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Performance-Based Standards and Indicators for Sustainable Commercial Vehicle Transport

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18

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Content

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Executive Summary

INTRODUCTION

Commercial vehicle performance-based standards (PBS) are a set of metrics, traditionally intended to assess vehicle compatibility with the infrastructure and to quantify the dynamic characteristics of particular configurations with respect to rollover, yaw instability and lane encroachment. More recently they have been used to assess vehicle performance in terms of fuel use and emissions produced for particular freight tasks or services.

THE PBS PRECURSORS

PBS were first introduced in the mid-1980s during a successful effort to harmonise heavy vehicle weight and dimension regulations in Canada. This was accomplished through scientifically structured size and weight research program which included full scale testing of vehicles and pavements and computer simulation analysis of vehicle dynamic performance. Through this process it was recognised that vehicle configuration type, axle layout, and the characteristics of the load profoundly influence vehicle stability and control characteristics as well as the compatibility of the vehicle with highway geometry. To objectively assess various truck size and weight policy options, a set of "Performance-based Standards" was created. Using the PBS and the results of a sensitivity analysis, Canada developed truck size and weight policy consisting of a number of "vehicle envelopes" that provide flexibility in design for various vehicle classes while ensuring that the vehicles would have desirable performance attributes. The envelope concept reduced the burden of compliance evaluation when small variations in vehicle design were required.

In the late 90's, Australia embarked on a nationwide size and weigh reform where PBS would replace most of the prescriptive regulations pertaining to heavy vehicles including network access of road freight vehicles. As with Canada, PBS was developed in response to what were broadly agreed as inflexible prescriptive heavy vehicle regulations thereby providing objective and transparent national standards for vehicle compliance. The process of developing and implementing PBS in Australia occurred over a period of some 12 years and consisted of six consecutive phases.

The following list summarises the Australian Performance Measures:

PERFORMANCE STANDARDS	
Vehicle stability standards	
1	Static rollover threshold
2	Directional stability under braking
3	Yaw damping coefficient
Trailer dynamic performance standards	
4	High-speed transient offtracking
5	Tracking Ability on a Straight Path
6	Rearward Amplification
Vehicle powertrain standards	
7	Startability
8	Gradeability
9	Acceleration capability
Vehicle manoeuvrability standards	
10	Low-speed swept path
11	Frontal swing
12	Tail swing
13	Steer tyre friction demand
Infrastructure standards	
14	Bridge loading
15	Tyre contact pressure distribution
16	Pavement horizontal loading

It is estimated that the implementation of PBS in Australia will result in financial, social and environmental benefits of $AU 5.71 bn over a 20 year time frame. The estimated annual compliance cost is approximately $AU 4.7 mm which represents and additional $AU 1.2 mm per year compared with compliance costs for the previous system. All types and sizes of commercial vehicles can benefit from the implementation and use of performance-based standards in a way that allows for the analysis of a fully integrated road transport system which is critical for sustainable transport policy development.

TWO DIFFERENT REGULATORY APPROACHES SUPPORTED BY PBS: THE CASES OF CANADA AND AUSTRALIA

This paper documents two different PBS systems that have been implemented by two countries, each using very different regulatory approaches supported by PBS.

The distinctly different approach taken by both countries underscores the degree of flexibility open to regulators regarding the creation of regulatory instruments based on or supported by PBS. In both cases, there is strong evidence that such systems have significantly improved transport efficiency, creativity and safety. Whereas in Canada, PBS have been used as a basis for developing a prescriptive limits regulatory framework (the changes in performance following changes in vehicle configuration and dimensions are then determined by computer simulations or physical tests), in Australia, the approach is far more prescriptive. Possibly the first approach would fit best the EU cost-efficiency requirements in terms of enforcement and compliance.

This paper provides examples of how PBS could be further developed in the form of “essential requirements” supported by “key performance indicators” to assess and encourage improvements in the sustainable value of road transport.

The potential for combining PBS in the form of “essential requirements” together with “key performance indicators” will provide vehicle performance assurance as well as performance outcome data to actively measure the net societal benefits attributable to the most efficient vehicles. Moreover, such objective information would be useful to counter the emotional arguments that often are used to block the implementation of more efficient vehicles such as EMS.

Examples of key performance indicators may include lives and injuries saved, fuel and emissions reductions, infrastructure consumption reduction, and intermodal activity. Performance indicator data can also be used to fine tune policy over time as size and weight regulation should be considered a living entity requiring constant vigilance and periodic adjustment to deal with the unexpected.

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1.

Introduction

Commercial vehicles come in all shapes and sizes, and exist to do work for the benefit of society. They are purpose built to transport products related to manufacturing, mining, and agriculture, and to transport food and goods to the manufacturing and retail sector and increasingly, small packages to households. Large commercial vehicles are governed by size and weight policy that directly influences safety, productivity and efficiency. Therefore, depending on the quality of the regulation, transportation efficiency and safety can be improved or inhibited.

Unlike light vehicles, commercial truck safety must be considered within the context of the transport system, as safety outcome is highly dependent on vehicle productivity and design which are largely dictated by the characteristics of the product to be transported and the vehicle size and weight constraints contained in regulations. The combination of these factors has direct influence on national freight transport efficiency, on fuel use, emissions, infrastructure consumption and safety therefore heavy vehicle size and weight policy has far-reaching implications for society. This paper focuses on performance-based standards approach to regulation and examines how these metrics can be used to evolve policy towards a more sustainable transport path. Proponents argue that this new approach has advantages over prescriptive regulation in that it provides flexibility for vehicle design allowing the shipper to optimise efficiency, productivity and safety performance ensuring maximum societal benefit.

It is clear that the concept of replacing prescriptive regulation with performance-based standards is not necessarily a suitable option for many jurisdictions, including the EU. However, the PBS approach can be successfully used to improve the societal value of prescriptive regulation by developing a specific subset of measures to underpin fuel conservation, emissions output and safety. Within the context of the EU, such an approach presents the possibility of creating a PBS/Prescriptive hybrid, possibly in the form of "Essential Requirements", to encourage more sustainable goods transport.

2.

Defining Performance-Based Standards

The Canadian Experience

INTRODUCTION

Commercial vehicle performance-based standards were originally conceived as a set of metrics intended to assess vehicle compatibility with the infrastructure and to quantify the dynamic characteristics of particular configurations with respect to rollover, yaw instability and lane encroachment.

PBS were first introduced during a successful effort to harmonise heavy vehicle weight and dimension regulations in Canada during the mid-1980s [1] [2]. In Canada each province independently controls its own truck size and weight policy, for all roads within the particular province. Since the Canadian federal government has no dominion over the provinces in this regard, it is not surprising that regulations in each province were unique and varied considerably from province to province thereby impeding efficient transport across provincial boundaries. The lack of regulatory uniformity compromised interprovincial transport efficiency presenting significant challenges given that the country spans some 5,000 km and consists of ten provinces with most borders vertically aligned and a primary road system that runs horizontally from coast to coast crossing these boundaries.

The Canadian approach [3] sought to achieve regulatory harmonisation of size and weight policy by conducting a comprehensive size and weight study based on rigorous scientific study and engineering methods to analyse pavement and vehicle performance. The research included a parametric sensitivity analysis using vehicle dynamic simulation and field testing for stability and offtracking, full scale pavement testing for axle loads and axle spacing. It also included laboratory road/vehicle dynamic shaker testing to define dynamic load characteristics of suspensions leading to the identification of road friendly suspensions. In the course of this research, it became apparent that the provincial regulators would be in the best position to achieve harmonisation if a set of objective metrics were created to help establish technical principals upon which the regulatory framework could be based.

SUMMARY OF CANADIAN PBS METRICS

The extensive testing and computer simulation carried out under the Canadian size and weight research program served to evaluate and document the wide range of stability and control characteristics of vehicles found in the commercial transport fleet at the time. In reviewing the findings, it was recognised that the manner in which the vehicle was configured, the means by which trailers were coupled, the axle layout and the manner in which the load was distributed profoundly influence the stability and control characteristics and the compatibility of the vehicle with highway geometry. Based on these observations, a set of regulatory principles were established that directed size and weight policy development within the context of the following objectives:

- To encourage the use of the most stable heavy vehicle configurations through the implementation of practical, enforceable weight and dimensions limits.
- To balance the available capacities of the national highway transportation system by encouraging the use of the most productive vehicle configurations relative to their impact on the infrastructure.
- To provide the motor transport industry with the ability to serve markets across Canada using safe, productive, nationally acceptable equipment.

The Canadian weights and dimensions study "Implementation Planning Subcommittee" compiled regulatory principles and proposed weight and dimension limits for a set of vehicle configurations that were evaluated against seven performance measures [4]. As recommended by the Technical Steering Committee of the research program, vehicles exhibiting performance which meet or exceed the reference levels for the performance measures should be encouraged. The measures were categorised into two distinct groups; Stability and Control Measures and Offtracking Measures: Descriptions of these measures can be found in the Appendix A.

CANADIAN VEHICLE ENVELOPES

Using the PBS and the results of the sensitivity analysis, the Implementation Committee developed a set of "vehicle envelopes" defining the general vehicle layout including ranges for certain component variables such as axle spacing and hitch placement. This PBS/Prescriptive approach provides flexibility in design for various vehicle classes. The envelope concept reduces the burden of compliance evaluation by giving the vehicle designer some flexibility for vehicle optimisation within a prescriptive regulatory system. An example of the vehicle envelope is shown in FIGURE 1. To qualify vehicles that are outside of the envelopes, PBS can be used as a compliance tool to judge acceptability.

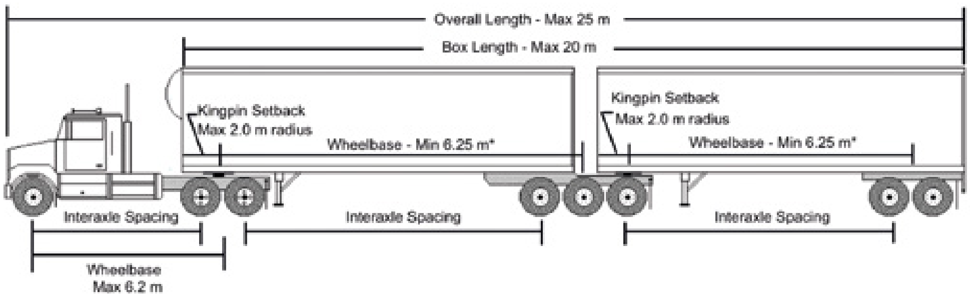
Canada has developed unique policies with respect to the operation of long combination vehicles and some provinces use PBS to approve candidate vehicles [5]. In most provinces, LCVs (Longer Combination Vehicles) operate under a special permit program governed by strict operating conditions. The structure and enforcement mechanisms of the policy engender a level safety consciousness within the LCV fleet, which far exceeds that found in other vehicle classes. The principle motivating factor for heightened safety performance is related to the special safety requirements and fact that a special permit can easily be revoked for safety performance failure. The special permit system requires that operators be trained to meet and maintain the requirements outlined in the Canadian Trucking Alliance's "Longer Combination Vehicles Driver's Manual." The province of Alberta has the following requirements for LCV drivers:
Drivers must obtain an annual certificate verifying that they are in compliance with certain requirements related to the type of license, training, driving experience, physical fitness, criminal records.The permit conditions also place controls on where LCVs can operate including hours of operation (time of day), vehicle dimensions such as wheelbase, hitch offset and dolly drawbar length. The policy also contains operational requirements such as adverse weather restrictions, requirements that the vehicles track properly and do not sway, and requirements that vehicles do not cross opposing lanes of traffic unless absolutely necessary.

The Alberta policy governing LCV movements is designed to reduce high risk travel of the LCV fleet. This is done by restricting movement in urban areas during peak hours, public holidays or during inclement weather. The safety performance of the Alberta LCVs was found to be in the order of 3 to 5 times better than the standard tractor semi-trailer fleet operating on identical roads (crashes, fatalities, injuries per distance travelled).

Figure 1 Example of Canadian vehicle envelope created using PBS

SOURCE TAC

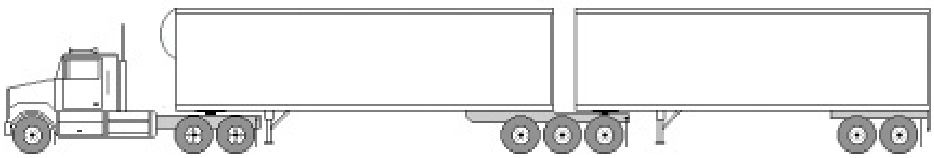
Category 3 B Train Double | Part 1 - Dimension Limits



DIMENSION	LIMIT
Overall Length	**Maximum 25 m**
Overall Width	**Maximum 2.6 m**
Overall Height	**Maximum 4.15 m**
Box Length	**Maximum 20.0 m**
Tractor	
Wheelbase	Maximum 6.2 m
Tandem Axle Spread	Minimum 1.2 m / Maximum 1.85 m
Lead Semitrailer	
Wheelbase	Minimum 6.25 m
Kingpin Setback	Maximum 2.0 m radius
Tandem Axle Spread	Minimum 1.2 m / Maximum 1.85 m
Tridem Axle Spread	Minimum 2.4 m / Maximum 3.1 m
Track Width	Minimum 2.5 m / Maximum 2.6 m
Fifth Wheel Position	No more than 0.3 m behind the centre of the rearmost axle on the semitrailer

DIMENSION	LIMIT
Second Semitrailer	
Wheelbase	Minimum 6.25 m
Kingpin Setback	Maximum 2.0 m radius
Tandem Axle Spread	Minimum 1.2 m / Maximum 1.85 m
Tridem Axle Spread	Minimum 2.4 m / Maximum 3.1 m
Track Width	Minimum 2.5 m / Maximum 2.6 m
*** Sum of Semitrailer Wheelbases**	**Maximum 17.0 m**
Interaxle Spacings	
Single Axle to Single or Tandem Axle	Minimum 3.0 m
Tandem Axle to Tandem Axle	Minimum 5.0 m
Tandem Axle to Tridem Axle	Minimum 5.5 m
Tridem Axle to Tridem Axle	Minimum 6.0 m

Category 3 B Train Double | Part 2 – Weight Limits



Max 5500kg

Single Axle – Max 9 100 kg
Tandem Axle – Max 17 000 kg

Tandem Axle – Max 17 000 kg
Tridem Axle:
spread 2.4 to < 3.0m: Max 21 000 kg
spread 3.0 to 3.1m: Max 23 000 kg

Single Axle – Max 9 100 kg
Tandem Axle – Max 17 000 kg

WEIGHT	LIMIT
Axle Weight Limits	
Steering Axle	Maximum 5 500 kg
Single Axle (dual tyres)	Maximum 9 100 kg
Tandem Axle	
Axle Spread 1.2 m - 1.85 m	Maximum 17 000 kg

WEIGHT	LIMIT
Tridem Axle	
Axle Spread 2.4 m to less than 3.0 m	Maximum 21 000 kg
Axle Spread 3.0 m to 3.1 m	Maximum 23 000 kg
Gross Vehicle Weight Limits	
Five Axles	Maximum 40 700 kg
Six Axles	Maximum 48 600 kg
Seven Axles	Maximum 56 500 kg
Eight Axles	Maximum 62 500 kg

SOURCE Task Force on Vehicle Weights and Dimensions Policy: Heavy Truck Weight and Dimension Limits for Interprovincial Operations in Canada.

The Australian Experience

INTRODUCTION

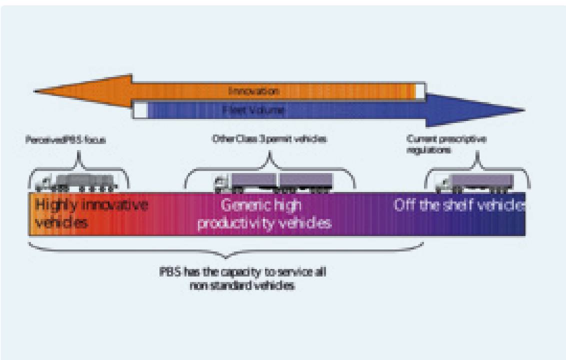
Australia has implemented a nationwide PBS system for regulating weights and dimensions that is tied to a road access network based on freight vehicle class. As with Canada, the Australian PBS was developed in response to what were broadly agreed as inflexible prescriptive heavy vehicle regulations. The reformed system provides for flexibility in vehicle design, allowing creative forces to be applied to the development of specialised vehicles that improve the efficiency and safety of particular transport tasks. Australia took PBS to a higher level by largely replacing the prescriptive system with a unique PBS regulatory instrument. The original objectives of the Australian PBS effort can be summarised as follows:

1. Provide more sustainable transport systems through improved road vehicle regulations controlling heavy vehicle safety and infrastructure impacts.
2. Provide more flexible road transport regulations that allow increased innovation and more rapid adoption of new technologies, while providing seamless operations nationally.

Consideration was given to fleet implications as depicted in FIGURE 2. The focus of the PBS system was towards individual vehicle assessment spanning the space between generic high productivity vehicle such as B-doubles and highly innovative vehicles that are often required by the agriculture and mining industries.

Figure 2 **Performance-based assessment – fleet coverage objectives**

SOURCE **NTC**



THE SIX PHASES OF PBS IMPLEMENTATION IN AUSTRALIA

The road to implementing PBS in Australia was long requiring comprehensive analysis, significant institutional change within a judicious process. The project consisted of six phases [6] [7] spanning some 12 years as described below and illustrated in FIGURE 3:

- **PHASE A: Performance Measures and Standards**
  Identifying the appropriate performance measures and standards and surveying the performance of the current heavy vehicle fleet.
- **PHASE B: Regulatory and Compliance Processes**
  Establishing a regulatory system in which Performance-based Standards can operate as a seamless national alternative to existing prescriptive regulations including national compliance and enforcement arrangements.
- **PHASE C: Guidelines**
  Preparing guidelines detailing the procedures and processes for the consistent application of Performance-based Standards.
- **PHASE D: Legislation**
  Developing the legislative arrangements for Performance-based Standards to operate as an alternative to prescriptive regulations.
- **PHASE E: Case Studies**
  Assembling work previously conducted and demonstrating the practical application of Performance-based Standards to nationally agreed priorities.
- **PHASE F: Implementation**
  Putting in place the necessary legislative and administrative systems to allow Performance-based Standards to operate nationally and providing the training and information to support these changes.

The Australian heavy truck regulatory system is comprised of prescriptive regulations, a permit system and a PBS access system. The regulations are bifurcated in the following way:

- National "model" regulations developed by the National Transport Commission in collaboration with road agencies and approved by ATC - the Australian Transport Council, a ministerial forum for consultations and advice to governments on the coordination of national transport and road issues.
- As state or territory regulations which may complement national model regulations, or substitute for them (where a state or territory has not accepted the model regulations).

The national Australian PBS legislation classifies heavy vehicles on the basis of freight task as follows:

- **General access vehicles**, which are those complying with the vehicle standards and mass and loading regulations (e.g. rigid trucks, semi-trailers, standard type truck trailers).
- **Class 1 vehicles** are engaged in “special purpose” transport operations, which include oversize and over mass, agricultural and mobile plant vehicles (e.g. low loaders, concrete mixer trucks).
- **Class 2 vehicles** are specific types and combinations, which are compliant with applicable model regulations. As a result of their size and/or mass, they are subject to restricted access (e.g. B-doubles, road trains and long buses).
- **Class 3 vehicles** are non-standard heavy vehicles which do not fall within the class 1 or 2 categories. These are typically higher productivity vehicles which operate under concessional access/permit schemes or under the PBS scheme (e.g. super B-doubles and under existing legislation, all PBS vehicles). Their access to the road network is either restricted or in accordance with the PBS access levels.

One of the objectives of the Australian PBS system was to develop a system that would match vehicles to appropriate road networks. As a result, a stratified road network classification was devised which became known as the “performance-based standards road network levels”. Under the prescriptive system, there were four network levels that restricted heavy vehicle use in the following order:

- General access (subject to a 50 tonne gross mass limit)
- B-doubles
- Road train type I
- Road train type II

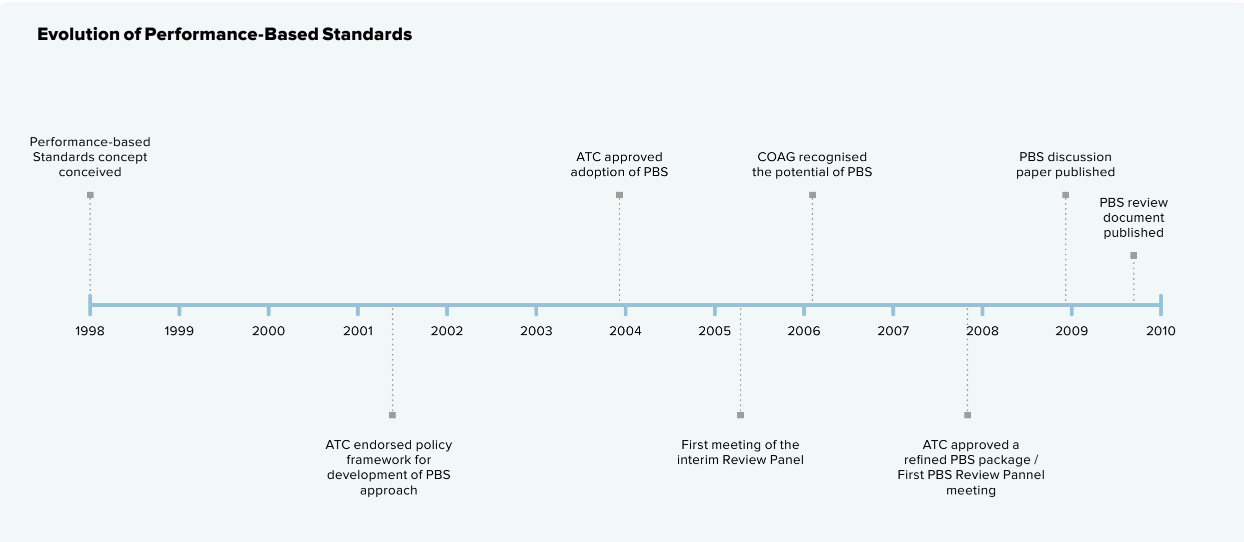
PBS mass and dimension limits have precedence over the normal limits.

TECHNICAL ASSESSMENT OF PBS VEHICLES IN AUSTRALIA

There is well defined protocol detailing the procedures by which a candidate vehicle is assessed using PBS [8]. The assessment may be carried out by a qualified certifier using either field tests or numerical simulation. Vehicle characteristics such as engine, gearbox differential, mass, wheels, tyres, axles, couplings, suspensions and dimensions must be formally recorded in a specified format. At the discretion of the assessor, a sensitivity analysis may be required if it is believed that small changes in “risk sensitive parameters” will likely result in large variations in vehicle behaviour. Once the candidate vehicle is found to be in compliance with the individual standards, a “certificate of compliance’ is issued. The assessor is required to retain all documentation related to the analysis for a period of 5 years.

Figure 3 **Timeline of PBS development**

SOURCE **NTC**



PBS compliance can be achieved either with field testing or simulation. In addition, a vehicle type approval option exists for vehicles built in accordance with a particular design that has achieved compliance. The PBS system includes a provision that may allow a successful vehicle to be exempted from prescriptive regulation in the following dimensional and component categories:

- Width
- Length of single motor vehicles
- Length of single trailers
- Length of combinations
- Rear overhang with an exception
- Trailer drawbar length
- Height
- Attachment of couplings and drawbar eyes on long road trains
- Tow coupling overhang on long road trains
- Retractable axles

ACTIVE PBS REQUIREMENTS IN AUSTRALIA

Sixteen standards relating to the operational performance of a vehicle form the basis of the Australian PBS system which represents a distillation of the measures outlined in the Definition of Potential Performance Measures and Initial Standards study [9]. The measures are organised as follows within Table 1 and a full explanation of the measures is provided in Appendix B:

- Vehicle stability standards
- Trailer dynamic performance standards
- Vehicle powertrain standards
- Vehicle manoeuvrability standards
- Infrastructure standards

Table 1 **Summary of Australian PBS measures**

PERFORMANCE STANDARDS	DESCRIPTION
Vehicle stability standards	
1 Static rollover threshold	Ensures that geometry and suspension provide a set level of vehicle stability
2 Directional stability under braking	Ensures that vehicles remain controllable when braking in a turn
3 Yaw damping coefficient	Ensures that vehicles do not suffer excessive roll oscillation after manoeuvres
Trailer dynamic performance standards	
4 High-speed transient offtracking	Ensures that trailers follow the path of the prime mover during unbraked avoidance manoeuvres
5 Tracking Ability on a Straight Path	Ensures that trailers of multi-articulated vehicles do not swing excessively after avoidance manoeuvres
6 Rearward Amplification	Ensures that trailers do not have excessive lateral response during evasive manoeuvres.
Vehicle powertrain standards	
7 Startability	Ensures that the fully laden vehicle may start on a hill of set grade
8 Gradeability	Ensures that the fully laden vehicle may maintain speed on a hill of set grade
9 Acceleration capability	Ensures that a vehicle may accelerate at an appropriate rate to clear traffic lights etc.
Vehicle manoeuvrability standards	
10 Low-speed swept path	Ensures that a vehicle may safely manoeuvre around corners typical of those found on its compatible network without cutting the corner
11 Frontal swing	Ensures that a vehicle may safely manoeuvre around corners typical of those found on its compatible network without contacting the rear of the vehicle
12 Tail swing	Ensures that a vehicle may safely manoeuvre around corners typical of those found on its compatible network without contacting the rear of the vehicle
13 Steer tyre friction demand	Ensures that steering axle will be effective in changing the course of the vehicle as required by driver input
Infrastructure standards	
14 Bridge loading	Ensures that vehicle mass is compatible with bridge infrastructure for set route
15 Tyre contact pressure distribution	Ensures that pressure transferred to the road surface by the tyres is compatible with road infrastructure for set route
16 Pavement horizontal loading	Ensures that horizontal force transferred to the road surface by the tyres is compatible with road infrastructure for set route

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ECONOMIC IMPACT OF PBS IN AUSTRALIA

NTC produced a Regulatory Impact Statement [10] that contains an estimate of the impact of PBS. The financial analysis was based on work reported by Hassall [11]. The key objectives of the Australian PBS scheme are as follows:

- improved freight productivity
- reduced impact on the environment with regard to vehicle emissions and CO_2, and
- reduced impact on society with regard to reductions in road trauma and congestion.

The analysis was conducted under with the assumption of the following options:

- **OPTION 1** – Maintain the status quo by keeping the current administrative scheme in place in which PBS acts as a national assessment system requiring state-based permits for road network access.
- **OPTION 2** – Move to a state-based assessment and access system to provide high levels of flexibility and better single state access assurance.
- **OPTION 3** – Move to a national assessment and access framework utilising the national heavy vehicle law and national heavy vehicle regulator to improve national consistency and certainty of access.

The following TABLES 2 › 4 summarise impacts benefits and compliance costs.

Table 2 Summary of option impact against objectives

BENEFIT SECTOR	OPT. 1	OPT. 2	OPT. 3
Improved industry participation	LOW	MEDIUM	HIGH
Improve freight sector productivity	MEDIUM	MEDIUM	HIGH
Reduced impact on the environment	MEDIUM	MEDIUM	HIGH
Reduced impact on society (road trauma)	MEDIUM	MEDIUM	HIGH
Certainty of access	LOW	HIGH	HIGH
National consistency	MEDIUM	LOW	HIGH
Reduced compliance cost	LOW	MEDIUM	MEDIUM

Table 3 Summary of financial, social and environmental benefits by option

ASSESSMENT METRICS	OPT. 1	OPT. 2	OPT. 3
1. Fatality Savings to 2030	23.8	20.4	87.3
1A. Fatality Savings ($ nominal)	$0.083 bn	$0.071 bn	$0.305 bn
2. Total CO_2 Savings Million tonnes	0.99 Mt	0.72 Mt	3.75 Mt
2A. Total CO_2 Savings ($ nominal)	$0.023 bn	$0.017 bn	$0.086 bn
3. PBS Kilometer Savings 2011 - 2030	1.06 B kms	0.95 B kms	3.7 B kms
3A. Direct Financial Savings 2011 – 2030 ($ nominal)	$1.79 bn	$1.74 bn	$5.54 bn
Total Savings (1A+2A+3A) Nominal	**$0.083 bn**	**$0.083 bn**	**$0.083 bn**
4. Compliance Costs ($ Nominal)	$-0.084 bn	$-0.136 bn	$-0.112 bn
5. Administration Costs ($ Nominal)	$-0.011 bn	$-0.029 bn	$-0.016 bn
Total Costs (4+5) Nominal	**$-0.095 bn**	**$-0.165 bn**	**$-0.128 bn**
Net Direct Savings PBS 2011 -2030 (Nominal)	**$1.805 bn**	**$1.665 bn**	**$5.712 bn**

Table 4 Compliance cost per annum by option

COST	OPT. 1	OPT. 2	OPT. 3
Compliance cost ($/year)	$3,120,000	$5,044,000	$4,152,000
Administrative cost ($/year)	$419,600	$1,100,000	$580,800
Total Costs ($/year)	**$3,539,600**	**$6,144,000**	**$4,732,800**

3.

Discussion

INTRODUCTION

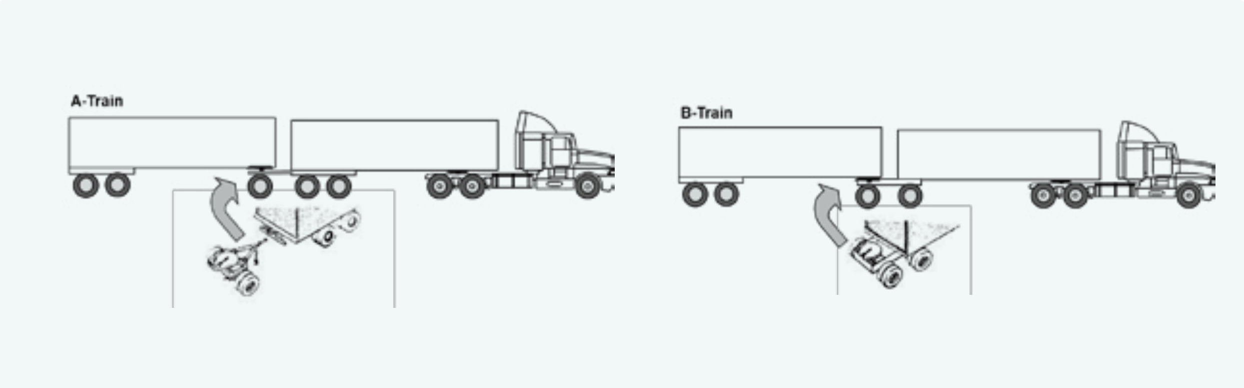
Australia and Canada have evolved two distinct size and weight policy instruments based on PBS. The Canadian situation prior to regulatory reform was highly fractured as there was little uniformity in size and weight policy even for common workhorse vehicles. Canada achieved uniformity by creating a set of vehicle envelopes based on configuration type containing dimensional ranges for key vehicle parameters allowing some variability in design to optimise vehicle productivity. The reform policy provided a standardised nationally fleet for inter-provincial transport however some provinces retained their original size and weight regulations for intra-provincial transport. PBS assessment was retained on an exception basis to evaluate highly specialised vehicles. This approach provided a less complex implementation process, minimizing regulatory change and disruption to the industry.

The new regulations allowed greater GVW for B-train configuration than the A-train configuration shown in FIGURE 4. This is because the B-train has superior stability and control characteristics compared with the A-train. The preferential mass of approximately 5.5 tonnes that was given to the B-train had the effect of greatly reducing their number of A-trains within the Canadian fleet. The B-train gives Canada considerable transportation advantage over its trading partner the U.S. Compared with vehicles operating on the U.S. interstate system which are limited to 36,000 kg, the B-train has a productivity advantage of a factor of two, with 68% less fuel and GHG output based on cargo mass and 20% improved crash rate compared to tractor semi-trailers. This gives Canada a significant competitive, environmental, carbon footprint and safety advantage in road freight transport in relation to its largest trading partner.

Prior to the introduction of PBS in Australia, there was good size and weight uniformity for workhorse vehicles such as the tractor semitrailer and single unit trucks. However there were very few options for higher productivity vehicles except for the road trains that operated in remote regions. The Australian PBS system helped unify regulations on B-trains and provides the opportunity for creativity in vehicle design to maximize productivity. Since Australia is a country without neighbouring borders, it is not encumbered with international considerations for road freight transport compatibility in size and weight. The Australian PBS system transformed the regulatory process diminishing the prescriptive regulatory component. The Australian PBS regulatory reform is a remarkable achievement given the complexity of the task, the thoroughness of the effort and the advancement of PBS metric use.

One striking omission with the set of PBS metrics used for both countries is the absence of fuel consumption, GHG emissions and achieved safety outcome measures (key performance indicators) for given vehicle configurations. Such measures would help to more comprehensively distinguish the societal value of particular vehicle units from others thereby providing an added dimension supporting policy evaluation and providing an objective means of measuring transport sustainability.

Figure 4 **Illustration "A-Train and B-Train Couplings"**



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PBS FOR SUSTAINABLE TRANSPORT

The OECD International Transport Forum recently completed research effort on truck transportation sustainability [12] [13] which examined how truck size and weight policy influences vehicle productivity, fuel use and vehicle emissions. In addition, the U.S. Academy of Sciences recently published a report [14] which was used to support the recently announced fuel economy standards for large commercial vehicles in the U.S. The U.S. study focused on the full range of commercial vehicles ranging from small commercial vehicles with GVW of 4,500 kg to the largest vehicles operating on public roads. Consideration of all sizes of commercial vehicles was very important because it provided an opportunity to extend the performance-based standard concept to all commercial vehicle classes in a way that allows for the analysis of a fully integrated road transport system which is critical for sustainable transport policy development.

Both of these studies stressed the importance of creating performance measures linking vehicle productivity to fuel use rather than focusing strictly on fuel consumption independent of freight task. Considering most truck transportation, the nature of the freight task can be classified as volume limited or mass limited. Mass-limited freight is of sufficiently high density that the GVW will be reached before the volumetric capacity of the vehicle is fully utilised. Volume limited freight is of sufficiently low density that it occupies all of the available cargo space before the GVW is achieved. Vehicles are often designed on the basis of mass or volumetric capacity, and the characteristics of these vehicles are somewhat sensitive to the methods used to calculate fuel consumption.

With this in mind, the Academy of Sciences Committee produced the following findings and recommendation pertaining to performance-based standards for improving truck fuel consumption [14]. (NOTE: for the purpose of this report the units have been converted to metric):

Finding 8-5. Choosing a metric associated with the movement of freight will promote improvements that increase the amount of cargo that can be carried per unit of fuel consumed, and thus provide a means of quantifying the benefits of more productive vehicles that move the same amount of freight with fewer trips and less distance traveled, such as longer combination vehicles (LCVs).

Finding 8-6. Setting a metric based exclusively on liters/tonne-km may not adequately address light-density freight that is limited by volume.

Recommendation 8-3. NHTSA should establish fuel consumption metrics tied to the task associated with a particular type of medium- or heavy-duty vehicle and set targets based on potential improvements in vehicle efficiency and vehicle or trailer changes to increase cargo-carrying capacity. NHTSA should determine whether a system of standards for full but lightly loaded (cube limited) vehicles can be developed using only the load specific fuel consumption metric or whether these vehicles need a different metric to properly measure fuel efficiency without compromising the design of the vehicles.

AERODYNAMIC DRAG

One of the most effective means of improving fuel efficiency of large commercial vehicles, apart from payload capacity, is to reduce aerodynamic drag. FIGURE 5 below depicts the energy losses of a typical tractor semitrailer operating within the U.S. At high speed, aerodynamic losses account for 15 to 22 percent of fuel use.

There are several vehicle treatments that can be used to alter aerodynamic drag, some of which lengthen the vehicle without increasing cargo capacity. One such solution is referred to as 'boat tails" shown in FIGURE 6, described extensively in [15]. It consists of a light-weight external extension of the trailer allowing the air flow to remain attached as the vehicle cross section diminishes resulting in a reduction in the area of negative pressure at the end of the vehicle, which reduces drag force.

Aerodynamic treatments of this type extend the length of the vehicle in the order of 50 to 60 cm which will contravene prescriptive size and weight regulations unless regulatory flexibility can be introduced to accommodate such innovation.

SPECIAL CONSIDERATIONS FOR THE EU

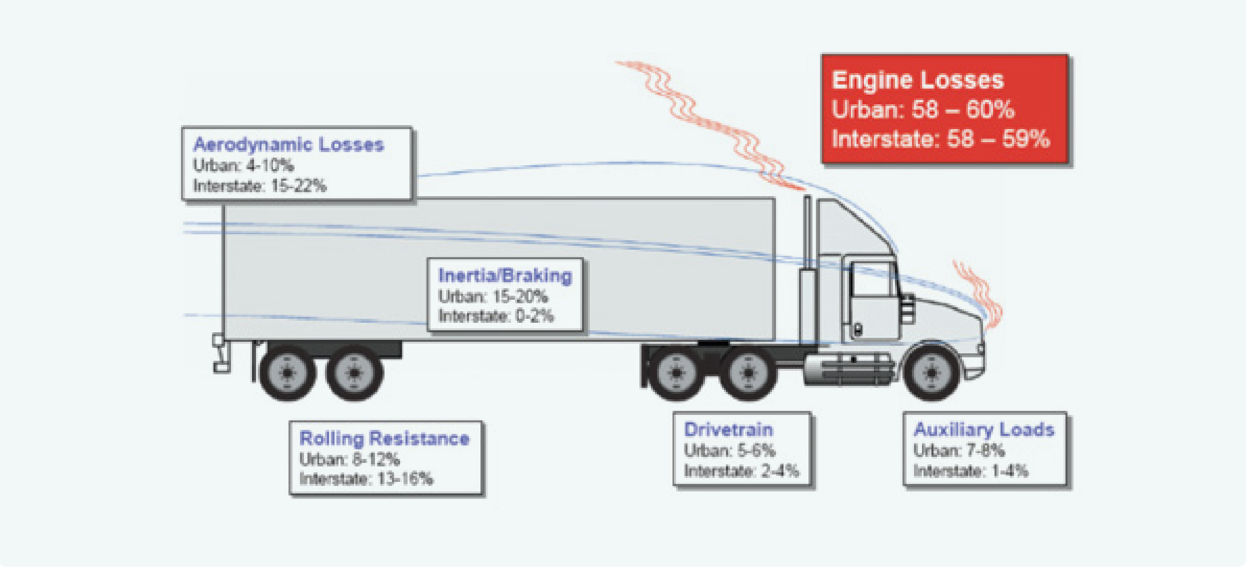
There are other aerodynamic treatments which may alter classic vehicle design and form in a way that may violate prescriptive regulations. For example in Europe, there are limited options available to truck tractor manufactures to include front end aerodynamic treatments given the very limited longitudinal length of these vehicles within regulated length constraints. Allowing additional frontal extension in front or as an extension of the occupant compartment would provide vehicle manufacturers with the ability to improve the drag coefficient of trucks through reshaping the front profile of the vehicle and provide additional space for occupants and for engine cooling to achieve emissions output improvements.

It is also conceivable that this additional space may allow for the development of improved crashworthiness. PBS would be a very effective means of controlling such extensions as shown in FIGURE 7, where the vehicle combination, despite a longer cab, does not require more space. Another PBS likely to be considered in this context is forward and downward vision.

Given the expanding need for industry to innovate in the face of fuel and emission constraints, there is a clear opportunity to extend the scope of performance-based systems within the context of size and weight policy to help promote

Figure 5 Energy loss proportion for a tractor semitrailer at cruise (GVW 36,000 kg)

SOURCE **TRB**



fuel efficiency and emissions reduction through innovation in vehicle design. Considering the examples given above, it is conceivable that performance-based standards could be developed to ensure that any additional length provided through regulation could be objectively assessed to determine the societal benefits while ensuring that freight task optimisation and safety remain in play. These standards could take the form of "Essential Requirements" specifically developed to promote societal benefit.

The European Modular System (EMS) concept was developed with the intent of using standardised loading units (7,82 m and 13,60 m), operating on specific roads and having compatibility with other transport modes. By any measure, EMS represents a significant step forward in the strategic systems approach to transport. The goal of making EMS "plug compatible" with rail, waterway and sea transport is an extremely important strategic policy initiative for future transport system optimisation. No other region of the world has endeavored to develop a homogeneous fleet with such broad compatibility. There is great potential for incorporating "Essential Requirements" within the context of EMS implementation. There is also the opportunity to incorporate "key performance indicators" to actively measure the net societal benefits attributable to EMS. Such information would be useful to counter the negative emotional arguments that often are used to block implementation of more efficient vehicles. Examples of key performance indicators may include lives saved, fuel and emissions reductions, infrastructure consumption reduction, and intermodal activity. Performance indicator data can also be used to fine tune policy over time.

EXAMPLES OF OTHER POTENTIAL OPPORTUNITIES

When examining the performance of smaller commercial vehicles, a unique set of metrics may be helpful in improving societal value. For example, the package freight industry servicing private residences is naturally motivated by customers to deliver packages in the most expedient manner possible which may not necessarily be the most efficient. This is because customers value quick delivery and are largely blind to vehicle efficiency. Current purchasing and product delivery systems are largely based on order-placement-to-house-delivery-time. Customers are given a choice of delivery options differentiated by price, such as next day, two day and standard delivery. At times, carriers are obliged to deliver packages to single households by a certain date irrespective of vehicle load factors within the destination area. Under such circumstances vehicle efficiency could be improved by holding packages at the sorting facility, perhaps for an extra day until truck load and distance factors for particular delivery areas reached a certain threshold. Developing performance metrics that promote vehicle efficiency for package delivery would provide customers with "green" delivery

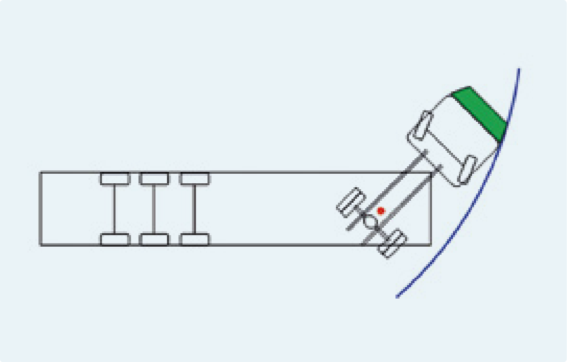
Figure 6 Aerodynamic "boat tail" used to reduce aerodynamic drag

SOURCE **TRB**

options. This would imply a reduction in vehicle distance travelled per packaged delivered which presumably would impact fuel use, emissions output, congestion and safety.

Another example of how performance-based metrics can be applied to smaller trucks are found in vocational vehicles. For example, specialised trucks with hydraulic lift buckets used by electrical utility companies are often stationary with the engine idling for most of the day as workers make repairs to infrastructure. Performance-based metrics could be used to encourage the use of battery power and automatic engine restart to energise the hydraulic system rather than continuously idling the main engine to generate hydraulic power which is needed only intermittently.

Figure 7 Example of how PBS could be used to control swept path



4. Conclusion

This paper documents two different PBS systems that have been implemented by two countries, each using very different regulatory approaches supported by PBS. Canada has a set of vehicle envelopes based on configuration type containing dimensional ranges for key vehicle parameters allowing some variability in design to optimise vehicle productivity. In Australia, all vehicle configurations and dimensions comply with PBS requirements. The distinctly different approach taken by both countries underscores the degree of flexibility open to regulators regarding the creation of regulatory instruments based on or supported by PBS. In both cases, there is strong evidence that such systems have significantly improved transport efficiency, creativity and safety. Key lessons learned from the Canadian experience are that high-efficiency vehicles can be operated under special permit systems that significantly reduce the risk of crashes and that the privilege of participating in such 'privileged" systems engenders a heightened safety culture within participating transport companies.

This paper provides examples of how PBS could be further developed in the form of "Essential Requirements" supported by "key performance indicators" to assess and encourage improvements in the sustainable value of road transport.

The potential for combining PBS in the form of "Essential Requirements" together with "key performance indicators" will provide vehicle performance assurance as well as performance outcome data to actively measure the net societal benefits attributable to different configurations. Such information would also be useful to counter the emotional arguments that often are used to block implementation of more efficient vehicles such as EMS.. Examples of key performance indicators may include lives and injuries saved, fuel and emissions reductions, infrastructure consumption reduction, and intermodal activity. Performance indicator data can also be used to fine tune policy over time as size and weight regulation should be considered a living entity requiring constant vigilance and periodic adjustment to deal with the unexpected.

Appendix

A.

Appendix A

Canadian Performance Measures

STABILITY AND CONTROL MEASURES

STATIC ROLLOVER THRESHOLD

The Static Rollover Threshold defines the maximum severity of steady turn which a vehicle can tolerate without rolling over. The measure expresses the level of lateral acceleration, in units of g's of lateral acceleration, beyond which overturn occurs. In general, loaded trucks exhibit rollover threshold values in the range of 0.25 to 0.40 g, a range which lies modestly above the severity levels encountered in the normal driving of passenger cars. This measure of truck roll stability is known to correlate powerfully with the incidence of rollover accidents in highway service.

Target Performance Level:
Vehicles, in the loaded condition, should exhibit a static rollover threshold of 0.4 g or better.
Note: Static rollover threshold of 0.4 g is not strictly applied in the current system.

DYNAMIC LOAD TRANSFER RATIO

Dynamic Load Transfer Ratio characterises the extent to which a vehicle approaches the rollover condition in a dynamic steering manoeuvre such as in avoiding an obstacle in the roadway. This measure is expressed in terms of the fractional change in tyre loads between left- and right-side tyres in the manoeuvre, thus indicating how close the vehicle came to lifting off all of its tyres on one side, and rolling over. The value which is determined reflects the amplification tendencies by which multiple-trailer combinations tend to "crack the whip" in rapid steering manoeuvres. The Load Transfer Ratio is calculated as follows:

Load Transfer Ratio = sum|FL-FR|/sum(FL+FR)
FL = Left side tyre loads
FR = Right side tyre loads

Target Performance Level:
When a vehicle in the loaded condition negotiates an obstacle avoidance, or lane change manoeuvre at highway speeds, the load transfer ratio should not exceed 0.60.

FRICTION DEMAND IN TIGHT TURNS

The measure termed, Friction Demand in a Tight Turn, pertains to the resistance of multiple, non-steered axles to travelling around a tight-radius turn, such as at an intersection. Especially with semitrailers having widely spread axles, the resistance to operating in a curved path results in a requirement, or demand, for tyre side force at the tractor's tandem axles. When the pavement friction level is low, such vehicles may exceed the friction which is available and produce a jackknife-type response. The friction demand measure describes the minimum level of pavement friction on which the vehicle can negotiate an intersection turn without suffering such a control loss. When the vehicle design is such that a high-friction level is demanded, the vehicle is looked upon as inoperable under lower-friction conditions such as prevail during much of the Canadian wintertime.

Target Performance Level:
When a vehicle negotiates a 90 ° turn with an outside radius of 11 m, the peak required coefficient of friction of the highway surface to avoid loss of traction by the tractor drive tyres should not exceed 0.1.

BRAKING EFFICIENCY

A Braking Efficiency measure is used to indicate the ability of the braking system to fully utilise the tyre/pavement friction available at each axle. It is defined as the percentage of available tyre/road friction limit that can be utilised in achieving an emergency stop without incurring wheel lockup. For example, a vehicle achieves only a 50% braking efficiency level when it suffers wheel lockup while braking at 0.2 g's on a surface which could ideally support a 0.4 g stop. The braking efficiency measure is meant to characterise the quality of the overall braking system as the primary accident avoidance mechanism.

It is recognised that in-service heavy vehicle braking characteristics are influenced by a multitude of factors including the state of adjustment of the mechanical elements of the braking system, the response characteristics of the air supply system, the type and condition of tyres on the vehicle, the load distribution between axles and the characteristics of the road surface. As a consequence, the performance measure described above is somewhat theoretical in nature, and may not be easily verified through physical testing of appropriately configured vehicles. Nonetheless, the Braking Efficiency measure, as determined using simulation or analysis techniques, does provide a valuable, consistent basis upon which valid comparisons of the braking performance of differing vehicle configurations can be made, and provides a reasonable target performance level which vehicles in the fleet should be capable of achieving.

ACEA

Target Performance Level:
Vehicles in the loaded or unloaded condition should exhibit braking efficiencies of 70% or better. Braking efficiency is defined as the percentage of available tyre/road friction limit that can be utilized in an emergency stop of 0.4 g's deceleration without incurring wheel lockup. Note: Since these measures were developed in the mid 1980's, the original brake performance requirement is now clearly out of date.

OFFTRACKING MEASURES

LOW SPEED OFFTRACKING

Low-Speed Offtracking is defined as the extent of inboard offtracking which occurs in a turn. In a right-hand turn, for example, the rearmost trailer axle follows a path which is well to the right of that of the tractor, thus making demands for lateral clearance in the layout of pavement intersections. This property is of concern to compatibility of the vehicle configuration with the general road system and has implications for safety as well as abuse of roadside appurtenances.

Target Performance Level:
When a vehicle negotiates a 90 ° turn with an outside radius of 11 m, the maximum extent of lateral excursion of the last axle of the vehicle, relative to the path followed by the tractor steering axle, should not exceed 6 m.

HIGH SPEED OFFTRACKING

A High-Speed Offtracking measure has been defined as the extent of outboard offtracking of the last axle of the truck combination in a moderate steady turn of 0.2 g's lateral acceleration. This measure is expressed as the lateral offset, in meters, between the trailer and tractor paths. Recognizing that the driver guides the tractor along a desired path, the prospect of trailer tyres following a more outboard path that might intersect a curb or an adjacent vehicle or obstacle poses a clear safety hazard.

Target Performance Level:
When a vehicle negotiates a turn with a radius of 393 m at a speed of 100 km/h, the maximum extent of outboard lateral excursion of the last axle of the vehicle, relative to the path followed by the tractor steering axle, should not exceed 0.46 m.

TRANSIENT HIGH SPEED OFFTRACKING

The Transient High-Speed Offtracking measure is obtained from the same obstacle avoidance manoeuvre as that used to define the dynamic rollover stability level and is defined as the peak overshoot in the lateral position of the rearmost trailer axle, following the severe lane-change-type manoeuvre. The amount of overshoot in the rearmost-axle path can be viewed as a relative indication of the extent of potential intrusion into an adjacent lane of traffic, or the potential for striking a curb (risking an impact-induced rollover). In layman's terms, this measure quantifies the magnitude of the "tail-wagging" in response to a rapid steer input.

Target Performance Level:
When a vehicle negotiates an obstacle avoidance, or lane change, manoeuvre at highway speeds, the maximum lateral excursion of the rearmost axle of the vehicle, relative to the final lateral path displacement of the steering axle, should not exceed 0.8 m.

B.

Appendix B

Australian Performance Measures

VEHICLE STABILITY STANDARDS

STATIC ROLLOVER THRESHOLD

The purpose of this standard is to manage safety risk by limiting the rollover tendency of a vehicle during steady turns when operating up to the maximum laden mass constituting the least favorable load conditions. The highest steady state level of lateral acceleration that a vehicle can sustain without rolling over must be no less than 0.4 g for dangerous goods tankers and no less than 0.35 g for all other vehicles.

DIRECTIONAL STABILITY UNDER BRAKING

Since Australia has not mandated anti-lock braking systems for heavy trucks, there is a need to evaluate vehicle stability performance under severe braking. The purpose of this standard is to manage safety risk of vehicle instability when braking in a turn or on pavement cross slopes. Heavy braking in a turn is a challenging manoeuvre that subjects the vehicle to a combination of longitudinal and lateral forces placing demands on both driver and vehicle performance. The PBS regulation requires that a vehicle not exhibit gross wheel lock-up in any loading condition and must remain in a straight lane of width equal to that specified in the standard ‘Tracking ability on a straight path’ for the corresponding level of operation when it is braked from 60 km/h to achieve the assessment deceleration level on a high-friction surface roadway. Vehicles having ABS brake systems are deemed to comply with this requirement. The proposed assessment deceleration levels are shown in TABLE 5. Deceleration levels for vehicles participating in the scheme. The tests must be conducted with an unladen vehicle having tyre/road surface friction of not more than 0.80.

Table 5 Deceleration levels for vehicles participating in the scheme

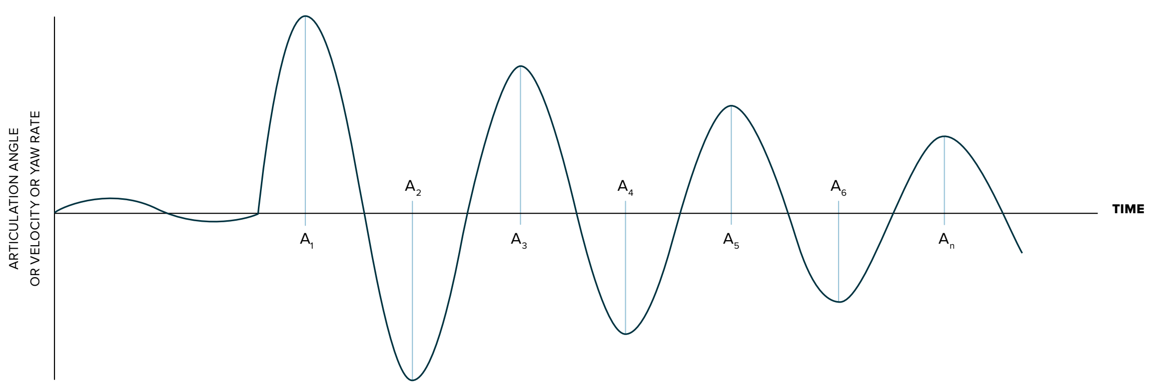
ROAD CLASS	Vehicle Configuration	Avg. Decl. from 60 km/h
ALL ACCESS LEVELS	Rigid trucks and buses	0.40 g
LEVEL 1	Semi-trailers	0.35 g
LEVEL 2	B-double combinations	0.30 g
LEVEL 3	Road-train A-doubles and B-triples	0.25 g
LEVEL 4	Road-Train A-triples	0.20 g

YAW DAMPING COEFFICIENT

The purpose of this standard is to manage safety risk by requiring acceptable attenuation of any sway oscillations of rigid vehicles or between the trailers of multi-articulated vehicles. An important consideration in the stability and handling of heavy vehicles is how quickly swing, sway or yaw oscillations take to decay after a severe manoeuvre has been performed. The parameters that influence rearward amplification have similar strong influences on yaw damping coefficient.

Figure 8 Illustration of Yaw damping

SOURCE NTC



Amplitude A_n must be at least 5% of A_1 and the calculation of the mean value of the amplitude ratios must be based upon at least 6 amplitudes, as shown in FIGURE **8**. The mean value of the amplitude ratios must be calculated separately for each articulation joint, or vehicle unit. The damping ratio must not be less than 0.15 at the certified vehicle speed and applies equally to all road classes. The prescribed manoeuvre used in this analysis is the "Single Sine-Wave Lateral Acceleration Input", specified in ISO 14791:2000(E) (International Standards Organisation, 2000).

TRAILER DYNAMIC PERFORMANCE STANDARDS

HIGH-SPEED TRANSIENT OFFTRACKING

The purpose of this standard is to manage safety risk by limiting the sway of the rearmost trailers of multi-articulated vehicles in avoidance manoeuvres performed without braking, at highway speeds. During an evasive manoeuvre, the lateral displacement of the rear end of the last trailer of an articulated vehicle may "overshoot" the path of the power unit as illustrated in FIGURE **9**. The prescribed manoeuvre used in this analysis is the "Single Sine-Wave Lateral Acceleration Input", specified in ISO 14791:2000(E) (International Standards Organisation, 2000). The performance levels are listed in TABLE **6**.

TRACKING ABILITY ON A STRAIGHT PATH

The purpose of this standard is to manage safety risk associated with lane width and lateral clearance by ensuring that a vehicle remains within its traffic lane when travelling at high speed on straight roads with uneven surfaces. This requirement is intended for long vehicle combinations. The standard considers total swept width while travelling on a straight path, including the influence of variations due to crossfall, road surface unevenness and (normal) driver steering activity, as shown in FIGURE **10**. The vehicle must traverse a road segment not less than 1 000 m long at a travel speed not less than 90 km/h. The vehicle must be driven in a normal manner at the specified speed while following a straight path as closely as possible. The performance levels are listed in TABLE **7**.

Table 6 High speed transient offtracking performance levels

ROAD CLASS	Maximum Allowable
LEVEL 1	No greater than 0.6 metre
LEVEL 2	No greater than 0.8 metre
LEVEL 3	No greater than 1.0 metre
LEVEL 4	No greater than 1.2 metre

Table 7 Tracking ability performance levels

ROAD CLASS	Time to travel 100m
LEVEL 1	Not greater than 2.9 metre
LEVEL 2	Not greater than 3.0 metre
LEVEL 3	Not greater than 3.1 metre
LEVEL 4	Not greater than 3.3 metre

Figure 9 Illustration of high-speed transient offtracking overshoot

SOURCE NTC

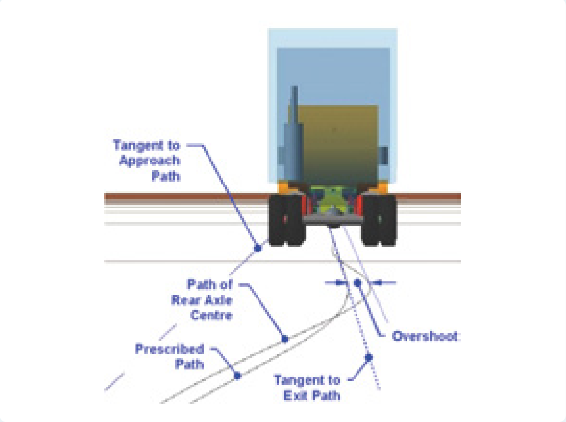
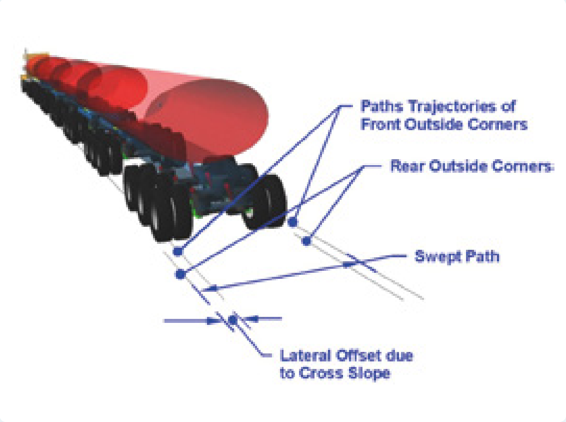


Figure 10 Illustration of path trajectories in the tracking ability on a straight path test

SOURCE NTC



REARWARD AMPLIFICATION

The purpose of this standard is to manage safety risk by limiting the lateral directional response of multi-articulated vehicles in avoidance manoeuvres performed at highway speeds without braking. Rearward amplification generally pertains to heavy vehicles with more than one articulation point, such as truck-trailers and road/train combinations. It shows as a tendency for the following or trailing unit(s) to experience higher levels of lateral acceleration than the towing unit. It is a serious safety issue in rapid path-change manoeuvres as it can lead to rear-trailer rollover. Rearward amplification is the ratio of the lateral acceleration of the following unit to that of the first unit. The analysis method depends upon whether or not the vehicle units are roll-coupled. The manoeuvre used for this measure is the "Single Sine-Wave Lateral Acceleration Input", specified in ISO 14791:2000(E) (International Standards Organisation, 2000). The performance criteria are the same for all road classes. Rearward amplification must not be greater than 5.7 times the static rollover threshold of the rearmost unit or roll-coupled set of units taking account of the stabilising influence of the roll coupling.

VEHICLE POWERTRAIN STANDARDS

STARTABILITY

The purpose of this standard is to manage safety risk associated with starting on grade by ensuring that a vehicle has adequate starting capability on grades. The candidate vehicle must be capable of starting on the steepest grade it has to negotiate on the nominated route when operating at its maximum allowed gross mass. The startability performance levels are listed in TABLE **8**.

Table 8 Startability performance Levels

ROAD CLASS	Performance Requirement
LEVEL 1	At least 15%
LEVEL 2	At least 12%
LEVEL 3	At least 10%
LEVEL 4	At least 5%

GRADEABILITY

The purpose of this standard is to manage safety risk associated with travel on grade by ensuring that a vehicle has the capability to maintain acceptable speeds on upgrades. The gradability performance levels are listed in TABLE **9**.

Table 9 Gradeability Performance levels

ROAD CLASS	Grade level	Performance Requirement
LEVEL 1	At least 20%	At least 80 km/h
LEVEL 2	At least 15%	At least 70 km/h
LEVEL 3	At least 12%	At least 70 km/h
LEVEL 4	At least 8%	At least 60 km/h

ACCELERATION CAPABILITY

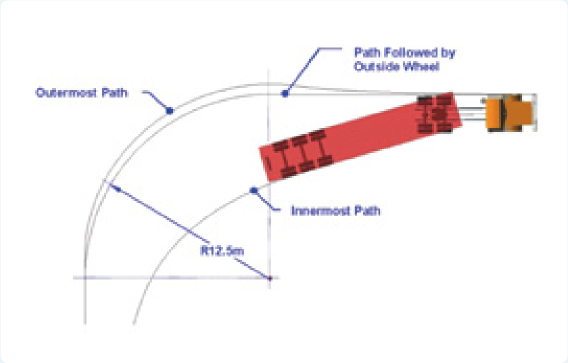
The purpose of this standard is to manage safety risk associated with travel through intersections and rail crossings by specifying minimum times for a loaded vehicle to accelerate from rest, to increase speed, and travel at least 100 m. The acceleration performance levels are listed in TABLE **10**.

Table 10 Acceleration Performance levels

ROAD CLASS	Time to travel 100 m
LEVEL 1	20 sec
LEVEL 2	23 sec
LEVEL 3	26 sec
LEVEL 4	29 sec

Figure 11 Illustration of Swept Path

SOURCE NTC



VEHICLE MANOEUVRABILITY STANDARDS

LOW-SPEED SWEPT PATH

The purpose of this standard is to manage safety risk associated with turns at intersections by limiting the road space required by a vehicle when making low-speed in a prescribed 12.5 m radius 90° low speed turn shown in FIGURE **11**, and the tyre reference point is illustrated in FIGURE **12**.

Low speed swept path performance levels:

ROAD CLASS	Time to travel 100 m
LEVEL 1	Not greater than 7.4 metre
LEVEL 2	Not greater than 8.7 metre
LEVEL 3	Not greater than 10.6 metre
LEVEL 4	Not greater than 13.7 metre

FRONTAL SWING

The purpose of this standard is to manage safety risk by limiting the road space requirement of a vehicle when making a tight turn at low speed. The test procedure is the same as low-speed swept path consisting of a 12.5 m radius 90° low speed turn as illustrated in FIGURE **13**. The frontal swing performance levels are listed in TABLE **11**.

Table 11 Permissible fontal swing out performance levels

ROAD CLASS	Time to travel 100 m
LEVEL 1	No greater than 0.20 metre
LEVEL 2	No greater than 0.20 metre
LEVEL 3	No greater than 0.20 metre
LEVEL 4	No greater than 0.20 metre

Figure 12 Illustration of outside wheel reference point

SOURCE NTC

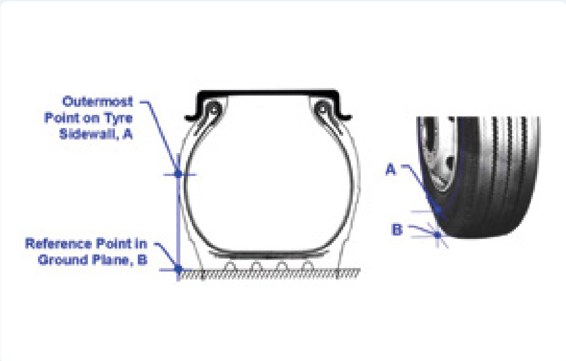
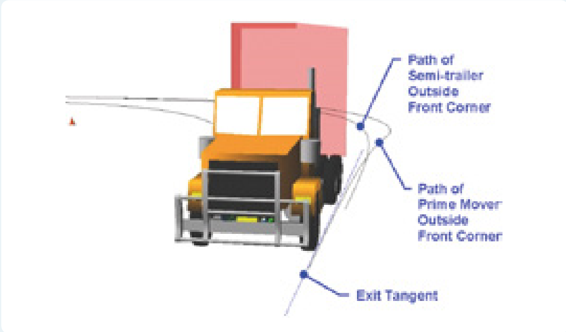


Figure 13 Illustration of path trajectories in low-speed for frontal swing

SOURCE NTC



TAIL SWING

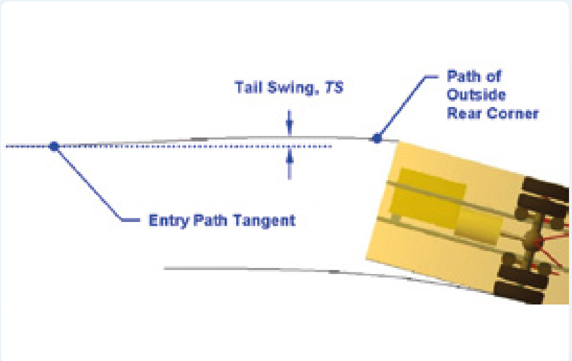
The purpose of this standard is to manage safety risk by limiting the road space requirement of a vehicle when making a tight turn at low speed. Tail swing references the maximum outward lateral displacement of the outer rearmost point on a vehicle unit during the initial and final stages of a prescribed 12.5 m radius 90° low speed turn shown in FIGURE **14**. The tail swing performance levels are listed in TABLE **12**.

Table 12 Tail swing performance levels

ROAD CLASS	Tail Swing
LEVEL 1	No greater than 0.30 metre
LEVEL 2	No greater than 0.35 metre
LEVEL 3	No greater than 0.35 metre
LEVEL 4	No greater than 0.50 metre

Figure 14 Illustration of tail swing performance in low-speed turn

SOURCE NTC



STEER TYRE FRICTION DEMAND

The purpose of this standard is to manage safety risk by limiting the likelihood of a vehicle losing steering control when making a tight turn at low speed. The maximum friction level demanded of the steer tyres are measured during a prescribed 12.5m radius 90° low speed turn. Friction demand is the ratio of friction required to friction available expressed as a percent. The performance limit is 80% and applies equally to all road classes.

INFRASTRUCTURE STANDARDS

BRIDGE LOADING

The bridge loading standard addresses the issue of bridge strength and ensures that a vehicle does not induce effects on bridge structures that exceed accepted limits as specified by the bridge owner. The regulation references three tiers;

- **Tier 1 General Access or Restricted Access** – must meet a specific bridge formula;
- **Tier 2 Special Access** – must not cause more effects than those caused by existing commercial vehicles (assessment must be conducted by a prequalified bridge engineer);
- **Tier 3 Special Access** – approval by the owners of the bridges to use all of the bridges on a specific link based on detailed individual bridge assessment (assessment should be undertaken by the bridge owner).

TYRE CONTACT PRESSURE DISTRIBUTION

The purpose of this standard is to restrict road wear by setting minimum tyre widths and by limiting the local contact pressure between the tyre and the road within the tyre contact patch.

Requirements: Existing prescriptive requirements relating to minimum tyre width and maximum pressure have been retained and applied to vehicles participating in the PBS system.

PAVEMENT HORIZONTAL LOADING

The purpose of this standard is to regulate road wear by limiting the impact on the surface of road pavements of:

- Horizontal tyre forces of a multi-axle group when turning
- Tractive tyre forces of the drive axle or axles when starting or climbing an upgrade

Requirements: For tandem axle groups with an axle spacing of more than 2 meters, at least one axle must be steerable. For axle groups with three or more axles and a spread of greater than 3.2 meters, all axles beyond the 3.2 meter spread must be steerable.

For drive axles:

- all driving axles in a drive axle group must distribute tractive forces, such that the maximum difference in tractive force between any two driving axles in the group is not greater than 10% of the total tractive force delivered by the drive axle group.
- a vehicle or combination having one or two driving axles is not permitted when the gross mass of the vehicle or combination exceeds specified weight limits.

MEASURES CONSIDERED BUT NOT INCLUDED IN PBS

Other Standards that were considered but not included in the PBS are as follows:

OVERTAKING PROVISION

The overtaking provision is based on vehicle length in relation to road class and access class as follows. Length becomes a surrogate for performance but in reality it has the form of a prescriptive regulation. This provision resides in the Network Classification Guidelines. The overtaking vehicle length limits are listed in TABLE **13**.

Table 13 Vehicle limits pertaining to overtaking performance

ROAD CLASS	Vehicle length (m) Access class A	Access class B
LEVEL 1	L ≤ 20	
LEVEL 2	L ≤ 20	26 < L ≤ 30
LEVEL 3	L ≤ 36.5	36.5 < L ≤ 42
LEVEL 4	L ≤ 53.5	53.5 < L ≤ 60

Note: The PBS network is divided in two categories, namely 'Access Class A' and 'Access Class B'. These two PBS access categories are defined according to the maximum length of the PBS vehicles allowed to circulate on each network. The general rule is that for a given PBS level (PBS level 1, 2, 3 or 4), longer vehicles are allowed to circulate on the 'Class B' network. This is due to the fact that the class B network is deemed suitable for these longer vehicles, which is inherently linked to the geometrical characteristics of the road network. For instance, it may be the case that road sections belonging to the class B network allows the overtaking of longer vehicles or the safe turning of vehicles with larger swept paths. More information can be found at: www.ntc.gov.au/filemedia/Reports/PBSSchemeNetwkClassifGLinesOct07.pdf

ACEA

RIDE QUALITY (DRIVER COMFORT)

The purpose of this standard is to manage safety risk by limiting driver whole body vibration, especially on uneven roads where travel speeds are high and vibration levels are expected to be significant. This standard has yet to be defined. Its three main components (a performance measure, a test procedure from which to obtain the performance measure, and a performance level, or levels, to be satisfied) are not able to collectively be defined to an acceptable level of robustness at this time, based on current research.

HANDLING QUALITY (UNDERSTEER/OVERSTEER)

The primary purpose of this standard is to manage safety risk by ensuring adequate vehicle handling characteristics. Handling quality, expressed in terms of the "understeer oversteer" coefficient, quantifies the responsiveness and "driver feel" of the vehicle to steering input during manoeuvres. The understeer/oversteer behaviour of heavy vehicles has been found to vary significantly with lateral acceleration, and in some situations, this marked change in steering response may make the vehicle difficult to control. NTC has not implemented this measure.

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