lighting ‘tell-tales’, trailer electrical socket, electrical wiring and battery.

  - Headlamps

  - Front and rear position lamps, side marker lamps, end outline marker lamps and daytime running lamps
  - Stop lamps
  - Direction indicator and hazard warning lamps
  - Front and rear fog lamps
  - Reversing lamps
  - Rear registration plate lamp
  - Retro-reflectors, conspicuity (retro reflecting) markings and rear marking plates
  - Tell-tales mandatory for lighting equipment
  - Electrical connections to trailer
  - Electrical wiring
  - Non obligatory lamps and retro-reflectors
  - Battery(ies)
- Axles, wheels, tyres and suspension

  Axle, wheel bearing, wheel and tyres, tyre pressure monitoring system (TPMS), and suspension (including springs, shock absorbers, and suspension arms and joints).

  - Axles including wheel bearings
  - Wheels and tyres
  - Suspension system including springs, shock absorbers, and joints
- Chassis and chassis attachments

  Structure and attachments (including exhaust system and bumpers), and body and interior (including doors and catches, seats and floor).

  - Chassis or frame and attachments including condition of chassis and attachments such as exhaust, fuel tank, tow bar, spare wheel carrier, transmission, engine mounting and engine performance.
  - Cab and bodywork including condition, mounting, doors, seats, driving controls.
- Other equipment

  Seat belts and restraint systems, airbags, anti-theft devices, horn, speedometer, speed limiter and electronic stability control (ESC).

  - Safety-belts/buckles and restraint systems
  - Lock and anti-theft device
  - Fire extinguisher, warning triangle, first aid kit, wheel chocks (if needed)
  - Audible warning device (horn)

  - Speedometer
  - Tachograph and speed limitation device (if fitted / needed)
  - Odometer
  - Electronic Stability Control (ESC) (if fitted / needed)
- Nuisance

  Noise, exhaust emissions, engine malfunction indicator lamp (MIL) (sometimes called an engine management light or 'EML'), and fluid leak.

  - Noise
  - Exhaust emissions
  - Electromagnetic interference suppression
  - Fluid leaks
- Supplementary tests for passenger carrying vehicles categories M2, M3

  Entrance and exit doors, emergency exits, passenger grab handles, steps and stair.

  - Doors
  - Demisting and defrosting system
  - Ventilation & heating system
  - Seats
  - Interior lighting and destination devices
  - Gangways, standing areas
  - Stairs and steps
  - Passenger communication system
  - Notices
  - Requirements on the transportation of children
  - Requirements on the transportation of persons with reduced mobility
  - Other special equipment such as installations for food equipment and sanitary installations

A.2 Description of vehicle MOT classes / related information

A description of vehicle MOT classes, together with their European-type approval categories and age at which the first test is required are listed in Table A.1 below.

Table A.1: Vehicle MOT class compared to European type approval category

Figure Table Vehicle class (UK)	European type approval category	Class Description	Age at which first test is needed (years)
Class 1	L1, L3 or L4	Motorcycles (with or without sidecar) capacity up to 200cc, max continuous power < 4kW, max design speed < 45 km/h (28mph)	3
Class 2	L3 or L4	Motorcycles (with or without sidecar) that are not class 1, i.e. capacity > 200cc, max continuous power > 4kW, max design speed > 45 km/h (28mph)	3
Class 3	L2 or L5	Three-wheeled vehicles not exceeding 450kg unladen weight (ULW) (excluding motorcycle combinations)	3
Class 4	L5	Three-wheeled vehicles more than 450kg unladen weight ULW	3
Class 4	L6 or L7	Quadricycles	3
Class 4	M1	Cars, passenger vehicles, motor caravans, Private Hire Vehicles, and dual-purpose vehicles in all cases with up to eight passenger seats.	3
Class 4	N1	Goods vehicles not exceeding 3,000kg DGW	3
Class 4	M1	Taxis and ambulances in either case with up to eight passenger seats	1
Class 4	M2	Passenger vehicles, ambulances, motor caravans and dual-purpose vehicles in all cases with nine to twelve passenger seats that: • are fitted with no more seat belts than the minimum needed because of their construction; or • are identified as having been fitted with a type approved seat belt installation when built; or • have been tested as class 4A, 5A or 6A (PSV) with at least the same number of seat belts as are currently fitted.	1
Class 5	M2 or M3	Private passenger vehicles, ambulances, motor caravans and dual-purpose vehicles with 13 or	1

Figure Table Vehicle class (UK)	European type approval category	Class Description	Age at which first test is needed (years)
		more passenger seats (including community and play buses, etc.) that: • are fitted with no more seat belts than the minimum needed because of their construction; or • are identified as having been fitted with a type approved seat belt installation to all seats when built; or • have been tested as class 5A or class 6A (PSV) with at least the same number of seat belts as are currently fitted.	
Class 6 / 6A	M2 or M3	Public Service Vehicle (PSV) fitted with nine or more passenger seats (not including driver seat)	1
Class 7	N1	Goods vehicles over 3,000kg and up to and including 3,500kg DGW	3
HGVs and trailers	N2 or N3, O3 or O4	Heavy Goods Vehicles > 3,500 kg Trailers with maximum mass > 3,500 kg	1

Appendix B Electronic Braking System (EBS) warnings

UN Regulation No. 13 requires the fitment of the following optical brake failure and defect warning signals (5.2.1.29):

- 5.2.1.29.1.1: A red warning signal which indicates failures within the vehicle braking equipment which preclude achievement of the prescribed service braking performance and/or which preclude the functioning of at least one of two independent service braking circuits
- 5.2.1.29.1.2: A yellow warning signal indicating an electrically detected defect within the vehicle braking equipment, which is not indicated by the red warning signal described in paragraph 5.2.29.1.1 above
- 5.2.1.29.2: Power-driven vehicles equipped with an electric control line and/or authorised to tow a trailer equipped with an electric control transmission, shall be capable of providing a separate yellow warning signal to indicate a defect within the electric control transmission of the braking equipment of the trailer. The signal shall be activated from the trailer as follows:

  (a) Via pin 5 of the electric connector conforming to ISO 7638:20039 or, as relevant, via the equivalent pin of an automated connector

  (b) By the amber warning signal request whenever the trailer provides corresponding failure information via the data communications part of the electric control line.
- 5.1.4.7.1: Verification of warning signals at PTI - Where the operational status is indicated to the driver by warning signals, as specified in this Regulation, it shall be possible at a periodic technical inspection to confirm the correct operational status by visual observation of the warning signals following a power-on

Specific failures and defects that require warning include:

- 5.1.3.3: Incompatible trailer coupling – a tractor equipped with one pneumatic supply line and one electric control line shall recognise that a trailer equipped with one pneumatic supply line and one pneumatic control line is not compatible. When such vehicles are electrically connected via the electric control line of the towing vehicle, the driver shall be warned by the red optical warning signal specified in paragraph 5.2.1.29.1.1.and when the system is energised, the brakes on the towing vehicle shall be automatically applied. This brake application shall provide at least the prescribed parking braking performance.

  Note that this warning is effectively mandatory because it will need to be fitted to all tractors.
- 5.1.3.4.3: No trailer pneumatic signal - When the electric control signal has exceeded the equivalent of 100 kPa for more than 1 second, the trailer shall verify that a pneumatic signal is present; should no pneumatic signal be present, the driver shall be warned from the trailer by the separate yellow warning signal specified in paragraph 5.2.1.29.2.

Note that this warning is effectively mandatory because will it need to be fitted to all tractors.

- 5.1.3.6.3: Trailer electric control line failure: When a power-driven vehicle is equipped with an electric control line and electrically connected to a trailer equipped with an electric control line, a continuous failure (> 40 ms) within the electric control line shall be detected in the power-driven vehicle and shall be signalled to the driver by the yellow warning signal specified in paragraph 5.2.1.29.1.2.

  Note that this warning is effectively mandatory because it will need to be fitted to all tractors.

- 5.2.1.8.1: EBS braking compensation defect (M2, M3, & N category vehicles, for O category see 5.2.2.5.1) - Compensation by the electric control transmission for deterioration or defect within the braking system shall be indicated to the driver by means of the yellow warning signal specified in paragraph 5.2.1.29.1.2. This requirement shall apply for all conditions of loading when compensation exceeds the following limits:

  5.2.1.8.1.1. a difference in transverse braking pressures on any axle of:

  (a) 25 per cent of the higher value for vehicle decelerations 2m/s2

  (b) A value corresponding to 25 per cent at 2m/s2 for decelerations below this rate.

  5.2.1.8.1.2. An individual compensating value on any axle:

  (a) > 50 per cent of the nominal value for vehicle decelerations 2 m/s2

  (b) A value corresponding to 50 per cent of the nominal value at 2m/s2 for decelerations below this rate.

  Compensation as defined above, is permitted only when the initial brake application is made at vehicle speeds greater than 10 km/h.

  Notes:

  - The paragraph specified is applicable to vehicles of category M2, M3 and N only. However, there is an equivalent requirement for category O vehicles in paragraph 5.2.25.1 (exact same wording).
  - This warning is effectively optional because it only needs to be fitted if the action of the service braking system is not distributed evenly between wheels of one and the same axle symmetrically.

- 5.2.1.13: Energy reservoir low - Any vehicle fitted with a service brake actuated from an energy reservoir shall, where the prescribed secondary braking performance cannot be obtained by means of this braking system without the use of the stored energy, be provided with a warning device, in addition to a pressure gauge, where fitted, giving an optical or acoustic signal when the stored energy, in any part of the system, falls to a value at which without re-charging of the reservoir and irrespective of the load conditions of the vehicle, it is possible to apply the service brake control a fifth time after four full-stroke actuations and obtain the prescribed secondary braking performance (without faults in the service brake transmission and with the brakes adjusted as closely as possible). This warning device shall be directly and permanently connected to the circuit. When the engine is running under normal operating conditions and there are no faults in the braking system, as is the case in approval tests for this type, the warning device shall give no signal except during the time required for charging the energy reservoir(s) after start-up of the engine. The red warning signal specified in paragraph 5.2.1.29.1.1. shall be used as the optical warning signal.

Note that this warning is effectively mandatory because it will need to be fitted to all tractors.

- 5.2.1.27.3: Electric control transmission failure - failure within the electric control transmission, not including its energy reserve, that affects the function and performance of systems addressed in this Regulation shall be indicated to the driver by the red or yellow warning signal specified in paragraphs 5.2.1.29.1.1. and 5.2.1.29.1.2., respectively, as appropriate. When the prescribed service braking performance can no longer be achieved (red warning signal), failures resulting from a loss of electrical continuity (e.g. breakage, disconnection) shall be signalled to the driver as soon as they occur, and the prescribed residual braking performance shall be fulfilled by operating the service braking control in accordance with paragraph 2.4. of Annex 4 to this Regulation. These requirements shall not be construed as a departure from the requirements concerning secondary braking.

  Note that this warning is effectively mandatory because it will need to be fitted to all tractors.

Appendix C Earned recognition

The DVSA earned recognition scheme is a voluntary scheme to prove that a licensed operator is compliant with legal requirements and maintains high standards of operation. The main requirement is for the operator to use a DVSA-validated IT system for vehicle maintenance and drivers' hours which monitors a set of key performance indicators (KPIs) and every 4 weeks reports to DVSA if any KPIs are missed. If this happens, DVSA will work with the operator to fix any problems.

The benefits of the scheme include:

- proof of being an exemplary operator, which can be used when bidding for contracts
- lesser likelihood to have vehicles stopped at the roadside for inspections
- lesser likelihood to have DVSA enforcement staff visit your premises
- use the DVSA earned recognition logo on your website and other publicity materials (but not on your vehicles)
- recognition as a DVSA-accredited operator on GOV.UK
- direct access to a dedicated earned recognition team in DVSA

To be eligible for the scheme an operator must meet the following criteria:

- held a heavy goods vehicle (HGV) or public service vehicle (PSV) operator licence for at least 2 years
- had no regulatory action (other than a formal warning) taken by the Traffic Commissioner on any operator licences in the last 2 years
- have management systems for vehicle maintenance and digital management systems for drivers' hours, which can be used to track the KPIs and report if they're missed
- meet the earned recognition audit standards

There is no application fee, but to join the scheme and every two years after joining the operator's systems and processes must be audited by a DVSA-authorised audit provider. The audit includes the following areas:

- Operator licences
- Transport manager or responsible person
- Vehicle standards
- Drivers' hours
- Operation management
- Security requirements
- Driver management
- Training

- Additional policies
- ADR - carriage of dangerous goods

A KPI for vehicle standards (roadworthiness) is an initial pass rate of 95% or more[24] for the annual MOT test.

[24] Note: If the fleet has 20 or less vehicles, the 95% key performance indicator (KPI) does not apply. Instead, there must be no more than one initial fail in a rolling 12 months.

Appendix D Stakeholder topic guide

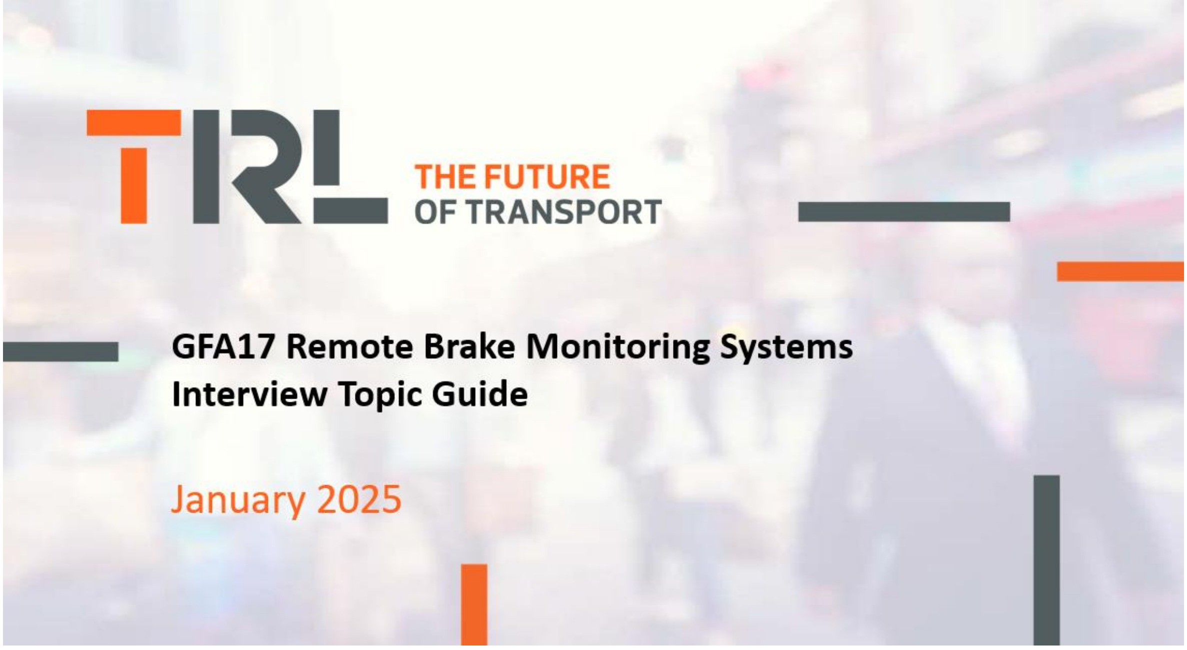

Figure D.1: GFA17 Brake performance Monitoring Systems Interview Topic Guide

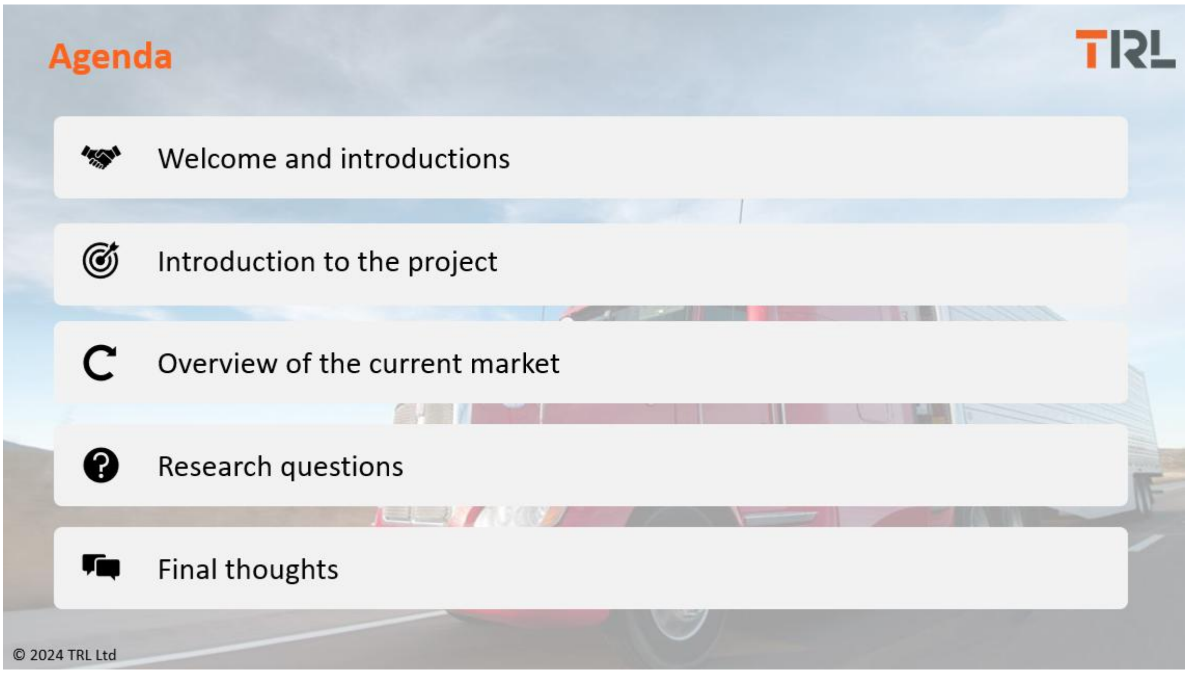

Figure D.2: Agenda

Introduction to the project

The project aims to investigate remote brake monitoring systems to understand better current and future capabilities, benefits and disbenefits, high-level costs, and feasibility with respect to predictive maintenance, roadworthiness/safety, and periodic technical inspection (MOT).

Project aim:

To assess the effectiveness and feasibility of technical solutions for brake performance monitoring systems for current and future vehicles with all relevant stakeholders.

Figure D.3: Introduction to the project

Project background

- **Braking performance is critical for vehicle safety and roadworthiness**. Safe performance is ensured via Periodic Technical Inspection (PTI) and additional, more frequent, intermediate safety inspections for large commercial and passenger vehicles.
- **Advancements in technology** - Electronic Brake Performance Monitoring Systems (EBPMS) - have offered the possibility of monitoring brake performance while the vehicle is in use.
- **In the future, the need for electronic monitoring will be greater** because, in the case of Automated Vehicles (AVs), there will not be a driver present to monitor that the vehicle is functioning correctly.
- **The extent to which EBPMS can be used for current and future automated vehicles** to substitute for PTI and roadworthiness checks requires further investigation in terms of capability and effectiveness compared to current testing regimes.
- This project focuses on exploring EBPMS to assess how effectively they could be used to ensure road safety, both for current vehicles and for future vehicles that may have no driver at all to directly assess braking performance feedback.

Figure D.4: Project background

Project aims

- Investigate current remote brake monitoring systems and related developments to understand their current and potential future capability
- Identify benefits and disbenefits of remote brake monitoring systems compared with current methods for periodic technical inspection and roadworthiness/safety
- Identify high-level costs and feasibility of remote brake monitoring systems compared with current methods for periodic technical inspection and roadworthiness/safety
- Identify the applicability of remote braking system for automated vehicles and implications for PTI and roadworthiness/safety

Figure D.5: Project aims

Intended outputs

A comprehensive research report synthesizing the findings on:

- Information on current and future remote brake performance monitoring technologies
- The viability for remote braking performance systems as an alternative to the driver for in-use monitoring, safety inspections and the statutory PTI
- Identification of the benefits and disbenefits of remote monitoring compared to the existing methods
- Identification of the high-level cost implications of remote monitoring compared with existing methods
- The feasibility of developing a recognized standard for remotely monitored braking performance systems
- Implications of remote brake performance monitoring for automated vehicles

Figure D.6: Intended outputs

Figure D.7: Benefits of taking part

Overview of the current project findings

- Current EBPMS only fitted to trailers and semi-trailers because these vehicles have standardised CAN format. For other current vehicle types this is a major technical barrier
  - Current systems measure whole vehicle deceleration and allow:
    - Measurement of braking performance in use, so can monitor performance over time and use for predictive maintenance
    - Assessment that braking performance meets requirements without time/cost associated with roller brake test (fully laden)
  - Issues identified for current systems:
    - Selection of braking events is not defined by current standard. It could also take time to collect and act upon the sample of braking events
    - Accuracy of extrapolation to brake performance in fully-laden condition at 6.5 bar brake pressure demand (for trailers)
    - Unable to identify individual wheel or axle brake deficiencies
    - Frequent changes of tractor and trailer combination may reduce the accuracy of tracking trailer brake performance over time
    - Some factors relating to brake condition assessed at PTI are not/cannot be assessed
- Future EBPMS will be necessary for automated vehicles to monitor in-use brake performance
  - Likely to have similar issues with PTI as current vehicles?
  - Require standardisation of, or minimum dataset available from, the CAN or CAN equivalent

Figure D.8: Overview of the current project findings

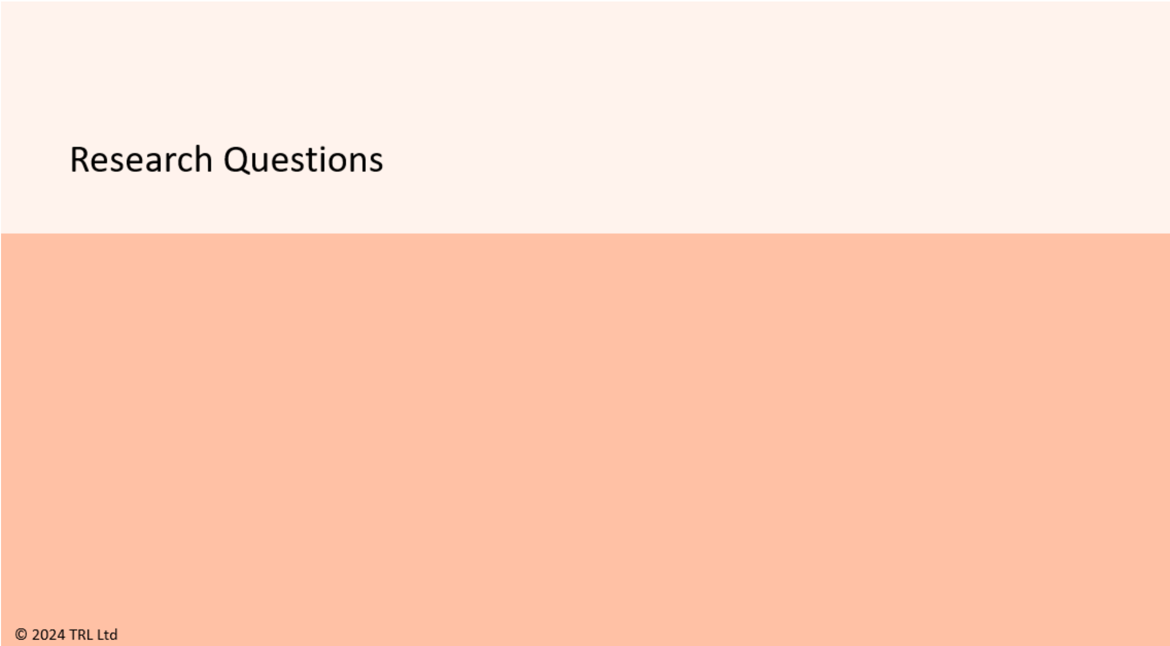

Figure D.9: Research Questions

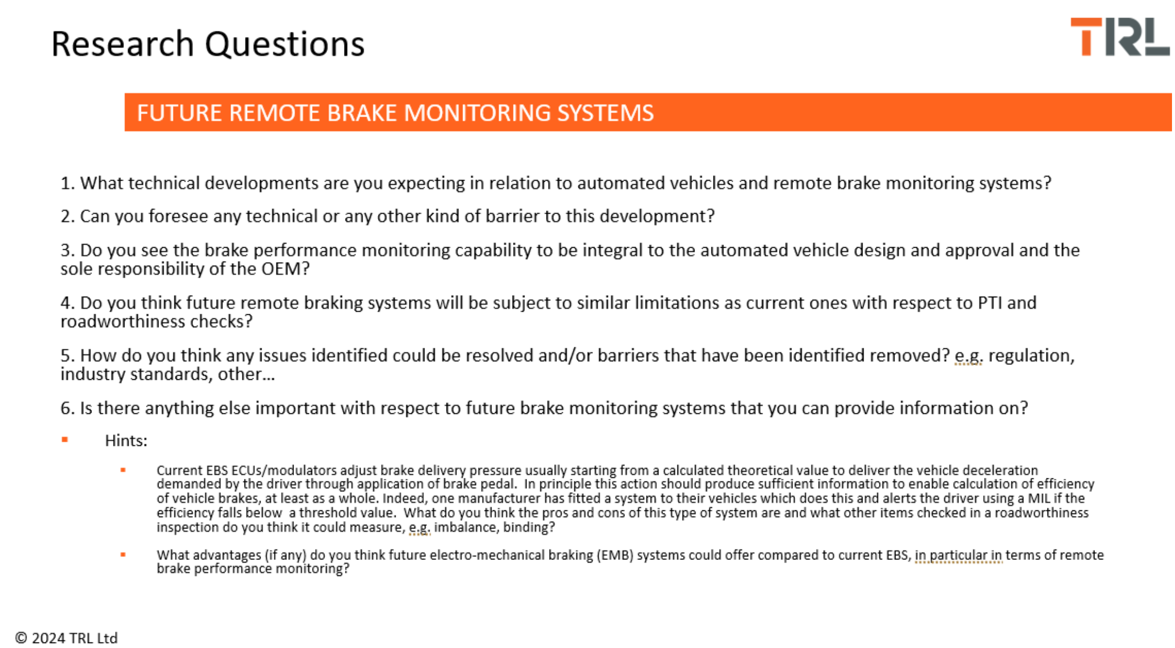

Figure D.10: Research Questions: Future Remote Braking Monitoring Systems

Research Questions

EBPMS Manufactures/Suppliers – CURRENT SYSTEMS

1. What vehicle types can your EBPMS be installed on?
2. What issues do you/would you experience in developing systems for passenger cars, vans, and other vehicle types? Can you explain any technical barriers
3. What EBS manufacturer systems does your EBPMS work with?
4. What is the trade name of your EBPMS and what telematics package(s) is it sold as part of?
5. Is your EBPMS compliant with the DVSA standard?
6. Do you have an information document for your EBPMS? If yes, please can you supply copy of document.
7. Can your EBPMS detect issues with individual wheel brakes?
8. Does/can your EBPMS report anything else other than Braking Performance Value (BPV)? If yes, please describe what else reported

Figure D.11: Electronic brake performance monitoring systems Manufacturers/Suppliers – Current Systems

Research Questions

EBPMS Manufactures/Suppliers – CURRENT SYSTEMS

9. What demand pressure does your EBPMS estimate the Braking Performance Value (BPV) for?
10. What testing / calibration of your EBPMS have you performed to verify that it can detect an under-performing braking system? Can you provide any details?
11. What benefits could an operator expect to realise from fitment of your EBPMS? Can you quantify this?
12. As well as measuring brake efficiency, a Roller Brake Test (RBT) measures brake bind, imbalance and ovality. Do you think that EBPMS could be developed to measure any of these and/or other brake defects? If yes, please explain how.
13. What additional capability do you think EBPMS may be able to offer in the future?
14. Is there any other information that you consider relevant that has not been covered in the questions?

Figure D.12: Research Questions: Electronic brake performance monitoring systems Manufacturers/Suppliers – Current Systems

Research Questions

Operators– CURRENT SYSTEMS

1. Do you use EBPMS? If so, which specific EBPMS do you use (e.g make, trade name) for the trailers you use?

2. Do your tractor units have any brake performance monitoring systems? Do you have any issues with compatibility of systems?

3. Is the EBPMS you use compliant with the DVSA standard?

4. Do you have an information document for your EBPMS? If yes, please can you supply copy of document.

5. Can the EBPMS detect issues with individual wheel brakes?

6. Does/can the EBPMS report anything else other than Braking Performance Value (BPV)?

7. What demand pressure does the EBPMS estimate the Braking Performance Value (BPV) for?

8. What is the approximate cost for the system per vehicle? Or can you define the cost another way?

Figure D.13: Operators – Current Systems

Research Questions

Operators – CURRENT SYSTEMS

9. What benefits have you realised from fitment of EBPMS? Can you quantify this? Example answer: reduced number of Roller Brake Tests with saving of £X per year, per trailer. allows preventive maintenance actions, cost saving £X, other..

10. Have you experienced any implementation or in use problems of EBPMS? If yes, can you provide details

11. What else would you like it to do that it doesn't already?

12. What maintenance if any is necessary for the system and how frequently and what is the approximate cost per vehicle?

13. Is there any other information that you consider relevant that has not been covered in the questions?

Figure D.14: Research Questions: Operators – Current Systems

Research Questions

Brake and Truck manufacturers– CURRENT SYSTEMS

1. What data do you make available from the EBS to an EBPMS? can you provide a list?

2. What brake defects can your EBS detect currently? In the future, what brake defects or type of brake defects do you think that it will be possible (and not possible) to detect through the use of electronic systems?

3. Is it possible to detect issues with individual brakes? If yes, can you explain how is this achieved?

4. Are you planning / performing any brake product developments for future automated vehicles? If yes, please explain what (with focus on maintenance / roadworthiness).

5. Is there any other information that you consider relevant that has not been covered in the questions?

Figure D.15: Research Questions: Brake and Truck manufacturers - Current Systems

Research Questions

Trailer manufacturers/leasing– CURRENT SYSTEMS

1. Do you use EBPMS? If so, which specific EBPMS do you use (e.g make, trade name)?

2. Is the EBPMS you use compliant with the DVSA standard?

3. Do you have an information document for the EBPMS? If yes, please can you supply copy of document.

4. Can the EBPMS detect issues with individual wheel brakes?

5. Does/can the EBPMS report anything else other than Braking Performance Value (BPV)?

6. What demand pressure does the EBPMS estimate the Braking Performance Value (BPV) for?

7. What is the approximate cost for the system per vehicle? Or can you define the cost another way?

Figure D.16: Research Questions: Trailer manufacturers/leasing - Current Systems

Research Questions

Trailer manufacturers/leasing– CURRENT SYSTEMS

8. What do you see as benefits? Can you provide any examples or approximate values on these? Example answer: reduced number of Roller Brake Tests with saving of £X per year, per trailer. allows preventive maintenance actions, cost saving £X, etc..

9. Have you experienced any implementation or in use problems? If yes, please can you provide details

10. What else would you like it to do that it doesn't already?

11. What maintenance, if any, is necessary for the system and how frequently?

12. Is there any other information that you consider relevant that has not been covered in the questions?

Figure D.17: Research Questions: Trailer manufacturers/leasing - Current Systems

Final thoughts

Figure D.18: Final thoughts

Appendix E Stakeholder questionnaire

E.1 Questions for brake and truck manufacturers

1. What data do you make available from the EBS to an EBPMS? can you provide a list?
2. What brake defects can your EBS detect currently?
   - In the future, what brake defects or type of brake defects do you think that it will be possible (and not possible) to detect through the use of electronic systems?
3. Is it possible to detect issues with individual brakes? Y/N
   - If yes, can you explain how this is achieved?
4. Are you planning / performing any brake product developments for future automated vehicles?
   - If yes, please explain what (with focus on maintenance / roadworthiness).”
5. Is there any other information that you consider relevant that has not been covered in the questions?

E.2 Questions for Electronic brake performance monitoring systems manufacturers/suppliers

1. What vehicle types can your EBPMS be installed on?
   - *Example answer: all trailer pneumatically operated systems with EBS and utilising a 7 pin ISO7638 connector incorporating CAN data bus.*

2. What issues do you/would you experience in developing systems for passenger cars, vans, and other vehicle types? Can you explain any technical barriers?

3. What EBS manufacturer systems does your EBPMS work with?
   - *Example answer: Wabco (ZF CV Solutions), Knorr-Bremse, Haldex (Saf-Holland), Other*

4. What is the trade name of your EBPMS and what telematics package(s) is it sold as part of?
   - *Example answer: Cargofleet, part of idem gateway telematics package.*

5. Is your EBPMS compliant with the DVSA standard?

6. Do you have an information document for your EBPMS? Y/N
   - *If yes, please can you supply copy of document.*

   Note: DVSA standard requires that information document made available which contains certain specified information

7. Can your EBPMS detect issues with individual wheel brakes? Y/N (Note: DVSA standard requires that a singular defective brake is identified if data is available to do this)

8. Does/can your EBPMS report anything else other than Braking Performance Value (BPV)?
   - If yes, please describe what else reported.

9. What demand pressure does your EBPMS estimate the Braking Performance Value (BPV) for?
   - *Example answer: 6.5 bar*

10. What testing / calibration of your EBPMS have you performed to verify that it can detect an under-performing braking system? Can you provide any details?

11. What benefits could an operator expect to realise from fitment of your EBPMS? Can you quantify this?
    - *Example answer: reduced number of Roller Brake Tests with saving of £X per year, per trailer. allows preventive maintenance actions, cost saving £X, other...*

12. As well as measuring brake efficiency, a Roller Brake Test (RBT) measures brake bind, imbalance and ovality. Do you think that EBPMS could be developed to measure any of these and/or other brake defects?
    - If yes, please explain how.

13. What additional capability do you think EBPMS may be able to offer in the future?

14. Is there any other information that you consider relevant that has not been covered in the questions?

E.3 Questions for operators

1. Do you use EBPMS? If so, which specific EBPMS do you use (e.g. make, trade name) for the trailers you use?

2. Do your tractor units have any brake performance monitoring systems? Do you have any issues with compatibility of systems?

3. Is the EBPMS you use compliant with the DVSA standard?

4. Do you have an information document for your EBPMS? Y/N

   (Note: DVSA standard requires that information document made available which contains certain specified information) If yes, please can you supply copy of document.

5. Can the EBPMS detect issues with individual wheel brakes? Y/N

   (Note: DVSA standard requires that a singular defective brake is identified if data is available to do this)

6. Does/can the EBPMS report anything else other than Braking Performance Value (BPV)?

7. What demand pressure does the EBPMS estimate the Braking Performance Value (BPV) for? e.g. 6.5 bar

8. What is the approximate cost for the system per vehicle? Or can you define the cost another way?

9. What benefits have you realised from fitment of EBPMS? Can you quantify this?

Example answer: reduced number of Roller Brake Tests with saving of £X per year, per trailer. allows preventive maintenance actions, cost saving £X, other...

10. Have you experienced any implementation or in use problems of EBPMS?

    - If yes, can you provide details

11. What else would you like it to do that it doesn’t already?

12. What maintenance if any is necessary for the system and how frequently and what is the approximate cost per vehicle?

13. Is there any other information that you consider relevant that has not been covered in the questions?

E.4 Questions for trailer manufacturers/leasing

1. Do you use EBPMS? If so, which specific EBPMS do you use (e.g. make, trade name)?
2. Is the EBPMS you use compliant with the DVSA standard? Y/N
3. Do you have an information document for the EBPMS? Y/N
   - If yes, please can you supply copy of document.

   (Note: DVSA standard requires that information document made available which contains certain specified information)
4. Can the EBPMS detect issues with individual wheel brakes? Y/N

   (Note: DVSA standard requires that a singular defective brake is identified if data is available to do this)
5. Does/can the EBPMS report anything else other than Braking Performance Value (BPV)?
6. What demand pressure does the EBPMS estimate the Braking Performance Value (BPV) for?
   - *Example answer: 6.5 bar*
7. What is the approximate cost for the system per vehicle? Or can you define the cost another way?
8. What do you see as benefits?
   - Can you provide any examples or approximate values on these?

   Example answer: reduced number of Roller Brake Tests with saving of £X per year, per trailer. allows preventive maintenance actions, cost saving £X, etc.
9. Have you experienced any implementation or in use problems? Y/N
   - If yes, please can you provide details
10. What else would you like it to do that it doesn't already?
11. What maintenance, if any, is necessary for the system and how frequently?
12. Is there any other information that you consider relevant that has not been covered in the questions?

Appendix F Standards and Regulation

F.1 Standards

ISO 26262: 2018 This standard is focused on electrical/electronic (E/E) systems and currently limited to malfunctioning behaviour without covering situational awareness, the intended functionality, or its implementation. This standard is being revised to account for the development of architectures for automated vehicles and is due for publication around 2027. These revisions include consideration of:

- Updates for artificial intelligence and machine learning, which will include alignment with the new standards ISO TS 5083 and PAS 8800 which offer industry specific guidance on the use of AI systems in safety-related functions.
- Updates for fail operational type architectures
- Updates to include requirements for software development and management.

Note that situational awareness and intended functionality type issues will be covered by a combination of other standards, in particular ISO 21448 'Safety of the intended functionality'.

F.2 Regulation

The UNECE GRVA 'Automated/Autonomous and Connected Vehicles' working party are developing new UN regulations (for the Automated Driving System (ADS)) and revising current UN regulations so that they are proper for the approval of automated vehicles. For braking, revisions to UN Regulation No. 13 and UN Regulation No. 13H are being developed currently. A main update which is being developed currently, is a revision to permit implementation of different safety concepts for automated vehicles and use of Electro-Mechanical Braking (EMC) systems.

For current Electronically controlled Braking Systems (EBS) the safety concept usually consists of an electric control transmission with a redundant pneumatic transmission and dual split circuits providing redundancy for energy transmission as illustrated in Figure F.1:.

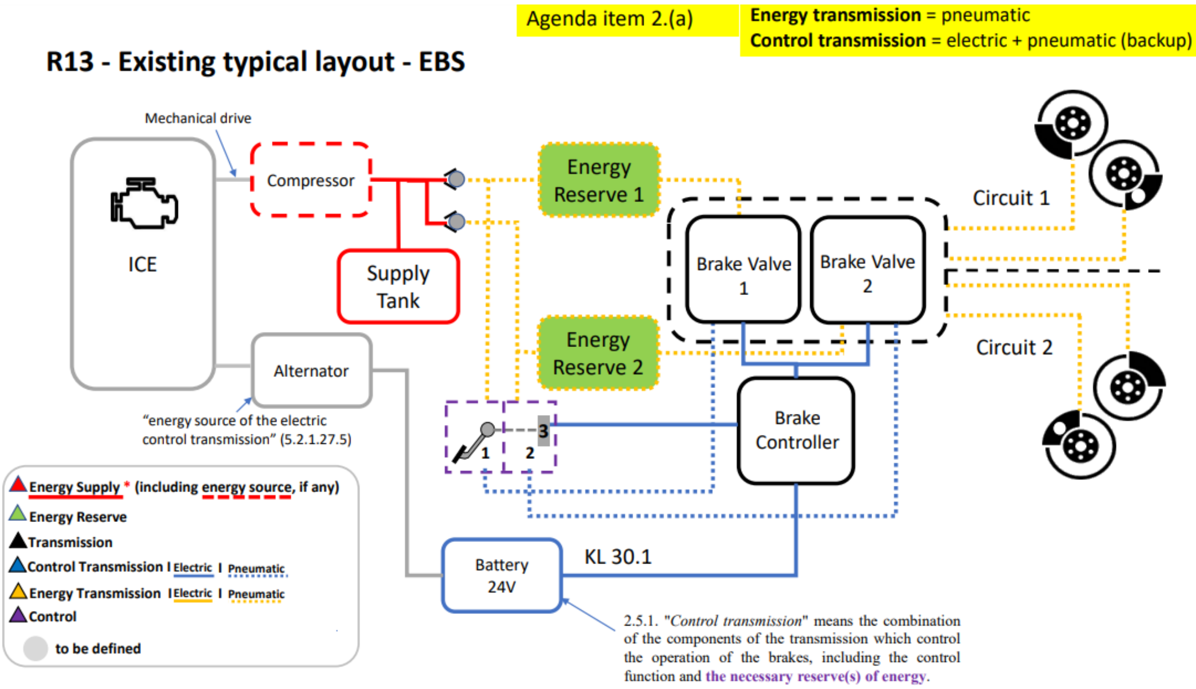

Figure F.1:Typical layout for current EBS showing safety concept, namely redundancy in control transmission (electric with pneumatic redundancy) and energy transmission (dual circuits). Source: UNECE Doc GRVA-EMB-02/Rev.1

The braking regulation is being revised to permit a safety concept suitable for automated vehicles with control transmission redundancy consisting of two electric circuits and brake controllers and energy transmission redundancy consisting of independent split dual pneumatic systems as illustrated in Figure F.2.

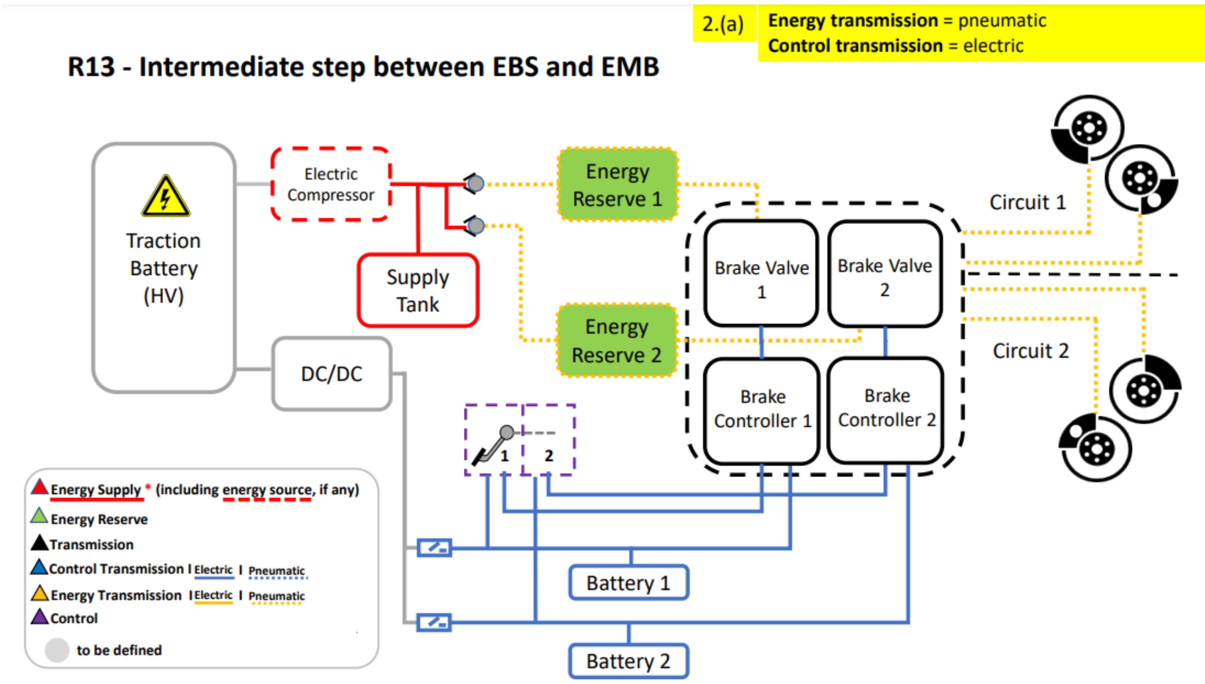

Figure F.2: Proposed layout for automated vehicle with pneumatic braking showing safety concept, namely redundancy in control transmission (dual electric circuits and controllers) and energy transmission (dual circuits). Source: UNECE Doc GRVA-EMB-02/Rev.1

The braking regulation is also being revised to permit the fitment of electro-mechanical braking (EMB) systems. A comparison of the energy transmission principles and components of EMB systems with current pneumatic systems is shown in Figure F.3: .

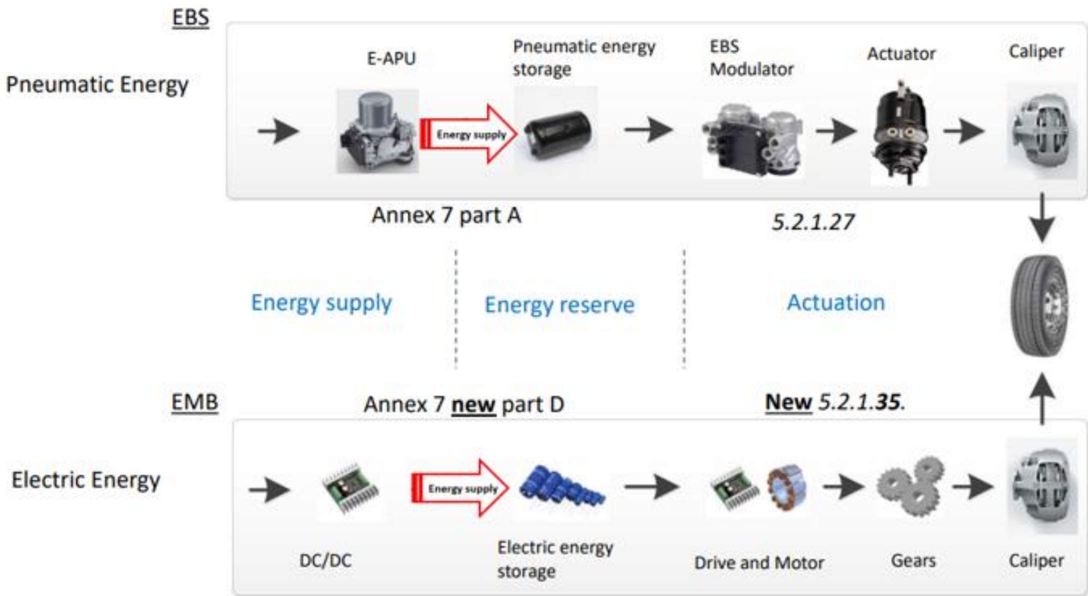

Figure F.3: Comparison of energy transmission for current pneumatic braking systems and future EMB systems. Source: UNECE Doc GRVA-EMB-02/Rev.1

This revision will permit a safety concept suitable for vehicles (automated and non-automated) with Electro-Mechanical Braking (EMB) systems with control transmission redundancy consisting of two electric circuits and brake controllers and energy transmission redundancy consisting of independent dual electric systems as illustrated in Figure F.4: .

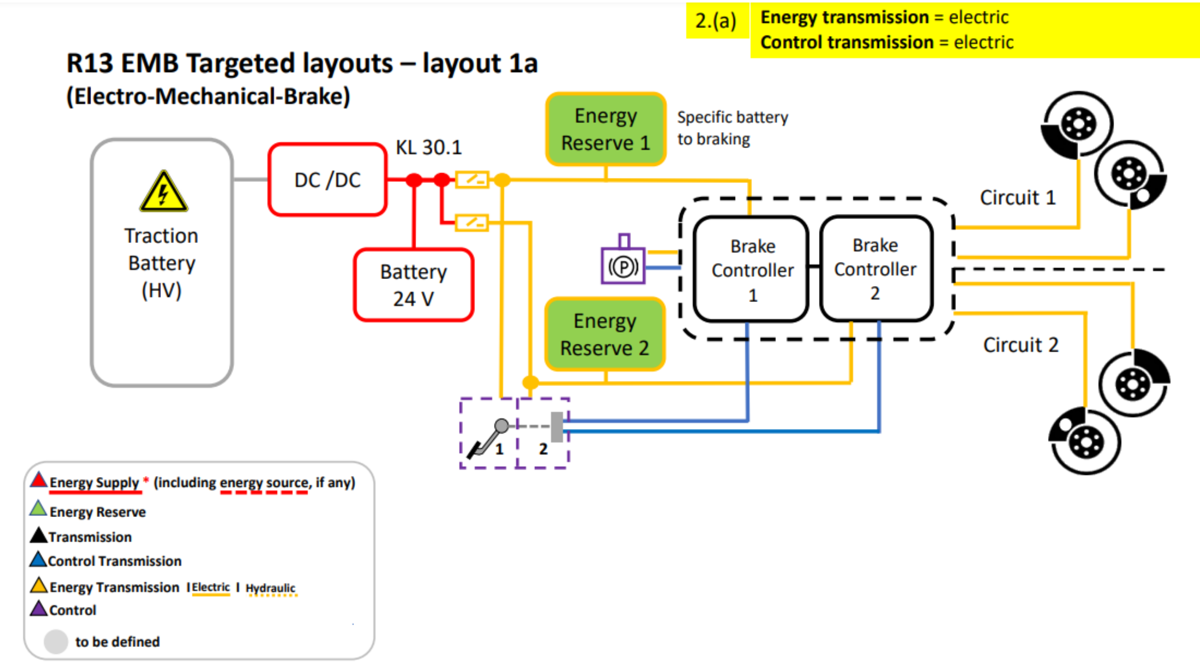

Figure F.4: Proposed layout for automated vehicle with electro-mechanical braking showing safety concept, namely redundancy in control transmission (dual electric circuits and controllers) and energy transmission (dual circuits). Source: UNECE Doc GRVA-EMB-02/Rev.1

It should be noted that electro-mechanical braking systems because of their electrical/electronic nature, should in principle offer more sensing opportunities than current pneumatic systems, and hence greater opportunities to detect potential deficiencies via remote monitoring.

A Review of Brake Performance Monitoring Systems

A study of the potential for BPMS to assure roadworthiness

This study investigated the extent to which brake performance monitoring systems (BPMS) can be used for current, conventionally driven vehicles and future automated vehicles to assure their roadworthiness. For current BPMS, the feasibility of improving inspection efficiency and reducing industry costs by substituting their use for roller brake tests carried out as part of safety inspections and at periodic technical inspection (PTI) was investigated. For future automated vehicles, the longer-term outlook and implications for BPMS was considered.

TRL Limited
Unit 19 The Business Centre
Molly Millars Lane,
Wokingham, RG41 2QY
United Kingdom
T: +44 (0) 1344 773131
E: enquiries@trl.co.uk
W: www.trl.co.uk

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