DEVELOPMENT OF THE AUSTRALIAN BRAKE BALANCE CODE OF PRACTICE

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Abstract

The *Australian Brake Balance Code of Practice* has been developed to provide guidance about intermixing of brake technologies on heavy combination vehicles. A wide range of braking technologies can know be intermixed on combination vehicles. In particular advanced electronic controls are being connected to basic vehicles. The *Code* identifies the intermix problems that can occur on combination vehicles and provides guidance about suitable mixes of technologies. A five-level cauterization is defined and a calculator has been developed for it.

The *Code* does not mandate any particular brake technologies. It provides a performance level guideline against which particular vehicles can be assessed. The recommended performance level is that a combination vehicle be able to achieve an instantaneous deceleration level on a sealed road at 60km/h of half the theoretically possible level (assumed to be 0.7g) **without exhibiting gross wheel lock-up.**

The *Code* also proposes a threshold pressure range of 10 kPa together with a design reference level of 65kPa. A tight threshold pressure range is important so that brake wear compatibility can be achieved, particularly when disc and drum brakes are mixed.

Further details can be found on the Australian Road Transport Suppliers (ARTSA) website.

Keywords: Heavy vehicle braking, combination vehicle braking, electronically controlled brake systems, brake compatibility, brake balance, threshold pressure.

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Introduction

The Australian Road Transport Suppliers Association (ARTSA) is developing an industry Code of Practice intended to improve brake balance on heavy combination vehicles. Development of the Code is being financially supported by:

- The Australian National Transport Commission (NTC),
- VicRoads,
- NSW Roads and Traffic Authority (RTA).

The need for a *Brake Balance Code of Practice* exists because of the wide range of vehicle brake technologies that exist in Australian service. Incompatibilities can arise that detrimentally affect stopping distance performance, stability and brake wear.

Brake balance in this context refers to the extent to which the braking effort is shared between the combination vehicle parts in proportion to the load carried by that part. This is the *compatibility brake balance*.

There are two other aspects of brake balance which are *distribution brake balance* – the extent to which the braking effort is shared between axle groups on each vehicle part – and the *threshold pressure balance* which is the extent to which the control levels at which brakes operate are the same.

The fundamental brake-balance challenge is to achieve stable and short stopping performance irrespective of the substantial weight variations that occur on commercial vehicles. A secondary important challenge is to achieve even brake wear on a given combination vehicle. Whilst these challenges have always existed, the increasing range of brake technologies and characteristics that could be mixed on combinations is producing new compatibility problems. Furthermore, Australia is a leading country for the application of multi-combination vehicles. Combinations with up to four parts are now used on suburban freeways.

The *Brake Balance Code of Practice* is mainly concerned with *compatibility brake balance* and *threshold pressure brake balance*. It provides guidance and recommended practices to help achieve adequate balance levels on a combination vehicle. The *Code* is applicable to heavy trucks (category NC / N3) in combination with heavy trailers (TD / T4).

The Australian design rules do not address the lightly laden compatibility domain and do not make recommendations about threshold pressure levels. Furthermore, combination vehicles are routinely configured from vehicles with different brake technologies and different There is a need for an industry Code of Practice to provide guidance.

Because of the wide range of brake technologies that are marketed in Australia the major concern is that the mixing of brake technologies might result in poor stability under braking when lightly laden. The *Code* makes recommendations about the mixing of different brake technologies and proposes a five-star rating scheme for the ranking of mixed brake technologies. A computational tool is provided that provides specific guidance and calculates the rating level.

The Code is directed in the first instance to truck and trailer manufacturers. It gives guidance about suitable brake system set-ups. Secondly, people responsible for specification and configuration of vehicles will be better informed about the compatibility issues that might arise. Finally the Code provides guidance for workshop managers and brake technicians about brake system checks and about set-up changes that they can make to improve brake compatibility performance.

Some might argue that Australian heavy vehicle brake performance is acceptable and that if compatibility problems become evident, the transport industry will solve those problems by a trial and error approach. This has worked to an extent in the past. The range and complexity of the brake technologies now on offer requires a more informed approach.

The guidance that the *Brake Balance Code of Practice* provides to the transport industry will hopefully contribute to improvements. Significant technological progress is occurring and it is important that full benefits are obtained by managing the application of new brake technologies.

2. An Overview of Brake Technologies on Heavy Combinations in Australia.

A wide range of heavy combination vehicles are used in Australia. The range spans from single-trailer types (semi-trailers and tip truck and dog trailers) to multi-trailer vehicles (A- and B-doubles and triples). New vehicle types such as A-B quad triples are proving to be safe and efficient.

Motive trucks are available from Australian, North American, European and Japanese suppliers. Trailers are mainly manufactured locally although harmonization of the Australian rules with ECE regulations is promoting the importation of European and Chinese manufactured heavy trailers. Brake technologies and design philosophies reflect the usual practices in the countries of manufacture.

Whilst the great majority of Australian trucks and trailers have S-cam drum brakes, a clear trend to the use of disc brakes is occurring. Antilock brakes are not mandated in Australia on any heavy vehicles except for B-double prime-movers and B-double trailers that display a dangerous goods placard. Despite this, the majority of new trucks have ABS because they are standard fitment in the country of origin. ABS is not widely used on trailers and when used it is generally as one element of an Electronically Controlled Braking System (**TEBS**).

There is a widespread Australian view that antilock brakes are unsuitable on gravel and poor quality roads. Antilock brakes are perceived to increase stopping distance on a loose surface, although there should be a compensating stabilizing benefit. Even if trailers have **ABS** the electrical connector may be left unplugged on trucks that routinely travel on gravel roads. **ABS** is sometimes available with an off-road mode setting. This feature should be used when combination vehicles travel on gravel roads.

Poor mantainance practices and poor designs can result in wheel speed sensors getting out of adjustment and restricting the usefulness of electronic brake control technologies.

Revolutionary changes are occurring with heavy vehicle brake technologies due to the application of electronic controls to braking and stability control. It is now possible to purchase in Australia, trucks with Electronic Brake Systems (**EBS**) or with Electronic Brake Distribution (**EBD**) on an **ABS** platform. Trailer EBS (**TEBS**) is available from several suppliers. Roll stability controls have been integrated into T**EBS.** Truck and trailer Electronic Stability Systems (**ESP**) are now available as an extension of the EBS platform.

Roll stability systems for trailers have generally performance well, although false triggers can occur on poor quality roads.

Whilst it may seem that these advanced systems with intelligent control will solve the brake balance challenge, this is not true when new and old technologies are mixed. Further, the range of adjustments that exist with intelligent brake control systems introduces a significant new issue. The advanced systems can be set-up to achieve a wide range of brake settings, potentially outside the design rule limits. Adjustments must be made carefully if performance is to improve.

The Australian brake design rules ADRs 35 and 38 are distinctly Australian. They were originally influenced by the US rule FMVSS 121. In the late 1980s a compatibility requirement was introduced for new trailers and in 1998 for new trucks. The requirement was based on the laden compatibility limits in UN ECE Regulation 13, Annex 10, Diagram 3 *Tractors for Semi-Trailers*. Unlike continental Europe, Australia never mandated lightly-laden compatibility limits.

The trailer rule ADR 38 allows trailer brakes to be certified by a sub-assembly approach. This provides flexibility to the local trailer manufacturing industry, although adherence to the original certified specification can be poor. The Australian design rules have a few minor requirements for antilock brakes and no requirements for advanced electronic brake control systems. The Australian authority has proposed adopting some ECE Regulation 13

ECE Regulation 13 is an acceptable alternative brake standard in Australia however, it is unlikely to be fully adopted in the foreseeable future.

Because there are no mandated Australian lightly-laden compatibility limits, there has been only a limited history of use of load-sensing brakes* (**LSBs**). There is no prohibition of load-sensing brakes and they were used on European manufactured prime-movers and rigid trucks until the early 2000s when electronic brake distribution took over. The widespread use of air-suspensions had facilitated the use of mechanical **LSBs** because a reliable weight signal (bag air pressure) is available.

* 'Load-sensing brakes' is defined in the ADRs as: 'Variable-proportioning brake system' – *A system that automatically adjusts the brake force at the 'Axles' to compensate for vehicle static 'axle load' and / or dynamic weight transfer between Axles during deceleration.* This encompasses mechanical proportioning relay valves because they respond to a weight signal. The requirement does not apply to an electronic brake distribution function because it senses wheel speed differences and not weight directly. In this paper **LSBs** is used to mean systems using a mechanical air-valve that responds to a weight signal.

The previous design rule ADR 38/02 required that when **LSBs** were used on a trailer, a control be provided so that the **LSBs** could be disabled when the towing vehicle did not have **LSBs**. This was a disincentive to use of **LSBs** and consequently **very** few Australian trailers had load-sensing brakes until recent times. The previous control requirement reflected a valid concern that the use of **LSBs** on one part but not other parts of a vehicle could result in a poor and unsafe configuration.

In 2009 an ‘optional’ lightly-laden compatibility requirement was added to ADRs 35 and 38. It is applicable when a new vehicle has mechanically-controlled load sensing brakes. The compatibility limits are based on the lightly-laden compatibility limits in ECE Regulation 13, Annex 10, Diagram 3, *Tractors for Semi-Trailers*. The motivation for the rule change was that **LSB** brakes on a relatively light trailer should improve brake balance when the trailer is pulled by a relatively heavy vehicle. Australian experience is that use of load-sensing brakes on dog trailers or tankers can be beneficial.

Some brake engineers complain that the unladen compatibility limits in ADR 38 are too low for Australia. The mixing of load-sensed and non load-sensed brakes on the one combination vehicle might degrade the brake balance performance unless the set-up is intentional and correct. The Australian experience with load-sensing brakes illustrates that the ADR rules do not deliver balanced compatibility braking because there is no mandated unladen compatibility requirement and no means of dealing with the mixing of brake control technologies that can be certified. A code of practice is needed.

There is a growing Australian interest in use of load-sensing brakes on light-weight trailers (such as dog trailers that have air-bag suspensions). **LSBs** are being used to reduce wheel lock-up events and are used as an alternative to an antilock brake system.

In general, load-sensing brakes can be safely used on trailers pulled by heavy trucks (without load sensed brakes) if the friction utilization of the trailer group can be matched to that of the drive-axle group when lightly laden. This guideline will probably result in the trailer set-up being above the ADR 38 lightly-laden compatibility limit. The brake compatibility balance can probably be improved but the set-up needs to be done with care. If however, the towing vehicle is relatively light then the risk of jack-knife increases and antilock brakes (**ABS**) should be used.

Load sensing brakes are not used on North American- or Australian-manufactured heavy trucks. They are used on light but not on heavy Japanese trucks. Meanwhile, Europe has moved well beyond mechanical load sensing brakes. Electronically Controlled Brakes System (**EBS**) is now predominant on European trucks and trailers. This incorporates electronic brake distribution, which balances wheel slip between controlled axle groups and trailer force control, which controls the trailer brake signal according to an ‘open-loop’ algorithm. Advanced electronic controls are not used in conjunction with load-sensing brakes on the one vehicle.

Electronically **C**ontrolled **B**rakes on trucks is usually set-up assuming that the trailer complies to the lightly-laden compatibility limit curves in ECE Regulation 13. In turn, European trailer **EBS** is set-up to comply with the ECE R13 trailer compatibility curves (Annex 10, Diagram 4A as determined by Diagram 4B). The ECE trailer lightly-laden compatibility limits are significantly lower than the ECE prime-mover limits.

Common Australian practice is to use powerful trailer brakes when compared to European trailers. Furthermore, load sensing brakes are rarely used on Australian trailers. Therefore, the **EBS** on a European prime-mover **EBS** is likely to under-estimate the brake power of an Australian trailer (without **EBS** or load-sensing brakes) and over-drive the trailer when the vehicle is lightly laden. If the trailer has **EBS** then electronic communication between truck and trailer should result in co-ordinated braking.

The **EBS** set-up on European prime-movers could be set-up for a typical Australian trailer which does not have **EBS** for load-sensing brakes. However, this is not usually done by manufacturers. Occasionally the set-up is changed to address a specific vehicle problem. One Japanese prime-mover manufacturer who markets a truck with a European-sourced **EBS** in Australia has set-up the **EBS** for trailers without load sensing brakes or **TEBS**.

The tendency for European **EBS** to over-drive Australian trailers is a serious impediment to the successful application of this major technology. The problem is even more important when ESC stability control is added to **EBS** because of a tendency to over-drive the trailer during emergency response. The brake suppliers could change the **EBS** set-up to improve balance on a ‘dumb’ trailer but this would be detrimental if the trailer(s) have **TEBS**. The only practical approach is to avoid mixing brake control technologies that are not well suited.

The application of **EBS** on two-trailer vehicles is now possible with full electronic communication. Triple trailer applications of **TEBS** is occasionally done. Voltage supply capability is yet to be proven. CAN bus communication limitations are being overcome.

Powerful engine brakes and retarders are common on trucks in Australia. Most light braking on long-distance haulage trucks is achieved using an auxiliary brake that is applied via the drive wheels. EBS and ABS systems can be installed to have veto control over auxiliary brakes but this is not mandated.

The mix of technologies that can now occur on a combination vehicle encompasses:

- Disc brakes mixed with drum brakes
- Antilock brakes mixed with no antilock
- Load sensing brakes on one vehicle part only
- Electronically Controlled Brakes (**EBS**) on the truck with no electronic control technology on the trailer(s).
- Electronic Stability Control (**ESC**) on one vehicle part only.

Significantly, market pull for advanced braking systems on heavy vehicles is common from large end-users of transport logistics. Truck manufacturers have responded to this. The assumption is made that electronic brake control technology will always improve vehicle braking stability. In reality the mixing of diverse brake technologies should only be done with informed consideration of the likely consequences for the vehicle brake balance.

Vehicle operators often assume that the Australian design rules will ensure that poor combinations will not occur. However, the design rules do not address lightly laden brake compatibility and so the assumption need not be true. There are some combinations of brake technologies that should not be mixed and others that can be satisfactorily mixed.

Figure 1 shows the hierarchy of brake technologies that exist in the Australian market place and Figure 2 classifies the level of use of each of each of these in Australia. Australia has a truly diverse range of control technologies and foundation brake types. It is important to realise that technical advancement has resulted in the antilock brake function being incorporated into **EBS**, **TEBS** and lately **EBD**. **ESC** is to be mandated on new heavy vehicles in Europe (2011+) and this is likely to occur in North America, Japan and Australia (2015+). Individual vehicles will increasingly fall into three categories, which are those with:

- Intelligent brake control,
- Load proportioning brakes, or
- No adaptive brake controls.

Most of the Australian fleet is in the last category.

The possibility exists of achieving a new generation of heavy trucks that have a quantum improvement in braking stability and shorter stopping distances if poor combinations can be avoided.

3. Structure and Philosophy of the Brake Balance Code

The *Brake Balance Code of Practice* does not mandate specific brake technologies. Rather it provides guidance on how to deal with the mixtures that can occur. The following performance-level guideline is proposed:

A combination vehicle should be able to achieve an instantaneous deceleration level due to braking of half the theoretical level without exhibiting gross wheel lock-up, in any load condition.

The principle that is inherent in the performance level is that it is undesirable to lock-up wheels on a heavy truck and that gross wheel lock-up is an indication of poor brake balance. The consequence of gross wheel lock-up could be loss of directional control – either jack-knife or trailer swing.

The above performance recommendation of the Code is applicable to moderate / high deceleration braking. It can be proven by calculations **or** by specification of a vehicle that has a preferred mix of brake control technologies.

The theoretical braking level is limited by tyre-to-pavement friction factor, which is assumed to be 0.75 on a sealed road. Therefore a combination vehicle should be able achieve an instantaneous fully developed deceleration of 0.375g at 60 km/h without experiencing sustained gross wheel lock-up. Gross wheel lock-up is defined as any sustained wheel lock-up on a single- or dual-axle group or sustained wheel lock-up on more than one axle on a tri- or quad-axle group.

The instantaneous braking deceleration can be calculated or measured by testing, although the practical difficulties involved in brake testing multi-combination vehicles make testing undesirable. The Code provides a calculator so that the performance can be estimated without road testing.

The Code assumes that the foundation brake capacity on a vehicle part is adequate to achieve the recommended deceleration level of 0.375g at 60 km/h. This is a conservative level compared to the Australian (ADR 35 & 39) and international brake rules (ECE R13). The requirement that gross wheel lock-up not be exhibited does require that the brake balance on the combination vehicle goes beyond the current Australian design and in-service rules.

If it is assumed that the vehicle has sufficient brake capability to easily achieve an 0.375g stop, then provision of wheel lock-up protection (ie antilock brakes) on each axle group of the vehicle should ensure that gross wheel lock-up does not occur and that the performance standard will be met.

It is a good principle not to mix different brake technologies on the one vehicle. However, this is impractical in many instances because vehicles are routinely configured from the available supply of vehicle parts. Some guidelines are needed to avoid poor choices.

In order to provide guidance to manufacturers and operators about the mixing of technologies, a classification scheme has been developed. The mixing of brake control technologies on a combination is categorized into one of five categories, which are:

- Category 5 - Recommended
- Category 4 - Preferred
- Category 3 - Suitable
- Category 2 - Satisfactory in most instances
- Category 1 - Unsatisfactory in most instances.

Section 4 of this paper provides further details.

Vehicles with brake control technologies that are in Categories 5, 4 or 3 are deemed to meet the performance recommendation because a high degree of confidence exists that the mix of technologies will prevent wheel lock-up occurring at moderate braking levels. This assessment assumes that the technologies have been set appropriately for the combination vehicle.

Vehicles with brake control technologies in Category 2 may meet the performance recommendation however, this should be proven either by test or calculation.

Vehicles with brake control technologies in Category 1 are unlikely to meet the performance recommendation because they have no (or inadequate) technology to improve unladen brake balance and no wheel lock-up protection. However, tests or calculations may show otherwise.

Mixing of foundation brake technologies can also occur. The vast majority of Australian heavy vehicles have S-cam drum brakes. Z-cam and wedge brakes are occasionally encountered. Over the past five years disc brakes have been (re) introduced and are growing in popularity. Drum and disc brakes have different behavior as they become hot. They may also have different torque levels and threshold pressure levels. None of these difference preclude drum and disc brakes working satisfactorily in combination however, problems can occur.

The Code recommends that threshold pressures be kept within a narrow pressure range so that all brakes on a vehicle operate for long-pressure braking events. It is important for mixed disc and drum brake vehicles that the torque balance (friction utilization balance) is considered. The brake calculator that the Code provides can be used for this.

Irrespective of the brake technologies used, a combination vehicle that meets the recommendations of the *Australian Brake Balance Code of Practice* will be able to:

- achieve an instantaneous deceleration of 0.375g at 60km/h on a sealed road without exhibiting gross wheel lock up; and
- have threshold pressures in the recommended range.

If vehicle parts are modified or adjusted to meet the *Code's* recommendations, then the compliance with the design rule performance levels needs to be verified. The *calculator* will assist with this assessment.

Some in the heavy vehicle industry have expressed concern that the five-level categorization will provide regulators with a 'quasi' in-service rule that will be applied to novel combination vehicles. These vehicles are currently regulated under or influenced by the Performance-Based Standards projects that the National Transport Commission (NTC) has developed.

The PBS project has a braking performance requirement applicable to combination vehicles that is very similar to that given above. The PBS braking standard accepts that vehicles with a mix of either wheel lock protection or load sensing brakes can be deemed to comply. This approach is the same as that used in the *Australian Brake Balance Code of Practice.* In fact, the *Code* is entirely consistent with the PBS braking standard and provides further more detailed guidance. A vehicle that meets the *Code's* recommendations will also meet the PBS braking standard.

The *Australian Brake Balance Code of Practice* has six written parts which are:

1 *Selecting Vehicles for Combinations* – A guide to the issues that arise from the mixing of brake technologies

2 *Set-Ups to Achieve Brake Balance* – Describes how brakes should be set-up to achieve suitable figures of merit.

3 *Workshop Guide to Combination Vehicle Brake Set-Up* – Directed to the workshop manager and technician, this part gives guidance abut set-ups and adjustments.

4 *Australian Heavy Vehicle Brake Performance* – Reference information about brake rules, actual performance and engineering principles.

5 *Review of Intelligent Brake Control Technologies for Heavy Vehicles* – A detailed review of current electronic brake control technologies.

6 *Brake Balance Calculation Examples* – Example calculations of braking figures of merit for a range of combination vehicles.

The Australian Brake Balance Code of Practice is an adjunct to the Air Brake Code of Practice (1999). The previous Code remains an important educative document for the transport industry. The new *Code* adds detailed new considerations about compatibility problems and issues arising from new technologies.

4. Guidelines for Mixing of Brake Technologies

Tables 1 - 5 identify the mixes of technologies in each of the control categories recommendations.

Category 5 vehicles have technologies that adapt the brake level in response to load or to wheel speed signals and have wheel slip protection. They have the same types of technologies on each vehicle part.

Category 4 vehicles have both an adaptive technology and antilock brake protection on each part. Unlike Category 5 there can be a mixture of technologies.

Category 3 vehicles have either an adaptive brake control (**EBS, EBD** or load sensing brakes) **or** antilock brake protection each part.

Category 2 vehicles have either adaptive brake controls or antilock brakes on two parts (of a three-part vehicle). If the vehicle has only two parts then the vehicle has adaptive control or antilock on one part only.

Category 1 vehicles have no adaptive control or antilock brakes on any part. Category 1 also includes configurations that are likely to have poor braking performance.

The characterization might be amended over time as new technologies arise or further experience is gained. In particular, experience of prime-mover **E**lectronic **B**rake **D**istribution on an **ABS** platform is relatively new and operational experience is yet to be gained.

Load sensing brake system (which have a relay valve responds to a weight signal) can improve brake balance in some cases and not in others. As a guide load-sensing brake valves should not be set to give a ration below 60% (lightly laden). Very low settings are likely to transfer too much of the brake effort to other vehicles.

When used, it is desirable to use load sensing brakes on all vehicles of the combination. However, if the towed vehicle is relatively light and the towing vehicle relatively heavy then significant lightly-laden compatibility brake balance might be achieved with an **LSB** valve on the towed vehicle only. The converse is not true. It is unwise to use load sensing brakes on a relatively heavy vehicle that is either pulled by or pulling a relatively light vehicle that does not have load-sensing brakes. If this situation exists, antilock brake protection should be used on the other vehicle parts.

Ultimately load sensing brake valves should be set-up for a particular combination so that the braking coefficient (friction utilization) of each controlled group when unladen is about the same. The problem is that vehicles get mixed and the brake balance condition changes.

Category 5 - Recommended

Truck	Trailer 1	Trailer 2	Comment
Electronic Braking System (**EBS**)	**TEBS** (incorporating **RSS**).	**TEBS** (incorporating **RSS**)	Electronic communication to both trailers is preferred
Electronic Brake Distribution (**EBD**)	**TEBS** (incorporating **RSS**).	**TEBS** (incorporating **RSS**)	Electronic communication to both trailers is preferred
Load Sensing* Brakes (**LSB**) and antilock (**ABS**)	Load Sensing Brakes* (**LSB**) and antilock (**ABS**).	Load Sensing Brakes* (**LSB**) and antilock (**ABS**).	* The Load Sensing Brake Valve should be set achieve about equal braking coefficient (friction utilization) on all the controlled axle groups.

Table 1 Category 5 – Preferred Control Technology Mix

Category 4 - Advanced

Truck	Trailer 1	Trailer 2	Comment
Electronic Braking System (**EBS**)	Load-sensing brakes* (**LSB**) and **ABS**.	**TEBS** (incorporating **RSS**)	Electronic communication to the rear trailer is preferred
Electronic Braking System (**EBS**)	**TEBS** (incorporating **RSS**)	Load-sensing brakes (**LSB**)* and antilock (**ABS)**.	Electronic communication to the front trailer is preferred
Electronic Brake Distribution (**EBD**)	**TEBS** (incorporating **RSS**).	**TEBS** (incorporating **RSS**)	Electronic communication to both trailers is preferred
Electronic Brake Distribution (**EBD**)	Load-sensing brakes (**LSB**)* and **ABS**.	**TEBS** (incorporating **RSS**)	Electronic communication to the rear trailer is preferred
Electronic Brake Distribution (**EBD**)	**TEBS** (incorporating **RSS**)	Load-sensing brakes (**LSB**)* and antilock (**ABS)**.	Electronic communication to the front trailer is preferred
Antilock Braking System (**ABS**) with load sensing brakes (**LSB**)	**TEBS** (incorporating **RSS**).	**TEBS** (incorporating **RSS**)	TEBS should be set-up for the actual trailer characteristics
Antilock Braking System (**ABS**) with load sensing brakes	Load-sensing brakes* (**LSB**) and (**ABS**).	TEBS (incorporating **RSS**)	As a guide LSB valves should not be set below 60% when lightly laden.
Antilock Braking System (**ABS**) with load sensing brakes (**LSB**)	**TEBS** (incorporating **RSS**)	Load-sensing brakes* (**LSB**) and antilock brakes (**ABS**).	*As a guide LSB valves should not be set below 60% when lightly laden.
Load Sensing Brakes (**LSB**) and antilock (**ABS**)	Load Sensing Brakes* (**LSB**) and antilock (**ABS**).	Load Sensing Brakes* (**LSB**) and antilock (**ABS**).	* The Load Sensing Brake Valve should be set achieve about equal braking coefficient (friction utilization) on all the controlled axle groups.

Table 2 Category 4 – Advanced Control Technology Mix

Category 3 - Satisfactory

Truck	Trailer 1	Trailer 2	Comment
Electronic Braking System (**EBS**)	Antilock (**ABS)**.	Antilock (**ABS**)	
Electronic Braking System (**EBS**)	**TEBS** (incorporating **RSS**)	Load-sensing brakes (**LSB**)*.	Electronic communication to the front trailer is preferred
Electronic Brake Distribution (**EBD**)	Antilock **ABS**.	Antilock (**ABS**)	
Electronic Brake Distribution (**EBD**)	Load-sensing brakes (**LSB**)*.	**TEBS** (incorporating **RSS**)	Electronic communication to the rear trailer is preferred
Electronic Brake Distribution (**EBD**)	**TEBS** (incorporating **RSS**)	Load-sensing brakes (**LSB**)*.	Electronic communication to the front trailer is preferred
Antilock Braking System (**ABS**)	**TEBS** (incorporating **RSS**).	**TEBS** (incorporating **RSS**)	TEBS should be set-up for the actual trailer characteristics
Antilock Braking System (**ABS**)	Load-sensing brakes* (**LSB**).	**TEBS** (incorporating **RSS**)	As a guide LSB valves should not be set below 60% when lightly laden.
Antilock Braking System (**ABS**) with load sensing brakes (**LSB**)	**TEBS** (incorporating **RSS**)	Load-sensing brakes* (**LSB**).	*As a guide LSB valves should not be set below 60% when lightly laden.
Load Sensing Brakes (**LSB**)	Load Sensing Brakes* (**LSB**).	Load Sensing Brakes* (**LSB**).	The Load Sensing Brake Valve should be set achieve about equal braking coefficient (friction utilization) on all the controlled axle groups.
Antilock Braking System (**ABS**)	Antilock **ABS**.	Antilock **ABS**.	

Table 3 Category 3 – Advanced Control Technology Mix

Category 2

Electronic Brake Distribution (**EBD**)	**TEBS** (incorporating **RSS**).	No adaptive brakes or wheel lock protection	
Electronic Brake Distribution (**EBD**)	No adaptive brakes or wheel lock protection	**TEBS** (incorporating **RSS**). Drum brakes	Euro EBS set-up assumes trailers have ECE R13 unladen characteristics
Electronic Brake System (**EBS**)	**TEBS** (incorporating **RSS**). Drum brakes	No adaptive brakes or wheel lock protection	
Antilock brakes **(ABS)**	Load Sensing brakes **(LSB)**	No adaptive brakes or wheel lock protection	**ABS** should be on the vehicle that tows the **LSB** vehicle
No adaptive control or wheel skid protection	Antilock brakes **(ABS)**	Load Sensing brakes **(LSB)**	**ABS** should be on the vehicle that tows the **LSB** vehicle
Load Sensing brakes **(LSB)**	Antilock brakes **(ABS)**	No adaptive brakes or wheel lock protection	
Load Sensing brakes **(LSB)**	No adaptive brakes or wheel lock protection	Antilock brakes **(ABS)**	
No adaptive control or wheel skid protection	Load Sensing brakes **(LSB)**	No adaptive brakes or wheel lock protection	This configuration may be unsatisfactory when the first trailer is heavy and the prime-mover is light
No adaptive control or wheel skid protection	No adaptive brakes or wheel lock protection	Load Sensing brakes **(LSB)**	This configuration may be unsatisfactory when the second trailer is heavy and the first trailer is light

Table 4 Category 2 – Satisfactory Control Technology Mix in Most Instances

Category 1 – Unsatisfactory Control Technology Mix in Most Instances

No load sensing brakes (**LSB**) or electronic brake control technology	Load Sensing Brakes (**LSB**)	No electronic control or load-sensing brakes	Poor brake balance may exist when unladen.
No load sensing brakes (**LSB**) or electronic brake control technology	No electronic control or load-sensing brakes	Load Sensing Brakes (**LSB**)	Poor brake balance may exist when unladen.
Electronic Braking System (**EBS**)	No electronic control or load-sensing brakes	No electronic control or load-sensing brakes	Euro EBS set-up assumes trailers have ECE R13 unladen characteristics.
No load sensing brakes or electronic brake control technology	No load sensing brakes or electronic brake control technology	No load sensing brakes or electronic brake control technology	This traditional vehicle can have poor brake balance when lightly laden.
Load Sensing brakes **(LSB)**	No adaptive brakes or wheel lock protection	No electronic control or load-sensing brakes	Unsatisfactory when the trailers are relatively light
No adaptive brakes or wheel lock protection	Load Sensing Brakes (LSB)	No adaptive brakes or wheel lock protection	Unsatisfactory when the rear trailer and the prime-mover are relatively light

Table 5 Category 1 – Unsatisfactory Control Technology Mix in Most Instances

The set-up of brake technologies is very relevant to the compatibility performance. Therefore set-up information is included in the recommendations. Further details are in Parts 1, 2 and 3 of the *Code*.

5 Threshold Pressure Balance

It is well known to brake engineers that threshold pressure balance largely determines brake wear balance. Because most braking is gentle, low-pressure brake balance has a major effect on brake wear balance. A brake system that has all the brakes operating at about the same control pressure level will have all the brakes contributing to low-level braking and hence achieve good wear balance.

Many studies have investigated the spread of threshold pressures on combinations. For example, the IRTE (UK, 1994), TRL (UK, 1998) and NZ Brake Code (1992) all proposed a threshold pressure range for vehicles. An investigation was also conducted in Australian by the regulator (Gascoyne et el, 1994) although no design rule requirements were adopted.

A threshold pressure guideline is needed in Australia so that vehicle manufacturers can work to a common standard. This need is becoming more important because of threshold pressure differences that can exist between drum and disc brakes. Threshold pressure values differ depending upon actuator size, friction in the brake mechanisms and air valve characteristics. Disc and drum brakes have different mechanisms and different actuator sizes. Therefore the mixing of disc and drum brakes on the one vehicle could have unacceptable threshold pressure balance and consequential brake wear problems.

The Australian Brake Balance Code of Practice recommends that all the threshold pressures on an Australian combination vehicles be within a 10 kPa range and that the design level by 65kPa. The threshold pressure is to be measured at the truck's trailer control coupling. The brake is assessed to be operating when the wheel resists a 10 Nm torque.

6. Conclusions

The application of electronic brake controls to heavy-vehicle braking is producing revolutionary changes to braking and stability performance. The performance of heavy combination vehicles can be improved substantially if the introduction of new technologies is well managed. Achievement of good compatibility brake balance on heavy combination vehicles has always been challenging because of the effects of load variation on brake balance. The Australian industry has learnt how to set-up 'traditional' vehicles to achieve acceptable performance.

New electronic control technologies, along with use of load sensing brakes, disc brakes and imported trailers with different characteristics are causing new and challenging intermixing issues to occur. *The Australian Brake Balance Code of Practice* is needed to provide guidance to industry about how to maximize the potential benefits of new brake technologies.

The *Code* introduces a category scheme with five levels for combination vehicles based on the mix of brake technologies present. This is intended to give simple guidance. The *Code* does not seek to mandate particular technologies and so a performance level, which is an alternative to the categorization scheme, is proposed. The performance level is that the vehicle should be able to achieve a deceleration due to braking of half the theoretically possible level (assumed to be 0.7g) without exhibiting gross wheel lock-up. Avoidance of wheel lock-up is important if short braking distances are to be achieved without loss of directional control.

Achieving brake wear balance is an important operator concern. Very poor wear balance is also important to safety because it is symptomatic of compatibility balance problems and likely to be associated with poor stopping distance performance. *The Australian Brake Balance Code of Practice* proposes that the threshold pressures of all the brakes on Australian combination vehicles be in a 10 kPa range and a recommended design level of 65 kPa. Threshold pressure balance is particularly relevant for satisfactorily mixing of disc and drum brakes on the one vehicle, which is becoming common situation.

A wide range of brake technologies now exists in the Australian heavy-vehicle marketplace. The potential compatibility problems are challenging. This industry *Code of Practice* seeks to guide Australian operators through these interesting developments.

7. References

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- The Institute of Road Transport Engineers (UK), “Braking Compatibility of Combinations – Code of Practice”, 1994.
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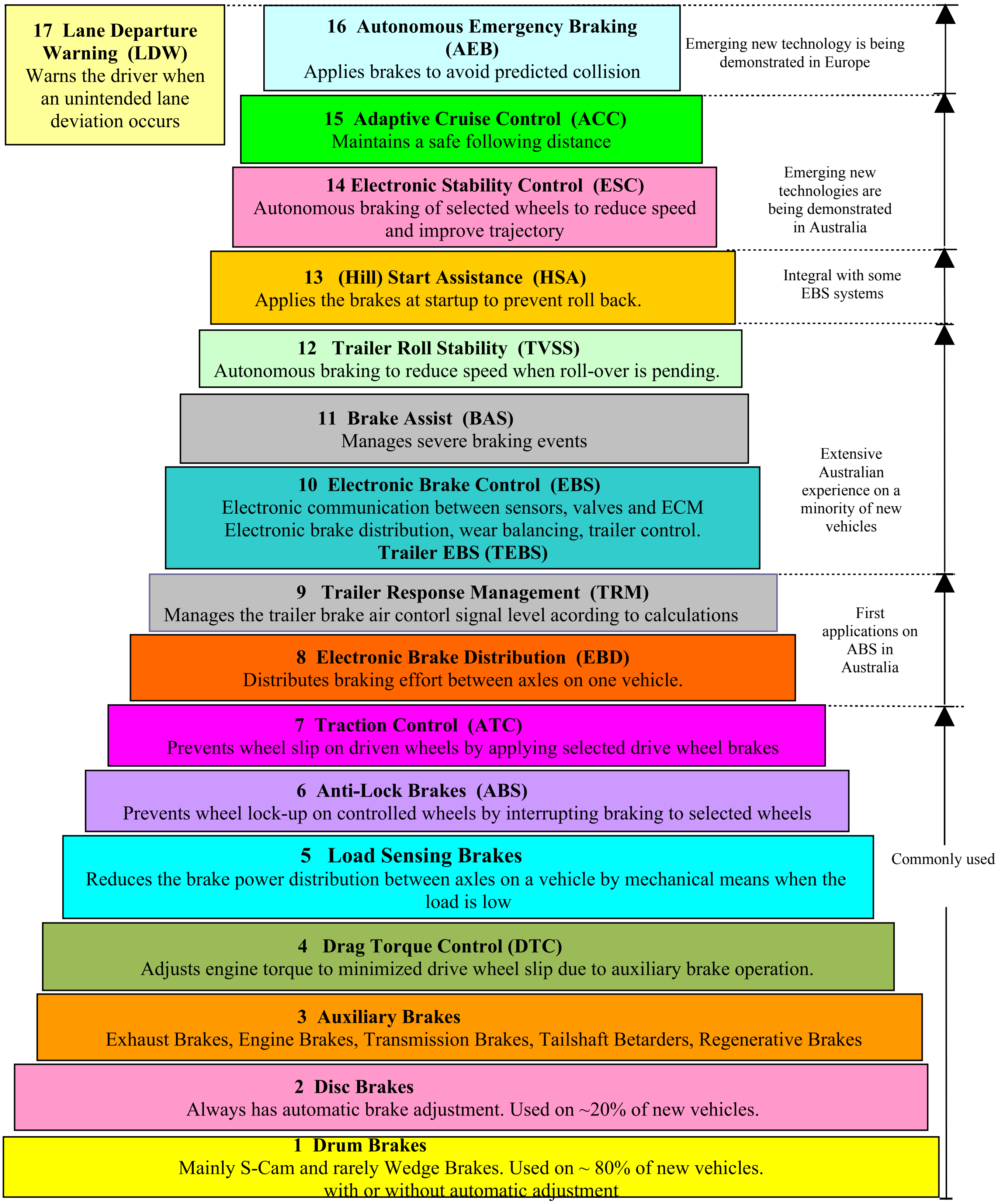

Figure 1 - The hierarchy of brake technologies that exist in the Australian marketplace.

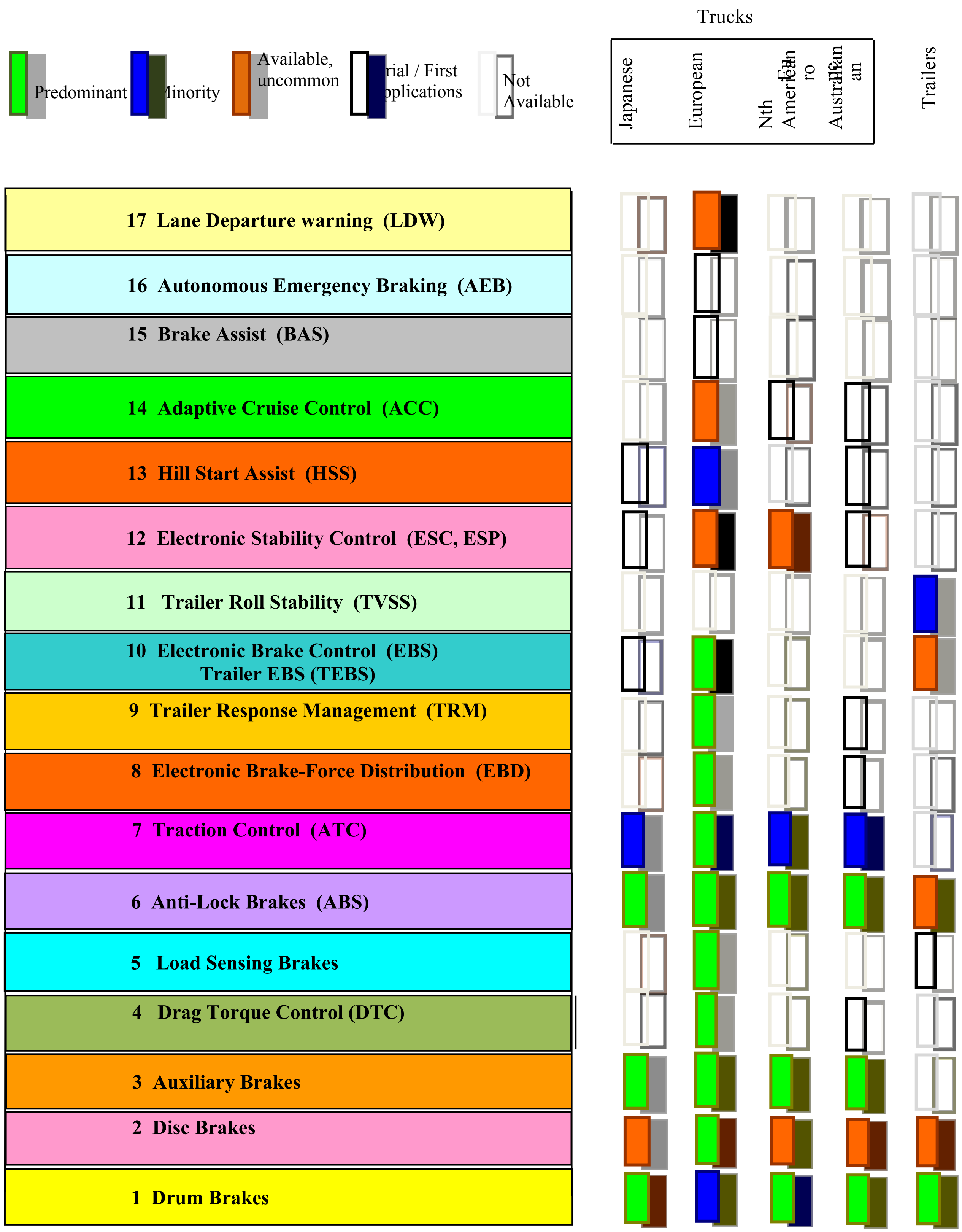

Figure 2 - A classification of the level of application of the various technologies