THE DEVELOPMENT OF A PERFORMANCE-BASED STANDARDS APPROACH FOR REGULATING THE USE OF HEAVY VEHICLES IN SOUTH AFRICA

PA Nordengen

PhD PROPOSAL

Submitted in partial fulfilment of the
requirements for the degree of PhD

School of Bioresources Engineering and Environmental Hydrology
University of KwaZulu-Natal
Pietermaritzburg

July 2008

Supervisors: Prof Peter Lyne (peter.lyne@sugar.org.za)
Prof Carel Bezuidenhout (bezuidenhoutc@ukzn.ac.za)

ABSTRACT

The regulation of the use of vehicles on the road network is aimed at ensuring acceptable safety and recovery of road maintenance costs, as well as minimising congestion, road wear, excessive noise and air pollution. The traditional approach of regulating heavy vehicles is prescriptive, i.e. enforcing regulations that primarily limit the mass and dimensions of these vehicles. This approach is generally favoured because such regulations are easy to understand and enforce. However, an underlying flaw is that the prescriptive approach does not always adequately safeguard the dynamic performance of heavy vehicles while travelling on the road. Principle-based and performance-based standards are primarily aimed at specifying desired outcomes, rather than how these outcomes should be achieved.

Under a performance-based standards (PBS) approach, performance measures (such as low-speed swept path, vehicle stability, handling and high-speed tracking) are utilised to specify the performance required from vehicles rather than prescribing how this performance should be achieved. Although more complex to regulate, a PBS approach has a number of potential benefits such as improved vehicle safety and productivity, reduced infrastructure wear and emissions, a more optimal use of the existing road network and the encouragement of innovation in vehicle design. During the past two decades, a number of countries have considered a performance-based approach to regulating heavy vehicles as part of their vehicle mass and dimension reviews. Australia, Canada and New Zealand have all implemented performance-based standards to regulate part of or the entire heavy vehicle fleet, each with a different approach.

The aim of the research is to show that an alternative approach to the design and operation of heavy vehicles can be developed and tested in South Africa with improved outcomes in terms of vehicle safety performance, vehicle productivity, emissions and consumption of road infrastructure. The work will build on the PBS experiences in Australia, New Zealand and Canada and take into account unique road and traffic conditions in South Africa. The project will involve the monitoring and evaluation of two PBS demonstration projects operating in the forestry industry in the KwaZulu-Natal province of South Africa.

TABLE OF CONTENTS

GLOSSARY OF TERMS

Acceleration capability. Ability of a vehicle to accelerate either from rest or to increase speed on a level road (no grade).

Directional stability under braking. The ability to maintain stability under braking.

Dynamic Load Transfer Ratio (DLTR). A measure of the load transfer from one side of a vehicle to the other during a rapid lane change manoeuvre.

Frontal swing. The maximum lateral outswing of the front outside corner of the prime mover and trailer in a prescribed 90° low-speed turn.

Gradeability. The ability of a vehicle to maintain a) forward motion and b) minimum speed on a specified grade.

Handling quality. The rate of response of steering to steering wheel input (standard still to be developed).

High-Speed Transient Offtracking (HSTO). The lateral distance that the last axle on the rear trailer tracks outside the path of the steer axle in a prescribed sudden evasive manoeuvre.

Low-speed swept path. The maximum width of the swept path in a prescribed 90° low-speed turn.

Rearward Amplification (RA). The degree to which the trailing unit(s) amplify or exaggerate lateral motions of the hauling unit.

Ride quality. Level of vibration to which a driver is exposed.

Startability. Ability of a vehicle to commence forward motion on a specified grade.

Static Rollover Threshold (SRT). The steady-state level of lateral acceleration that a vehicle can sustain during turning without rolling over.

Steer-tyre friction demand. The maximum friction level demanded of the steer-tyres of the hauling unit in a prescribed low speed turn.

Tail swing. The maximum lateral out-swing of the outside rear corner of the truck or trailer as the turn commences.

Tracking Ability on a Straight Path (TASP). The total swept width while travelling on a straight path, including the influence of variations due to crossfall, road surface unevenness and driver steering activity.

Yaw Damping Coefficient (YDC). The rate of decay of the 'sway' or yaw oscillations of the rearmost trailer after a single pulse steer input at the hauling unit.

1. INTRODUCTION

Worldwide the use of heavy vehicles on the public road network is predominantly regulated by prescriptive rules. These rules may differ substantially from country to country and even between jurisdictions in the same country (e.g. the USA), usually having a negative impact on road transport efficiency. Typically, the prescriptive approach involves setting tightly defined vehicle mass and dimension limits to ensure that transport operators use vehicles that are safe and do not cause unacceptable damage to the road infrastructure or disruption of traffic flows. Prescriptive standards are an indirect yet simple means of achieving specific safety and infrastructure preservation outcomes. However, having these standards in place does not guarantee that vehicles meeting the requirements will not have relatively poor safety performance. Safety issues, such as low-speed swept path, vehicle stability, handling and high-speed tracking are not evaluated and are only indirectly controlled.

Under a performance-based standards (PBS) approach, performance measures (such as those mentioned above) and performance levels, which may vary for different categories of the road network, are utilised to specify the *performance* required from vehicles rather than prescribing how this performance should be achieved. The PBS approach to regulation is well established in other sectors such as occupational health and safety, food standards and road construction and maintenance (OECD, 2005).

Most countries undertake a partial or comprehensive review of their mass and dimensions regulations for heavy vehicles every 10 to 20 years. During the past two decades a number of countries have considered a performance-based approach as part of their mass and dimension reviews. These include New Zealand (Edgar, 1995; de Pont *et al.*, 2002c), Canada (RTAC, 1986; RTAC 1988), Australia (Peters and Stevenson, 2000; Calvert, 2004) and the United States (US DoT, 2000; TRB, 2002; Fepke *et al.*, 2006a; Fepke *et al.*, 2006b). In addition, the Organisation for Economic Co-operation and Development (OECD) is currently carrying out a project entitled, “Heavy Vehicles: Regulatory, Operational and Productivity Improvements” (OECD, 2007). This project, which is expected to be completed during 2009, includes a benchmarking survey of the safety and productivity performance of heavy vehicles in a number of OECD member countries, based on a selection of performance measures that have been adopted in New Zealand, Canada and Australia. Although not a member of the OECD, South Africa is also participating in this project.

The main objective of this literature review and project proposal is to describe the development of the performance-based standards approach for regulation of heavy vehicles on the road networks in the three countries where such an approach has been implemented, *viz*. New Zealand, Canada and Australia. A second objective is to identify the need for developing a PBS approach/framework for heavy vehicles in South Africa. Chapter 2 describes various regulatory approaches, and highlights some of the benefits of a performance-based approach compared with the traditional prescriptive approach. Chapters 3, 4 and 5 describe the initiatives adopted by New Zealand, Canada and Australia, respectively, to utilise the PBS approach to improve the safety and productivity performance of heavy vehicles operating on their road networks. Discussions and conclusions are presented in Chapter 6, followed by details of the proposed project in Chapter 7.

2. REGULATORY PRINCIPLES AND OPTIONS

2.1 Introduction

The regulation of road use by vehicles is aimed at ensuring acceptable safety, recovery of road maintenance costs as well as minimising congestion, road wear, excessive noise and air pollution. The predominant approach worldwide for regulating the use of heavy vehicles is by prescriptive rules. However, as numerous new technologies have become available and more affordable for use on a large scale, other more optimal approaches to regulate heavy vehicles should be considered, as suggested in the OECD Report to Ministers on Regulatory Reform (OECD, 1997):

> "*All governments have a responsibility to review their own regulations and regulatory structures and processes to ensure that they promote efficiently and effectively the economic and social well-being of their people.*"
>
> "*Incentives have too often favoured vocal rather than general interests, short term over long term views, pursuit of narrow mission goals at any cost, and use of detailed and traditional controls rather than flexible and innovative approaches.*"

The introduction of improved regulation has a number of potential positive outcomes such as (OECD, 2005):

- Encouraging innovation;
- Providing a better match between vehicles and roads;
- Increasing regulatory transparency through more consistent and rational regulatory approaches;
- Improving performance through better controls on safety and infrastructure wear;
- Improving compliance.

2.2 A Comparison of Regulatory and Enforcement Approaches

The various approaches to regulation and enforcement are shown in Figure 2.2 (NRTC, 2001a; OECD, 2005). The prescriptive standards approach involves detailed and inflexible regulations that are generally only indirectly related to the desired outcomes, e.g. vehicle performance. (In this literature review, 'performance' refers to the impact of a vehicle in terms of safety – with regard to dynamic performance in particular, infrastructure preservation and productivity). However, enforcement of the regulations is simple and can be done on the road (e.g. with a tape measure and weighbridge). On the other extreme, principle-based standards are more flexible and specify only broad objectives. Outcomes are specified, rather than how they are to be achieved. Enforcement and compliance is more complex and may involve accreditation and quality management systems to ensure compliance with the operating conditions, which are often specific to a particular vehicle configuration. On-road enforcement is supported by audits of management systems and other forms of monitoring (e.g. GPS tracking).

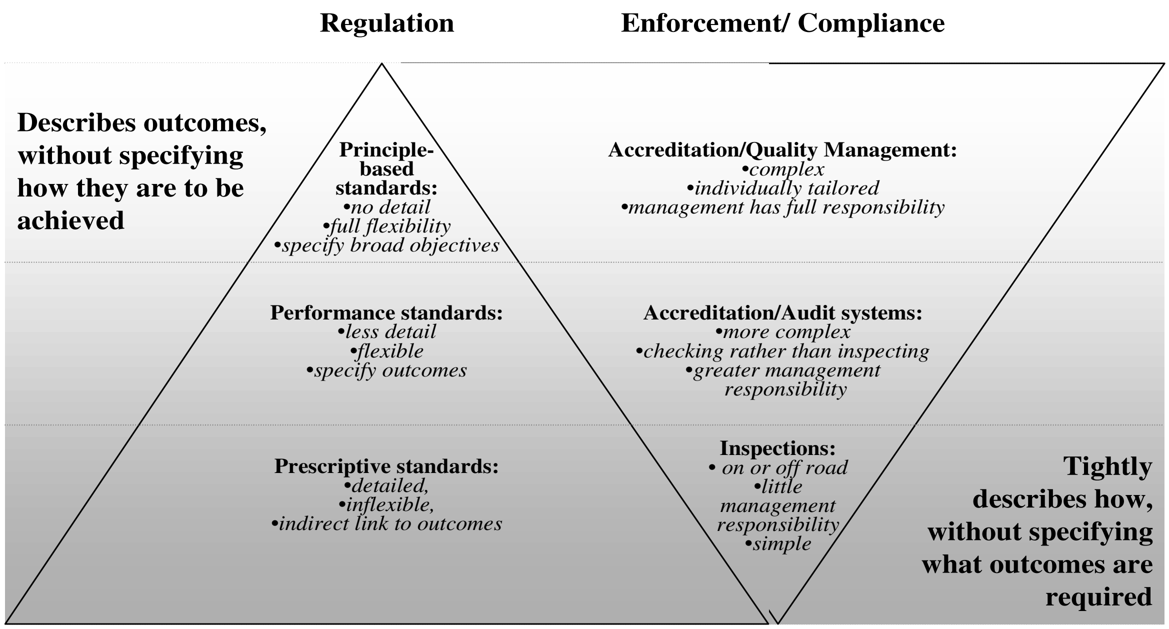


Figure 2.1 Hierarchy of possible approaches to regulation (NRTC, 2001a).

The PBS approach falls between the two extremes shown above. Performance-based standards are more precise than principle-based standards, but still allow sufficient flexibility regarding the manner in which the standards are achieved. Another regulatory approach is the introduction of performance-based prescriptive regulations that have been derived from PBS analyses. Under this approach, prescriptive rules are developed to achieve the same or similar outcomes that will meet specific performance criteria. This approach is likely to be less optimal than the PBS approach, as any innovative designs that do not meet the prescribed limits will not be allowed, even where the design meets the original performance criteria.

Six approaches for regulating the use of heavy vehicles have been identified (OECD, 2005):

- Prescriptive rules that have been developed over a long period of time and are most commonly used worldwide. They are usually not directly linked to performance criteria;
- The use of PBS as a basis for setting prescriptive rules;
- The use of PBS for evaluating and issuing exemption permits for vehicles exceeding the mass and dimension limits (abnormal loads);
- An holistic PBS approach which replaces prescriptive regulations with a PBS approach;
- A hybrid PBS approach which combines the advantages of the first three options. The majority of heavy vehicles would continue to operate in accordance with prescriptive rules; new vehicle combinations that meet either specified performance standards or modified prescriptive rules that are based on performance-based standards would be allowed to operate on specified sections of the road network;
- A road network approach, where varying performance levels for specific performance measures are assigned to different parts of the road network, thereby ensuring that lower road standards are matched by vehicles with improved performance. This approach may allow all existing vehicles access to the entire network, but with varying operating conditions on different sections of the network.

If successfully implemented, a regulatory framework for heavy vehicles incorporating a PBS approach is more likely to result in improved productivity, enhanced road safety and reduced negative environmental impacts (Peters and Stevenson, 2000; Bennet *et al*., 2003). This will be achieved by:

- Permitting the operation of safer, higher productivity vehicles controlled by critical performance measures such as rollover stability;
- More closely matching heavy vehicles and the roads on which they travel;
- Reducing the total emissions of the heavy vehicle fleet;
- Encouraging innovation in the heavy vehicle industry to meet customer needs by providing a significant ‘reward for effort’;
- Accelerating new vehicle and Intelligent Transport Systems (ITS) technology, and
- Improving compliance with transport regulations.

3. DEVELOPMENT OF PERFORMANCE-BASED STANDARDS FOR HEAVY VEHICLES IN NEW ZEALAND

3.1 Background

New Zealand was the first country to implement performance standards for regulating heavy vehicles (OECD, 2005). In the late 1980s, New Zealand increased the permissible maximum combination mass for large vehicles from 39 to 44 tonnes. This mass increase was limited to certain combinations, *viz*. B-trains and some truck-trailer configurations (Baas and White, 1989). The choice of vehicle configurations eligible for the 44 tonne combination mass was based on a PBS assessment. Subsequently, some A-trains were issued with permits for 44 t, provided they satisfied PBS criteria.

A government-initiated study on truck crashes in New Zealand (Anderson and Sinclair, 1996) identified the stability of trucks in the forestry industry as an area of particular concern. An analysis of crash statistics (Baas and Latto, 1997) showed that trucks in the forestry industry were involved in a disproportionately high number of crashes. The University of Michigan Transport Research Institute (UMTRI) Yaw-Roll software was used to simulate a range of heavy vehicles under typical loading conditions and to evaluate a range of performance measures. Two of the critical performance measures identified with respect to rollover were Static Rollover Threshold (SRT) and Dynamic Load Transfer Ratio (DLTR). The results showed that many vehicle configurations commonly used in the forestry industry had poor performance in relation to these two measures (de Pont *et al*., 2002a). The predominant vehicle configuration in the forestry industry is the rigid-drawbar (truck-trailer), which makes up about 90% of the timber vehicle fleet. The remainder are truck-semitrailers and interlinks (B-doubles).

3.2 Incorporation of Two Performance Standards into Heavy Vehicle Regulations

A study by White and Baas (1993) recommended a lower limit of SRT of 0.35 *g* (specific gravity) and an upper limit of DLTR of 0.6 as benchmarks for acceptable performance. Marginal performance was defined as between 0.3 and 0.35 for SRT and between 0.6 and 0.8 for DLTR. Further studies (Mueller *et al*., 1999; de Pont *et al*., 2002b) investigated various performance measures in relation to crash rates in New Zealand. The results showed a clear relationship between relative crash rate and SRT (Figure 3.2) and crash rate and DLTR (Figure 3.3).

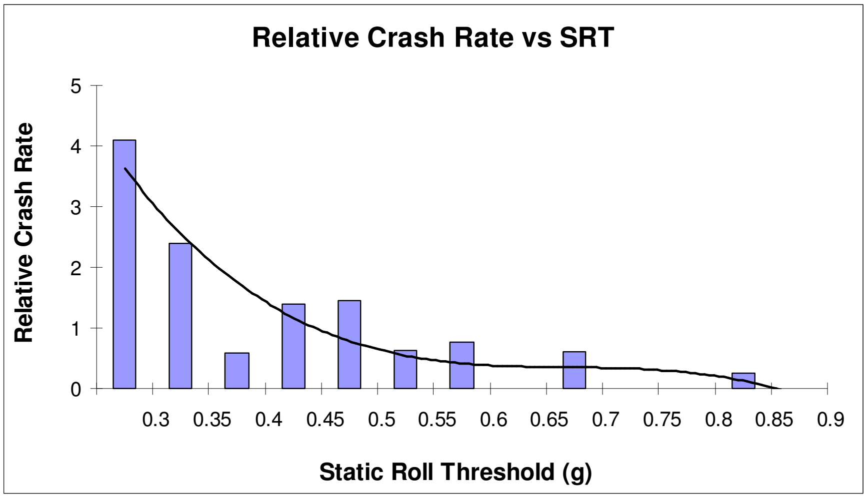


Figure 3.1 A comparison of Relative crash rate against Static Rollover Threshold (SRT) for all vehicles in New Zealand (de Pont *et al*., 2002a).

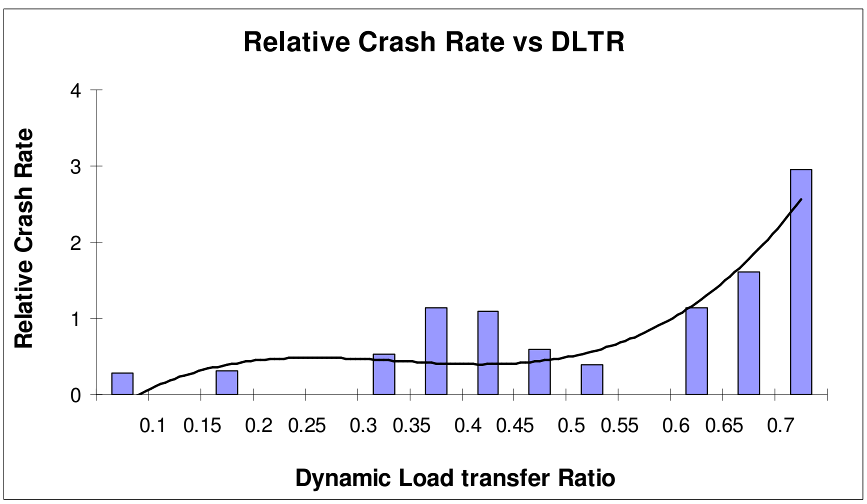


Figure 3.2 A comparison of Relative crash rate against Dynamic Load Transfer Ratio (DLTR) for all vehicles in New Zealand (de Pont *et al*., 2002a).

The above studies formed an important input to the Vehicle Dimensions and Mass (VDM) Rule 41001 (LTSA, 2002), which came into effect on 1 July 2002. For the first time anywhere in the world, so-called prescriptive regulations included a minimum rollover stability requirement for most heavy vehicles in the fleet. Some countries do have minimum stability requirements for certain categories of vehicles. For example, in the United Kingdom, there is a stability requirement for buses and coaches (HMSO, 1922) and in the European Union for tankers (ECE, 2001). Furthermore, in many countries, including South Africa, stability checks are required for abnormal vehicles carrying indivisible loads if the height to width ratio exceeds a certain limit.

3.3 The SRT Calculator

The stability requirement in the Vehicle Dimensions and Mass Rule applies to all heavy trucks in the class NC (greater than 12 tonnes) and class TD (greater that 10 tonnes). Heavy vehicles in these classes must achieve a minimum SRT of 0.35g (de Pont *et al*, 2004). In order to make this requirement possible for the industry, an SRT calculator was developed. This is a simple, low-cost method for assessing SRT (de Pont *et al.*, 2002b, de Pont *et al.*, 2002c) with reasonable accuracy. The basis of the SRT calculator is an algorithm which was derived from the formula for a vehicle subject to a lateral acceleration, α, when assuming small angles (see Figure 3.4):

$$SRT = \alpha = \left(\frac{T}{2H}\right) - \Phi \quad (3.1)$$

where T = track width [m],
H = centre of gravity height [m], and
Φ = total roll angle due to compliance [radians].

A mathematical solution was developed based on the graphical approach by Chalasani (Winkler *et al.*, 2000) to estimate the actual SRT (see Figure 3.5). The SRT calculator runs as a web-based application on the internet (www.ltsa.govt.nz/srt-calculator).

The SRT calculator algorithm was validated using results of 10 years of computer simulation in New Zealand using the Yaw-Roll software from UMTRI, together with the results of tilt table tests on a log transport trailer. A comparison of Yaw-Roll and SRT calculator results is shown in Figure 3.6 (de Pont *et al.*, 2002c).

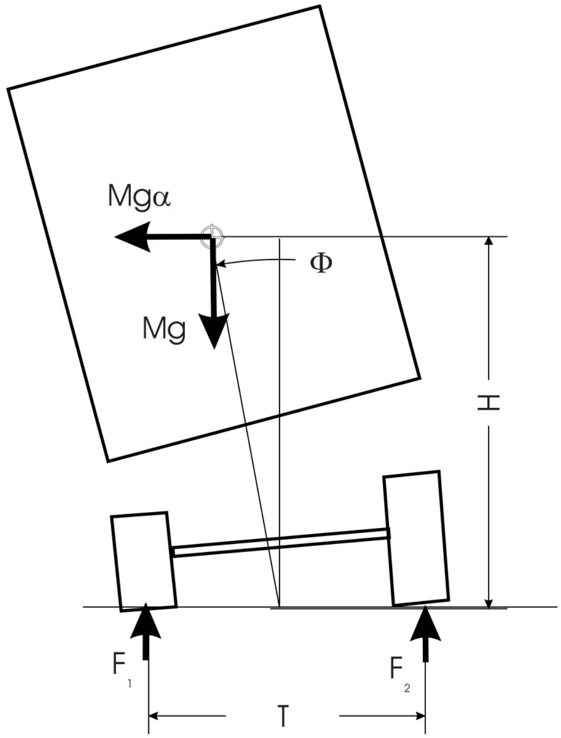


Figure 3.3 2-D truck model for SRT calculation (de Pont *et al.*, 2002c).

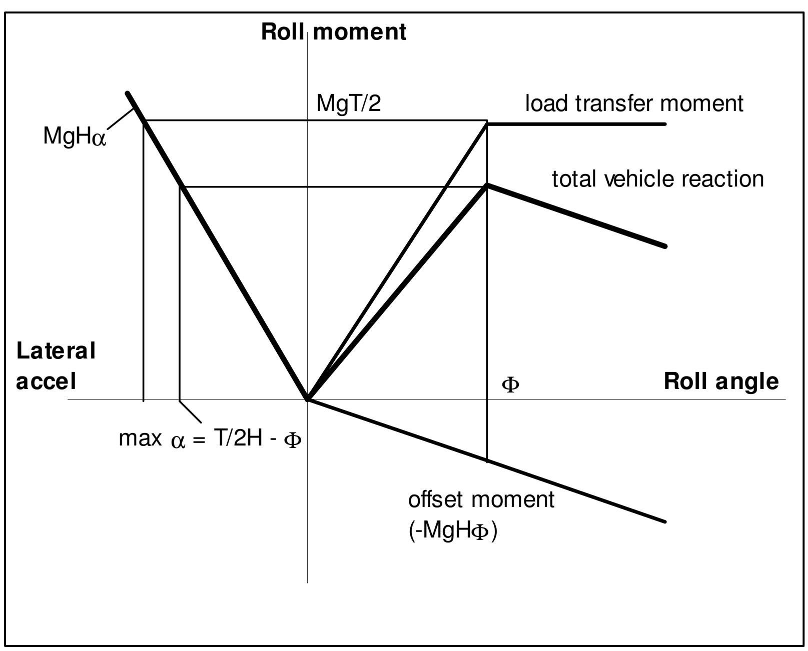


Figure 3.4 Graphical solution of SRT for simple case with compliant suspension and tyres (adapted from Winkler *et al.*, 2000).

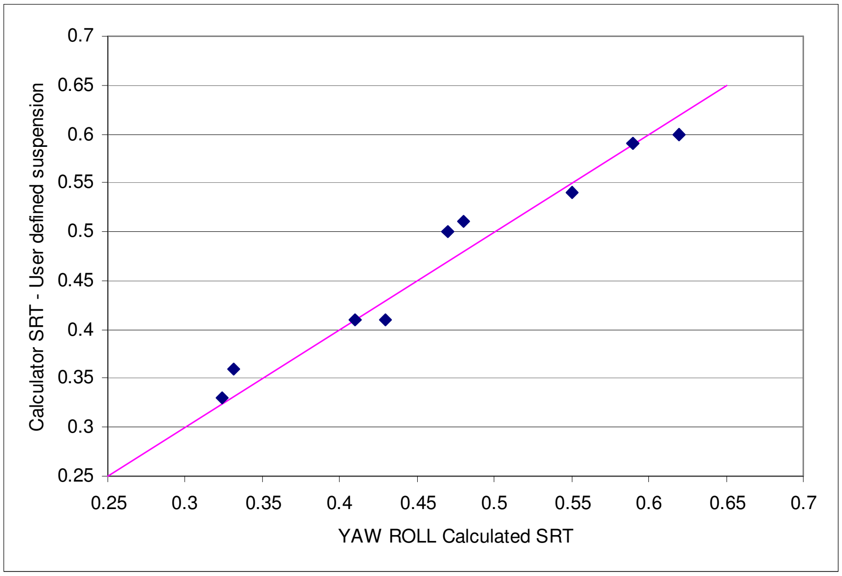


Figure 3.5 Comparison of SRT calculator results with user-defined suspension parameters and Yaw–Roll results (de Pont *et al.*, 2002c).

The advantage of this approach is that the minimum required inputs are generally known or easily measured by the transport operator. Increased accuracy can be achieved by obtaining suspension parameters; however, in most cases this is not necessary.

3.4 Fleet Performance in Forestry

The incidence of rollover crashes per 100 million km travelled in the forestry industry in New Zealand has been on the decline since at least 1999 (de Pont *et al.,* 2006). Figure 3.7 shows this trend based on data from the New Zealand Police Commercial Vehicle Investigation Unit (CVIU) and the more extensive Log Transport Safety Council (LTSC) for the period 1999 to 2004. This significant reduction in crashes (more than 75% reduction from 2001 to 2004) can be attributed to a number of measures that have been implemented, including improvements in:

- Vehicle loading,
- Vehicle operations,
- Driver behaviour, and
- Company management.

In terms of vehicle design, although the overall mass and dimension limits in New Zealand have not changed in the past 10 years, the following improvements have been implemented (de Pont *et al.,* 2006):

- Bolster bed heights are now typically up to 300 mm lower than previously, significantly improving rollover stability;
- Longer trailer wheelbases have further improved vehicle performance;
- Greater use of multi-bunk trailers. Almost all new trailers are now multi-bunk;
- Improved component design, including bolster design;
- The use of more roll-stiff suspensions improving rollover stability and handling.

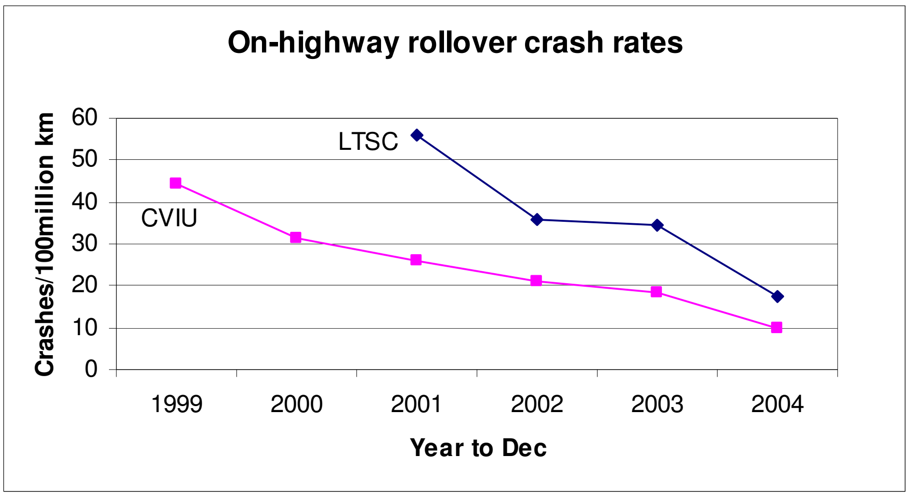


Figure 3.6 On-highway log truck rollovers per 100 million km in New Zealand over the period 1999 to 2004 (de Pont *et al*., 2006).

The SRT of new trailers for transporting timber in New Zealand is now typically 0.42, compared with less than 0.35 before the establishment of the LTSC and the subsequent initiatives to improve vehicle stability in the forestry industry.

In the road freight industry in general, fatal truck crashes per 100 million kilometres travelled declined by more than 50% from 1990 to 2003 (OAG, 2005).

4. DEVELOPMENT OF PERFORMANCE-BASED STANDARDS FOR HEAVY VEHICLES IN CANADA

4.1 Background

Prior to 1970, the regulations in Canada were simple and prescriptive. During the 1960s, primarily as a result of pressure from the trucking industry to be more competitive, mass and dimension limits in the province of Ontario were increased. In 1967 the Ontario Department of Transport undertook a truck mass and dimensions survey (Armstrong *et al.*, 1970) and found significant overloading of axles on heavy vehicles that were within or marginally over the permissible maximum vehicle/combination mass. The survey also found that, due to the absence of control on the spacing of axles, a large proportion of short trucks with closely spaced axles had the potential to be damaging to bridge structures. However, these vehicles did not appear to cause the distress to roads or bridges that would have been expected. The results of this survey led to further studies by the Ontario Department of Transport on the load carrying capacity of existing bridges, which resulted in the development of the Ontario Bridge Formula as a safe limit for heavy vehicle loads on bridges (Jung, 1969; Armstrong *et al.*, 1970; Jung and Witecki, 1971).

The Ontario Bridge Formula was included in the Highways Traffic Act in 1970. It allowed increased mass on axle units with a greater spread, especially on shorter heavy vehicles. It also allowed an increase in the axle load limits of about 10%. The permissible load on single axles was governed by pavement wear principles; the bridge formula extended this regulation to ensure safe loads on structures by limiting the load on a group of consecutive axles based on the axle spacing. The permissible maximum combination mass was increased from 55 338 kg (122 000 lb) to 63 503 kg (140 000 lb), while the permissible maximum overall length remained at 19.81 m (65 ft). The bridge formula did not control vehicle configurations, and vehicle designers soon developed numerous new vehicle configurations to maximise payloads under the new regulations. The new configurations resulted in significant transport productivity improvements for industries involved in transporting bulk and heavy commodities (Agarwal and Billing, 1986).

4.2 National Bridge Capacity Study

Because freight transport in Canada was primarily east-west prior to the Canada-USA Free Trade Agreement of 1988, Ontario's heavy vehicle mass increases in 1970 put pressure on other provinces to also implement increases. Other Canadian provinces thus increased their permissible maximum combination masses during the 1970s. The three prairie provinces and the four Atlantic provinces made changes to their regulations, resulting in considerable regional uniformity. However, significant differences remained between these two regions and the other three provinces. These changes in regulations tended to increase rather than decrease the diversity of heavy vehicle configurations in Canada. The 1973 oil crisis highlighted the need for improved road transport efficiency, which resulted in the Road Transportation Association of Canada (RTAC) forming a Vehicle Weights and Dimensions Committee with the aim of achieving uniformity in heavy vehicle masses, dimensions and vehicle configurations across Canada. The committee felt that there was insufficient clarity with regard to the live load capacity of bridges in Canada, particularly in terms of abnormal loads, and hence commissioned a national bridge capacity study (RTAC, 1980; cited in NCHRP, 2008). The study showed that provincial mass and dimension regulations followed Ontario's bridge formula fairly closely (Agarwal, 1978), which was not surprising considering that all provinces designed their bridges to the AASHTO (AASHTO, 1977) or Canadian Standards Association (CSA, 1978) codes.

When Ontario adopted the metric system in 1978, the regulations regarding the mass and dimensions of heavy vehicles were updated. A number of important changes were made at the same time including an increase in the permissible maximum length from 19.81 m (65 ft) to 21.0 m. In the early 1980s, the Ontario Commission of Truck Safety made a number of recommendations regarding vehicle dimensions, which resulted in an increase in the permissible maximum length from 21.0 to 23.0 m in 1983. However, there was a restriction on the kingpin-to-rear dimension for a double trailer combination in an attempt to reverse the trend of shortening truck tractor dimensions to maximise the trailer deck loading area.

The 1980 national bridge study had shown that further increases in axle unit and combination masses (towards the mass limits in Ontario) were possible, but most of the other provinces were not prepared to adopt the Ontario form of regulation, nor many of the truck configurations and axle arrangements (particularly liftable axles and tridem axle units) common in Ontario.

4.3 Vehicle Weights and Dimensions Study (1984 – 1986)

The joint Committee on Heavy Vehicle Weights and Dimensions of the Road Transportation Association of Canada (RTAC) and the Canadian Council of Motor Transport Administrators (CCMTA), which represented the provincial transport ministries responsible for size and weight regulations, commissioned a multi-disciplinary research project in 1984 involving research on vehicle dynamic performance and pavement response to axle unit loads (RTAC, 1986). The project was funded jointly by all provinces and territories (50%), the federal government (25%) and industry (25%). The CCMTA/RTAC vehicle mass and dimensions study included (all references are cited in NCHRP, 2008):

- A simulation study of candidate configurations (Ervin and Guy, 1986a; Ervin and Guy, 1986b), supported by a small amount of full-scale testing (Ervin and Guy, 1986b), and other assessments of simulation methodology (Gagne, 1986; Wong and El-Gindy, 1986);
- A full-scale test programme (Billing, 1986a; Billing, 1986b), supported by a simulation study to compare simulation results of test conditions (Billing, 1986c), and a specific examination of C-train stability (Billing, 1986d);
- An evaluation of rollover thresholds of heavy vehicles using a tilt table (Delisle and Pearson, 1986), supported by a study of simplified means to assess the roll threshold (Bedard, 1986); and
- A pavement test programme (Christison, 1986a; Christison, 1986b; Christison, 1986c), supported by an investigation of heavy truck suspension characteristics (Woodrooffe *et al.*, 1986).

After completion of the research, a seminar was held to present the findings to stakeholders. The study generated international interest and remains one of the most significant heavy vehicle mass and dimension studies to date. The work was subsequently presented at the first International Symposium on Heavy Vehicle Weights and Dimensions held in Kelowna, British Columbia, in June 1986. This symposium has been succeeded by nine others in seven countries, including South Africa.

Following the mass and dimension study, the CCMTA/RTAC committee formed an Implementation Planning Subcommittee in 1986, with the following tasks (NCHRP, 2008):

- Develop a plan to assist each jurisdiction in implementing vehicle mass, dimension and configuration regulatory principles that would lead to national uniformity;
- Develop schedules for proposed implementation of recommendations; and
- Monitor the progress of the implementation of the recommendations as they may be agreed to by the Council of Ministers Responsible for Transportation and Highway Safety at its meeting in September 1987.

The Vehicle Weights and Dimensions Study provided a rational and objective means based on vehicle dynamic performance and pavement loading to define heavy vehicle mass and dimension parameters and vehicle configurations (RTAC, 1986). The national bridge study (RTAC, 1980; Agarwal, 1978) had established guidelines for regulating vehicle masses and dimensions in terms of structures, but the provinces had diverse approaches for assessing vehicle impacts on bridges. The Implementation Planning Subcommittee met with the provincial bridge engineers and agreed on various issues regarding axle unit masses, minimum inter-axle spacings and permissible maximum combination masses.

The Implementation Planning Committee developed recommended regulatory principles, which provided improved opportunities to safely exploit the available capacities of both the highway system and the motor transport fleet on a national basis (RTAC, 1987). These principles took the following into consideration:

- The findings of the research programme;
- Recognition of the safety of the users of the system;
- Engineering, economic and operational constraints of the highway system;
- The operational requirements of the trucking industry;
- The capabilities of the truck and trailer manufacturing industries.

The regulatory principles were developed in 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.

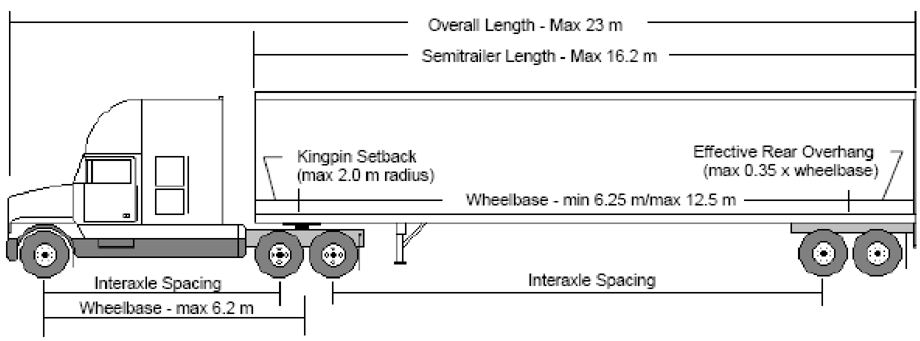
The seven performance standards (and target performance levels) that form the basis of the regulatory principles are given in Table 4.1. This was the first time that performance measures had been used to regulate vehicle design in Canada.

Table 4.1 Performance measures adopted in Canada as a basis for defining improved heavy vehicle configurations for inter-provincial operations

Performance measure	**Target performance level**
Static rollover threshold	Vehicles, in the loaded condition, should exhibit a static rollover threshold of 0.4 g or better.
Dynamic load transfer ratio	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 a tight turn	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 tires should not exceed 0.1.
Braking efficiency	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 utilised in an emergency stop of 0.4 g deceleration without incurring wheel lockup.
Low-speed offtracking	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 truck tractor steering axle, should not exceed 6 m.
High-speed offtracking	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 truck tractor steering axle, should not exceed 0.46 m.
Transient high-speed offtracking	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.

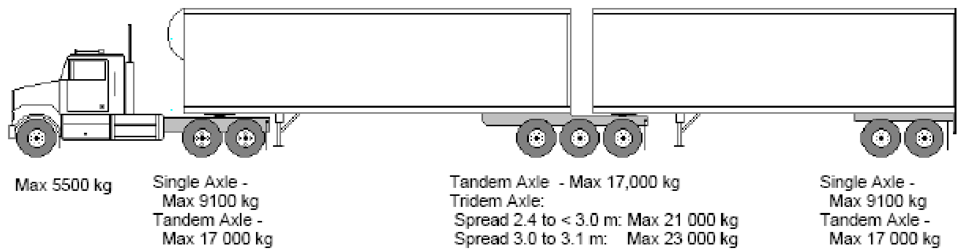
4.4 The Memorandum of Understanding regarding Heavy Vehicle Weights and Dimensions

Based on these regulatory principles, the Implementation Planning Committee took a conscious decision to regulate configurations using a prescriptive approach with parameters generally based on the dynamic performance of the configurations, rather than attempting to develop a performance-based system of standards (Billing, 2008). The committee developed detailed specifications for the most common vehicles for inter-provincial highway transportation (RTAC, 1988). The specifications included a drawing, maximum/minimum dimensions and permissible maximum masses for each configuration. Examples of dimension limits for a 5-axle tractor semitrailer and mass limits for an 8-axle B-double combination are given in Figure 4.2 and Figure 4.3, respectively.



DIMENSION	LIMIT
Overall Length	Maximum 23 m
Overall Width	Maximum 2.6 m
Overall Height	Maximum 4.15 m
Tractor:	
Wheelbase	Maximum 6.2 m
Tandem Axle Spread	Minimum 1.2 m/Maximum 1.85 m
Semitrailer	
Length	Maximum 16.2 m
Wheelbase	
Single, Tandem or Tridem Axle Group	Minimum 6.25 m/Maximum 12.5 m
Kingpin Setback	Maximum 2.0 m radius
Effective Rear Overhang	Maximum 35% of wheelbase
Tandem Axle Spread	Minimum 1.2 m/Maximum 1.85 m
Tridem Axle Spread	Minimum 2.4 m/Maximum 3.7 m
Track Width	Minimum 2.5 m/Maximum 2.6 m
Interaxle Spacings	
Single Axle to Single, Tandem or Tridem Axle	Minimum 3.0 m
Tandem Axle to Tandem Axle	Minimum 5.0 m
Tandem Axle to Tridem Axle	Minimum 5.5 m

Figure 4.1 Permissible dimensions for 5-axle tractor semitrailer (RTAC, 1988).



WEIGHT	LIMIT
Axle Weight Limits:	
Steering Axle	Maximum 5500 kg
Single Axle (dual tires)	Maximum 9100 kg
Tandem Axle:	
Axle Spread 1.2 m - 1.85 m	Maximum 17 000 kg
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

Figure 4.2 Permissible masses for 8-axle B-double combination (RTAC, 1988).

The specifications were sufficiently detailed to ensure that pavement, bridge and dynamic performance were all within acceptable limits. The specifications formed part of a Memorandum of Understanding (MoU) on Inter-provincial Heavy Vehicle Weights and Dimensions (RTAC, 1988), which was concluded in 1988 at the meeting of the Council of Ministers Responsible for Highway Safety. The MoU did not require that all provinces adopt it as their only form of regulation, but that the vehicle configurations it defined, with their mass and dimensional restrictions, be allowed to operate in all provinces on a highway network defined by each province.

The MoU was developed with recommendations for a semitrailer length of 16.2 m and an overall length for a B-double combination of 25 m. However, as a result of public opposition in Ontario to these increased lengths, and following consultations, a political decision was taken not to increase the current lengths of 14.65 m for a semitrailer and 23 m for a B-double combination. The other provinces agreed to support this decision. During the following 12 years, on the basis of the results of a number of studies (Good *et al.*, 1991; RTAC, 1992; cited in NCHRP, 2008) and consultations, the various provinces decided to adopt the increased lengths as originally proposed in the MoU.

4.5 Further Developments since the Memorandum of Understanding

The initial MoU that was adopted in 1988 produced specifications (maximum and minimum dimensions and permissible masses) for the most common vehicle configurations operating inter-provincially in Canada. These limits were derived from dynamic performance measures and target performance levels identified during the Vehicle Weights and Dimensions research project. However, each province had a range of other vehicle configurations that were commonly in use. The question was asked: How should these vehicle combinations be configured to ensure that they meet the same objective standards for dynamic performance as the configurations addressed by the MoU? Thus followed a number of studies to evaluate various vehicle configurations and components such as straight trucks and truck-trailer combinations (Billing and Lam, 1992; Billing *et al*., 1989), rigid liftable axles (Billing and Patten, 2003; Billing and Patten, 2004), the C-dolly and its hitches (Woodrooffe *et al*., 1986; CMVSS, 2007a; CMVSS, 2007b), the quad semitrailer (Nix *et al*., 1996; Agarwal *et al*., 1997), semitrailers with self-steering axles (Corbin *et al*., 1995) and vehicle combinations with a tridem drive tractor (Parker *et al*., 1998). This approach has also been applied to vehicle configurations that are very different to those defined in the MoU, such as the log truck fleets in Alberta and British Columbia. The forestry industry underwent a process to evaluate the performance of a range of existing and proposed configurations (FERIC, 1998). Vehicles with poor performance were either transitioned out of the fleet, or the configuration was modified to improve its performance. Subsequently, a range of new configurations has been developed, and some operate at combination masses considerably higher than the prevailing legal limits by special permit during the winter.

This approach has continued to be used by all provinces as part of the assessment of vehicle configurations proposed either for regulation or operation under a special permit. The provinces have different approaches to the process for approval, but the underlying assessment has remained consistent with that used for the MoU for the past 20 years. There has been no demand for a performance-based standards approach nor has there been a demand for further increases in vehicle mass limits (Billing, 2008).

5. DEVELOPMENT OF PERFORMANCE-BASED STANDARDS FOR HEAVY VEHICLES IN AUSTRALIA

5.1 Background

Heavy vehicles in Australia are regulated by prescriptive standards that have been developed over a long period, largely through empirical approaches (Peters and Stevenson, 2000). The National Transport Commission (NTC), formerly the National Road Transport Commission (NRTC), was established to achieve uniformity in road (and subsequently rail) regulations between all the States and Territories. The preferred approach of the NTC is to harmonise transport regulations through a performance-based regulatory environment (Moore, 2007). The heavy vehicle PBS project is the largest and most advanced of various reform projects being developed by the NTC on a performance basis (Rolland *et al*., 2006). During the period 1990 to 2000 there was a 50% reduction in heavy vehicle accidents and a 25% improvement in productivity. During the same period heavy vehicle road use in Australia increased by 53% and is expected to grow by another 100% by 2015 (Peters and Stevenson, 2000; NRTC, 2002d).

For several decades a number of States in Australia have permitted heavy vehicles (for example ‘road trains’), which do not comply with the prescriptive standards, to operate on parts of the road network. However, this segment of heavy vehicle operations reached a stage where the need for a national uniform approach was identified.

5.2 PBS Initiative in Australia

In 1999 the NRTC embarked on a process to develop a framework for introducing a performance-based approach for heavy vehicle regulation (Sweatman *et al*., 1998; Borbely *et al*., 2000; NRTC, 2000a; NRTC, 2001a). Initially four phases were identified (NRTC, 2000c) but at a later stage two additional phases were added, as shown in Table 5.1 (Rolland *et al*., 2006). An overview of these phases is presented in the following sub-sections.

Table 5.1 Phases of the PBS initiative in Australia (Rolland *et al.*, 2006).

Phase	Phase objectives
A: Performance measures and standards	Identify appropriate performance measures and standards and evaluate the performance of the existing heavy vehicle fleet.
B: Regulatory and compliance processes	Establish a regulatory system in which PBS can operate as a seamless national alternative to existing prescriptive regulations.
C: Guidelines	Prepare guidelines detailing the procedures and processes for the consistent application of PBS.
D: Legislation	Develop legislative arrangements for PBS to operate as an alternative to prescriptive regulations.
E: Case studies	Assemble work previously conducted and demonstrate the practical application of PBS to nationally agreed priorities.
F: Implementation	Put in place the necessary legislative and administrative systems to allow PBS to operate nationally and provide the training and information to support these changes.

5.3 Performance Measures and Standards (Phase A)

A number of studies (Woodrooffe *et al.*, 1998; NRTC, 1999a; NRTC, 2000b; NRTC, 2001b; NRTC, 2001c) were commissioned by the NRTC to establish the minimum required performance measures to ensure acceptable levels of safety and infrastructure protection. Initially, 97 potential measures were identified and were structured into a number of groups including safety, infrastructure, productivity and environmental impact. Through a rigorous process of design, assessment, consultation and independent review, 16 safety and four infrastructure performance standards were developed (Vuong *et al.*, 2002; NRTC, 2003b; NRTC, 2003c; NRTC, 2003d; Pearson and Leyden, 2004; Moore, 2007; NTC, 2007a). The safety and infrastructure performance measures and levels are given in Table 5.2 and Table 5.3 respectively (Edgar, 2004; NTC, 2007a). More detailed definitions of the standards are given in ARTSA (2003) and NTC (2007a).

Further work was carried out to determine the mass and dimension characteristics of the existing Australian heavy vehicle fleet (NRTC, 2001d) and then to assess the performance of the fleet in terms of the proposed standards (NRTC, 2002c).

In order to optimise the existing road network in terms of the types of heavy vehicles that can be operated on various parts of the network, four road types were defined (Levels 1 to 4). Where appropriate, different performance levels are specified for each of the four levels (see

Table 5.2). Road authorities are in the process of using the PBS Network Classification Guidelines (NTC, 2007b) to classify their road networks into the four levels.

Table 5.2 Safety standards and performance levels for PBS vehicles in Australia (NTC, 2007a). Definitions of terms are described by ARTSA (2003).

Performance measure	**Performance level**			
	Road Class			
	L1	**L2**	**L3**	**L4**
Startability (% slope)	≥ 15 %	≥ 12 %	≥ 10 %	≥ 5 %
Gradeability A (% slope) (maintain forward motion on grade)	≥ 20 %	≥ 15 %	≥ 12 %	≥ 8 %
Gradeability B (minimum speed on 1% grade)	≥ 80 km/h	≥ 70 km/h	≥ 70 km/h	≥ 60 km/h
Acceleration capability	≤ 20.0 s	≤ 23.0 s	≤ 26.0 s	≤ 29.0 s
Overtaking provision	Requirements moved to the Network Classification Guidelines (NTC, 2007b). NTC 2007a gives vehicle length limits for various access classes.			
Tracking ability on a straight path	≤ 2.9 m	≤ 3.0 m	≤ 3.1 m	≤ 3.3 m
Ride quality (driver comfort)	Yet to be defined			
Low-speed swept path width	≤ 7.4 m	≤ 8.7 m	≤ 10.6 m	≤ 13.7 m
Frontal swing: Rigid trucks, truck tractors and buses	Trucks and truck tractors: ≤ 0.7 m; Buses: ≤ 1.5 m			
Frontal swing: Semi-trailers	Maximum of difference (MoD): ≤ 0.4 m Difference of maxima (DoM): ≤ 0.2 m			
Tail swing	≤ 0.3 m	≤ 0.35 m	≤ 0.35 m	≤ 0.5 m
Steer-tyre friction demand	≤ 80% of the max. available tyre/road friction limit			
Static rollover threshold	≥ 0.35 g (≥ 0.40 g for road tankers and buses)			
Rearward amplification	≤ 5.7 SRT of rearmost unit or roll-coupled set of units			
High-speed transient offtracking	≤ 0.6 m	≤ 0.8 m	≤ 1.0 m	≤ 1.2 m
Yaw damping coefficient	≥ 0.15			
Handling quality (understeer/oversteer)	Yet to be defined			
Directional stability under braking	Vehicle must comply with requirements of the TASP standard under specified average decelerations from 60 km/h for various vehicle configurations.			

Table 5.3 Infrastructure standards for PBS vehicles in Australia (NTC, 2007a).

Performance measure	**Performance level**
Pavement vertical loading	Currently based on prescriptive regulations for axle unit and vehicle loads.
Pavement horizontal loading	Requirements relate to: axle spacing and steering axles for axle units; distribution of tractive force and maximum masses (dependent on road class) for drive axle units.
Tyre contact pressure distribution	Currently based on prescriptive requirements relating to minimum tyre width and maximum tyre pressure.
Bridge loading	Requirements are given for 3 tiers. Tier 1 requires compliance with various bridge formulae; Tiers 2 and 3 require bridge assessments by a qualified bridge engineer or road authority engineer.

5.4 Regulatory and Compliance Processes (Phase B)

Various processes were developed to provide a framework for a national alternative to the prescriptive regulations (NRTC, 2000c; NRTC, 2002a; NRTC, 2003a; NTC, 2005a). These processes include the following steps, which are required to operate a PBS vehicle:

- Application;
- Assessment of application by an accredited performance assessor;
- Draft approval;
- Verification of the vehicle after manufacture/modification, and certification of the operator, as having systems in place to ensure ongoing compliance with the PBS conditions;
- Possible field testing;
- Initial monitoring to ensure that actual performance matches expectations;
- Final approval based on outcomes of monitoring period;
- Addition to national PBS database;
- Operation of PBS-approved vehicle in accordance with conditions of approval.

5.5 Guidelines (Phase C)

Various documents (technical and administrative guidelines, codes and rules) have been developed to assist those involved in the PBS process and to ensure a consistent application of PBS as follows (Rolland *et al.*, 2006):

- Standards and vehicle assessment rules (NTC, 2005b; NTC, 2007a)
- Network classification guidelines (NRTC, 2004a; NTC, 2007b)
- PBS assessor accreditation rules (NTC, 2007c)
- Vehicle assurance and operating rules (NTC, 2006a)
- Vehicle certification rules (NTC, 2007d)
- Guidelines for determining national operating conditions (NTC, 2007e)
- Review Panel business rules (NTC, 2007f)
- Operator certification guidelines (NTC, 2006b)
- Compliance assurance guidelines (NTC, 2006c)
- Enforcement guidelines.

The rules for assessment of PBS vehicles specify in detail how a vehicle assessment, either by field testing or computer modelling should be undertaken. Differences in approach with computer modelling can produce different results (NRTC, 2001e), hence a detailed specification is required to ensure consistency in modelling results. In addition, an accreditation system was developed for PBS assessors to further ensure uniformity and an acceptable standard of assessments (Baas *et al*., 2002; NTC, 2007c).

5.6 Legislation (Phase D)

Phase D of the PBS initiative has involved the development of new legislation. The purpose of the legislation is threefold:

- To support the establishment and ongoing operating authority of the PBS approval body;
- To support institutional arrangements to give effect to PBS approvals on a national basis;
- To enable the application of enforcement and compliance systems.

The development of the PBS legislation follows the Compliance and Enforcement Bill that has extended the responsibility of goods transport to the consignor and/or consignee – the 'chain of responsibility' accountability structure – for a range of road traffic offences (NRTC, 2003e; NRTC, 2003f; McIntyre and Moore, 2002; McIntyre, 2005). By linking into this regulatory structure, the amount of new legislation to support PBS has been reduced.

5.7 Case Studies (Phase E)

Since the commencement of the PBS initiative in Australia, various PBS case studies have been monitored and evaluated to assess the benefits of the PBS approach to heavy vehicle regulation (NRTC, 1999b; NTC, 2008). Various state road authorities have used the PBS standards, as they have become available, as a basis for issuing permits for abnormal vehicles such as road trains and for assessing innovative vehicles. Many of these were approved as case studies and were used by the NTC to demonstrate the potential safety and productivity benefits of PBS (NRTC, 2002b; Coleman *et al.*, 2003; Di Cristoforo *et al*., 2003; Sweatman *et al*., 2003; Di Cristoforo, 2004; Prem *et al*., 2006a; Prem *et al*., 2006b; Johnston and Bruzsa, 2008; Prem *et al*., 2008).

5.8 Implementation (Phase F)

The first step in Phase F was the establishment of an Interim Review Panel (IRP) whose function was to assess PBS applications in terms of the Rules for Assessment (NTC, 2005b; NTC, 2007a). Of the initial eight applications to the IRP, only one was found to comply with the complete set of safety standards. As a result of these initial assessments, members of the IRP requested the NTC to review several of the approved performance standards.

During 2007, the IRP was replaced with a permanent Review Panel, whose main functions are as follows (NTC, 2007f):

- Determine whether or not a vehicle meets the PBS requirements;
- If necessary, specify special conditions under which a PBS vehicles is to operate;
- Maintain a database for tracking PBS applications and approvals;
- Accredit vehicle certifiers on the basis of recommendations of the States and Territories;
- Accredit and audit third party assessors, and
- Facilitate a mapping platform for the national road network.

5.9 Intelligent Access Programme

The Intelligent Access Programme (IAP) is an initiative in Australia that enables the remote monitoring of heavy vehicles to ensure that they adhere to certain agreed operating conditions (Baring and Koniditsiotis, 2008). Monitoring is done through in-vehicle systems that utilise sensors to monitor parameters such as position, time, speed, and axle unit masses, and wireless communication networks to transmit data (Austroads, 2004a; Austroads, 2004b). Queensland Transport is leading the initiative in Australia to include the IAP as a condition for operating certain PBS vehicles, which represents a fundamental shift in the management of heavy vehicles in Australia (Brusza *et al.*, 2008). Vehicles are fitted with a GPS tracking system and an on-board monitoring system, and their operation is monitored by a third party service provider (vehicle tracking company) who makes the data available to the relevant stakeholders. Service providers are also responsible for reporting to the road authorities any non-compliance events such as time and route restrictions, maximum speed and maximum mass.

5.10 Conclusions

The approach adopted in Australia for the design, manufacture and operation of PBS vehicles is more comprehensive and generic than the approaches in Canada and New Zealand. Provision is made in legislation for any transport operator to develop an innovative heavy vehicle design and operate the vehicle on the whole or a subset of the road network on condition that it meets all the specified requirements.

6. DISCUSSION AND CONCLUSIONS

In terms of the different approaches to regulating heavy vehicles on the road network described in Chapter 2, three countries, viz. Australia, Canada and New Zealand, have implemented a PBS approach in various ways.

In New Zealand, a problem with heavy vehicle crashes, i.e. rollovers, was identified and, subsequent to in-depth research, one performance standard (SRT) was included in the Vehicle Mass and Dimension rule. As from 1 July 2002 all trucks with a mass greater than 10 tonnes had to comply with this new rule. The SRT calculator was developed to assist operators with the assessment of their vehicles. Although only one performance standard was incorporated into the legislation, the impact was positive – the SRT for new timber trailers is typically 0.42 g compared with less than 0.35 g previously, and the rate of rollover crashes has continued to decrease. The advantage of this approach is that it is relatively simple and focussed. One or more additional performance standards could be incorporated into the legislation at a future date should a need be identified. Such an approach could be considered in South Africa to address problems in the existing heavy vehicle fleet. However, as in the case of New Zealand, sufficient data should be collected and analysed in order to assess the nature of the problem. Data should include causes of heavy vehicle crashes, and the performance standards of the existing fleet (in particular those of heavy vehicles that are involved in crashes). Unfortunately, in South Africa, these data are not readily available.

The Canadian approach was to introduce performance-based prescriptive regulations (based on seven performance measures) through the MoU of 1988, applicable to certain vehicle configurations. The MoU required that vehicles complying with these regulations be allowed to operate in all provinces on routes defined by each province. Subsequent to the implementation of the MoU, other vehicle configurations have been assessed using the same PBS approach. If compliant, such vehicle configurations have been allowed to operate on parts of the road network. The advantage of this approach is that the performance-based prescriptive regulations are simple to enforce on-road. However, each time an operator wishes to use a vehicle configuration that has not been previously approved, new assessments must be carried out. In the South African context, this approach could address about 80% of the existing heavy vehicle fleet that operate primarily on the rural road network if five- and six-axle articulated and seven-axle B-doubles (interlinks) were assessed.

Australia has adopted a holistic PBS approach for heavy vehicles. Because it is the most generic approach, it probably has the greatest potential for significant safety and productivity gains. However, the implementation of such a system is a massive (and costly) task, and could be too daunting for many transport operators. In addition, the classification of the entire network into the identified four levels is a costly and time-consuming exercise. Changes in the geometrics of the network due to upgrading will also require that the Road Classification System be upgraded periodically.

The use of the approach embodied in the Intelligent Access Programme supports the self-regulation philosophy, allowing all parties in the value logistic chain as well as the road authority and enforcement agency to monitor certain parameters of the heavy vehicle operation at any time as opposed to relying solely on on-road enforcement. Such an approach would have significant merit in South Africa where non-compliance with road traffic regulations is widespread, law enforcement is inadequate and the justice system is not sufficiently punitive with regard to traffic violations due to under-capacity problems.

The potential benefits of a PBS approach in terms of vehicle safety, road infrastructure wear, productivity and vehicle emissions have been highlighted in all three countries described in this literature review as well as by the OECD report on performance-based standards for the road sector (OECD, 2005). The current road freight environment in South Africa is one that features significant growth in heavy vehicle volumes, increasing global competitiveness, increases in fuel prices, traffic congestion, CO_2 emissions and high vehicle crash and road fatality rates. Taking this into account, consideration should be given to the development and implementation of a PBS approach in South Africa. Such an approach could be made applicable to the existing heavy vehicle fleet (or a portion thereof), a new category of PBS vehicles, abnormal load vehicles or a combination of the above.

7. PROJECT PROPOSAL

7.1 Proposed Title of Research Project

"Investigation of a Performance-Based Standards Approach for Regulating the Use of Heavy Vehicles in South Africa"

7.2 Problem Identification

South Africa's economic well-being is directly affected by the efficiency of its freight logistics system, particularly with regard to exported manufactured goods and raw materials. One of the significant problems in South Africa is that many of the major manufacturing and mining areas are located great distances from the sea ports and, to a lesser extent, from airports. A significant portion of local production costs to customers are rooted in the cost of transportation of raw products and goods; for example, 20 to 30% in the sugar industry and more than 60% in the forestry industry. This, together with a number of other inefficiencies, is one of the major contributing factors to the high cost of logistics in South Africa compared with many other countries, which has a negative impact on the country's global competitiveness. South Africa also has one of the highest road fatality rates in the world, including fatal crashes involving heavy vehicles (more than five times that of countries such as the USA, Canada, the United Kingdom, Germany and Australia). The current fleet of heavy vehicles in South Africa complies with a set of prescriptive regulations which specifies limits for a number of parameters, such as the vehicle mass and dimensions. However, these regulations do not adequately address the vehicle's dynamic performance, such as its tracking ability, its rollover threshold and its behaviour when a sudden directional change is made. The purpose of introducing a framework for operating performance-based standards (PBS) vehicles is to capitalise on the potential benefits identified and realised in other countries where such an approach has been implemented – improved productivity, safety performance and infrastructure preservation.

7.3 Background

Traditionally, throughout the world, heavy vehicles are regulated primarily through a prescriptive approach, i.e. regulations that limit the mass and dimensions of these vehicles.

One of the reasons why this approach is favoured is because such regulations are easy to understand and enforce. However, an underlying flaw is that this approach does not always adequately safeguard the dynamic performance of heavy vehicles while travelling on the road. This is particularly relevant when drivers have to make unexpected evasive manoeuvres at high speed in order to avoid a stationary or moving object on the road. The problem has been exacerbated by the introduction of lightweight high strength materials for vehicle manufacture. Reducing the tare mass of a vehicle increases its legal payload and hence its potential productivity, but also inevitably results in an increase in the height of the loaded vehicle's centre of gravity, which in turn makes the vehicle dynamically less stable on the road.

The PBS approach is to use performance standards rather than prescriptive mass and dimension limitations as criteria for the design and operation of heavy vehicles. Although this approach has been developed and implemented in various ways in Australia, New Zealand and Canada, the challenge is to design and implement an appropriate framework for South Africa. The framework will have to take into account the condition of the road network (including bridges), the volume of traffic and the training and skills of drivers in South Africa.

7.4 Aim and Objectives

The aim of the research is to show that an alternative approach to the design and operation of heavy vehicles can be developed and tested/implemented in South Africa with improved outcomes in terms of vehicle safety performance, vehicle productivity, emissions and consumption of road infrastructure.

The primary objectives are thus as follows:

i. Provide an overview of the current approach for regulating the use of heavy vehicles in South Africa and PBS approaches adopted in other countries;
ii. Develop definitions of heavy vehicle performance measures and set up a framework and rules for the implementation of PBS demonstration projects;
iii. Oversee vehicle design and manufacture of PBS demonstration vehicles;
iv. Monitor the operation of baseline and PBS demonstration vehicles;
v. Synthesise and evaluate the performance of PBS demonstration projects in comparison with baseline vehicles using the developed performance measures.

vi. Develop recommendations for the implementation of a performance-based approach for regulating the use of heavy vehicles in South Africa.

These objectives are illustrated in
Figure 7.1.

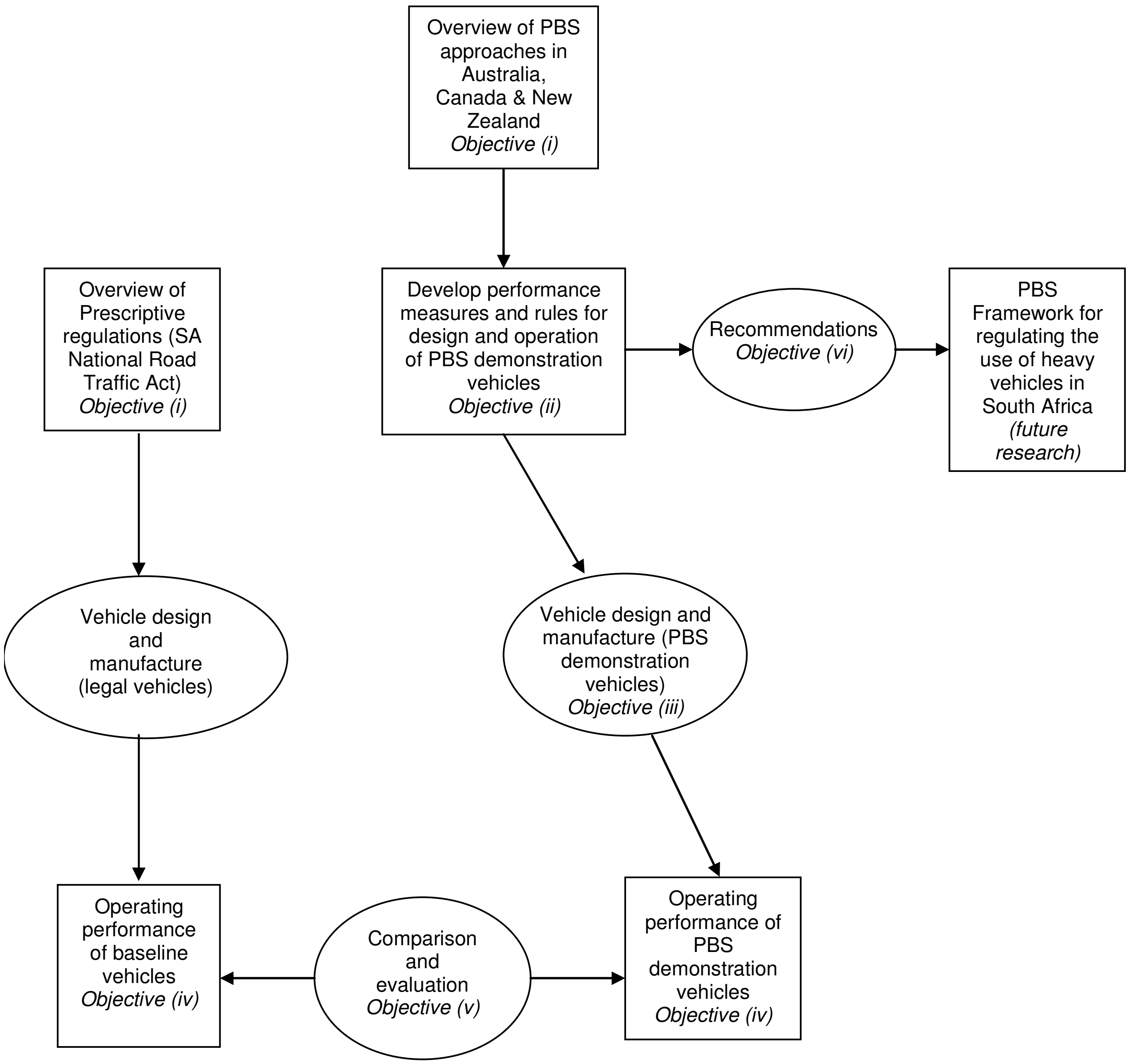


Figure 7.1 Diagram illustrating project objectives

7.5 Approach/Methodology

An initial set of PBS performance measures and performance levels appropriate for the South African situation will be developed for the PBS demonstration projects based on overseas experience. These standards will be aimed at making provision for new vehicles that may exceed one or more of the prescriptive regulations, and will therefore have to operate under a special permit. This approach will also be applicable for the performance assessment of the current South African heavy vehicle fleet (including baseline vehicles corresponding with the PBS demonstration vehicles). Such assessments could lead to a recommendation for the introduction of one or more performance standards applicable to the existing heavy vehicle fleet, in addition to the current prescriptive regulations (New Zealand approach).

Requirements for compliance and the monitoring of PBS vehicles will be developed. This will include the application of the self-regulating Road Transport Management System (RTMS) accreditation scheme for operators of PBS demonstration vehicles. Monitoring requirements will include vehicle tracking and accessibility of data (such as routes, vehicle speeds, stopping times, and combination masses) for road and law enforcement authorities.

A recommended process for the application and assessment of PBS vehicles (field testing and computer simulations) will be developed. Initiatives will be made to develop capacity in South Africa for PBS computer-based assessments in co-operation with overseas expertise.

Two PBS demonstration vehicles operating in the forestry industry will be monitored in terms of productivity and, if possible, safety benefits. The impact of these vehicles on the road infrastructure compared with the baseline vehicles will be assessed using the MePads software package developed at the Council for Scientific and Industrial Research (CSIR). The software is based on the South African mechanistic pavement design method. This approach takes into account the road wear impact of a number of vehicle parameters such as tyre pressure, tyre width, axle spacing, wheel spacing (per axle) and wheel load. The road wear impact will be assessed for a number of different pavement types representative of the South African road network.

Recommendations with regards processes that will have to be followed to make provision in legislation for the operation of PBS vehicles will also be developed.

7.6 Significance/Benefit of Research

The relatively high logistics costs and high rate of road crashes (including heavy vehicle crashes involving fatalities) in South Africa demand urgent attention to improve the country's global competitiveness and the quality of life of all its citizens. The regulation of the use of heavy vehicles using a PBS approach has been shown in various countries to produce improved safety, productivity, infrastructure preservation and emissions outcomes. Such an approach has the potential of generating similar outcomes in South Africa, despite its significantly different road traffic environment compared with developed countries such as Australia, Canada and New Zealand. In addition, greater commitment and diligence are required of operators to properly maintain their vehicles, ensure that loads are legal and properly positioned, and that drivers are properly trained.

7.7 Work Plan

Tasks - 2008	J	F	M	A	M	J	J	A	S	O	N	D
Literature review and project proposal				■	■	■	■	■				
Rules for compliance and monitoring	■											
Application and vehicle assessment requirements	■											
Monitoring of PBS demonstration projects			■	■	■	■	■	■	■	■	■	■
Comparison and evaluation of baseline and PBS vehicles								■	■	■	■	■
Prepare for/attend OECD working group meeting										■	■	

Tasks – 2009	J	F	M	A	M	J	J	A	S	O	N	D
Literature review update					■	■	■	■	■	■	■	■
Rules for compliance and monitoring	■	■	■	■								
Application and vehicle assessment requirements	■	■	■	■								
Monitoring of PBS demonstration projects					■	■	■	■	■	■	■	■
Comparison and evaluation of baseline and PBS vehicles										■	■	■
Prepare for/attend OECD working group meeting				■	■							
Write papers and reports; attend conferences	■	■	■	■	■		■					

Tasks – 2010	J	F	M	A	M	J	J	A	S	O	N	D
Literature review update	■	■	■	■	■	■						
Rules for compliance and monitoring	■	■	■									

Application and vehicle assessment requirements												
Monitoring and evaluation of PBS demonstration projects												
Comparison of baseline and PBS vehicles												
Recommendations for PBS framework in South Africa												
Write papers and reports; attend conferences												
Thesis write-up												

7.8 Equipment and Resources

Office

- Provide a safe organised environment in which to conduct the study.

Computer and disk storage space

- Data analysis;
- Communication;
- Research; and
- Thesis and report writing.

Telephone

- Communication.

Vehicles

- Travel to various meetings; and
- Site visits.

7.9 Health and Safety Considerations

This project is largely computer-based; hence there are no major health and safety considerations. However, travelling will be necessary for the attendance of meetings as well as site visits to transport operator depots, trailer manufacturing factories, potential PBS demonstration project routes and loading and off-loading points. In these cases the health and safety rules regarding fieldwork and vehicle use will be adhered to.

8. REFERENCES

AASHTO. 1977. *Standard Specifications for Highway Bridges*. Ninth Edition, 1965, Twelfth Edition, 1977. American Association of State Highway and Transportation Officials, Washington, D.C., USA.

Agarwal, A.C. 1978. *Vehicle Weight Regulations across Canada: A Technical Review with Respect to the Capacity of Highway Systems*, Report RR 214. Ontario Ministry of Transportation and Communications, Toronto, Canada.

Agarwal, A.C. and Billing, J.R. 1986. The Effect of Ontario's Weight Regulations on Commercial Vehicle Design, *Proceedings of the First International Symposium on Heavy Vehicle Weights and Dimensions*, 209-224. Kelowna, B.C., Canada.

Agarwal, A.C. et al. 1997. *Impact on the Highway Infrastructure of Existing and Alternative Vehicle Configurations and Weight Limits*, Ontario Ministry of Transportation and Communications, Toronto, Canada.

Anderson, R. and Sinclair, S. 1996. *Report of the Transport Committee on the Inquiry into Truck Crashes*. Transport Committee for the New Zealand House of Representatives 1.13B 175. New Zealand.

Armstrong, M.D., Jung, F.W. and Phang, W.A. 1970. *A Proposed Method of Regulating Vehicle Weights in Ontario.* Report RR 166. Ontario Department of Highways, Toronto, Canada.

ARTSA. 2003. *PBS Explained: Performance Based Standards for Road Transport Vehicles*, Issue 1. Australian Road Transport Suppliers Association, Melbourne, Australia. http://www.artsa.com.au/PBS_Explained_Sept_03.pdf.

Austroads. 2004. *Intelligent Access Program: Operational Guidelines – Overview*. Prepared by Koniditsiotis, C., Taylor, G., Davis, D. and Tomlimson, M. Austroads, Sydney, Australia.

Austroads. 2004. *Intelligent Access Program (IAP): Stage 1 Implementation – Functional & Technical Specifications and Associated Testing Protocols (Draft)*. Prepared by Koniditsiotis, C. *et al.* Austroads, Sydney, Australia.

Baas, P.H. and White, D.M. 1989. Safety improvements for increased weights and dimensions in New Zealand, *Proceedings of the Second International Symposium on Heavy Vehicle Weights and Dimensions*. Kelowna, B.C., Canada.

Baas, P.H. and Latto, D.J. 1997. *Logging truck stability analysis*. TERNZ 2nd edition. Manukau City, New Zealand.

Baas, P.H., Oliver, R. and Wright, I. 2002. *Accreditation of Assessors: Performance Based Standards*. National Road Transport Commission, Melbourne, Australia.

Baring, J. and Koniditsiotis, C. 2008. Australia's Intelligent Access Program. *Proceedings of the Tenth International Conference on Heavy Vehicles*, 349-358. Wiley. Paris, France.

Bedard, J. 1986. Vehicle Rollover Threshold Evaluation: An Assessment of Computer Simulation Models, *CCMTA/RTAC Vehicle Weights and Dimensions Study Technical Report Volume 12*. Roads and Transportation Association of Canada, Ottawa, Canada.

Bennett, D., Styles, E. and Wright, I. 2003. Benefits of performance based standards for heavy vehicles. *Proceedings of the 21st ARRB and 11th REAAA conference*, 54-68. Cairns, Australia.

Billing, J.R. 1986a. Demonstration Test Program: Summary of Tests of Baseline Vehicle Performance, *CCMTA/RTAC Vehicle Weights and Dimensions Study Technical Report Volume 3*. Roads and Transportation Association of Canada, Ottawa, Canada.

Billing, J.R. 1986b. Demonstration Test Program: Five, Six and Seven Axle Tractor Semitrailers, *CCMTA/RTAC Vehicle Weights and Dimensions Study Technical Report Volume 4*. Roads and Transportation Association of Canada, Ottawa, Canada.

Billing, J.R. 1986c. Comparison of Simulation and tests of Baseline and Tractor-Semitrailer Vehicles, *CCMTA/RTAC Vehicle Weights and Dimensions Study Technical Report Volume 5*. Roads and Transportation Association of Canada, Ottawa, Canada.

Billing, J.R. 1986d. Hitch Slack and Drawbar Length Effects on C-train Stability and Handling, *CCMTA/RTAC Vehicle Weights and Dimensions Study Technical Report Volume 6*. Roads and Transportation Association of Canada, Ottawa, Canada.

Billing, J.R., Lam, C.P. and Couture, J. 1989. Development of Regulatory Principles for Multi-axle Semitrailers, *Proceedings of the Second International Symposium on Heavy Vehicle Weights and Dimensions*. Kelowna, B.C., Canada.

Billing, J.R. and Lam, C.P. 1992. Development of Regulatory Principles for Straight Trucks and Truck-trailer Combinations, *Proceedings of the Third International Symposium on Heavy Vehicle Weights and Dimensions*, 36-44. Cambridge, England.

Billing, J.R. and Patten, J.D. 2003. *Performance of Infrastructure-friendly Vehicles*, National Research Council of Canada, Report CSTT-HVC-TR-058. Ottawa, Canada.

Billing, J.R. and Patten, J.D. 2004. *Full-scale Performance Testing of 5-axle Semitrailers*. National Research Council of Canada, Report CSTT-HVC-TR-084. Ottawa, Canada.

Billing, J.R. 2008. Personal communication. National Research Council of Canada, Agincourt, Canada, 9 July 2008.

Borbely, C.L., Gilks, G. and Pearson, J. 2000. Challenges to using performance criteria as a basis for vehicle weight and dimension regulations. *Proceedings of the Sixth International Symposium on Heavy Vehicle Weights and Dimensions*, 323-335. Saskatoon, Canada.

Bruzsa, L., Sack, R. and Shepherd, G. 2008. Smart Technologies and Policies for the Effective Management of Heavy Vehicles. *Proceedings of the Ninth International Symposium on Heavy Vehicle Weights and Dimensions*. State College, Pennsylvania, USA.

Calvert, F. 2004. Improving Regulation of Heavy Vehicles: Performance-Based Standards. *Proceedings of the Eighth International Symposium on Heavy Vehicle Weight and Dimensions*. Johannesburg, South Africa.

Christison, J.T. 1986a. Pavements Response to Heavy Vehicle Test Program - Part 1, Data Summary Report, *CCMTA/RTAC Vehicle Weights and Dimensions Study Technical Report Volume 8*. Roads and Transportation Association of Canada, Ottawa, Canada.

Christison, J.T. 1986b. Pavements Response to Heavy Vehicle Test Program - Part 2, Load Equivalency Factors, *CCMTA/RTAC Vehicle Weights and Dimensions Study Technical Report Volume 9*. Roads and Transportation Association of Canada, Ottawa, Canada.

Christison, J.T. 1986c. Pavements Response to Bump Induced Axle Loads: Experimental Findings, *CCMTA/RTAC Vehicle Weights and Dimensions Study Technical Report Volume 10*. Roads and Transportation Association of Canada, Ottawa, Canada.

CMVSS. 2007a. C-dolly Specifications. [Internet] Canadian Motor Vehicle Safety Standard 903. Transport Canada, Ottawa, Canada. Available from: http://www.tc.gc.ca/acts-regulations/GENERAL/m/mvsa/regulations/mvsrg/900/mvsr903.html. [Accessed: 4 July 2008]

CMVSS. 2007b. C-dolly Hitch Requirements. [Internet] Canadian Motor Vehicle Safety Standard 904. Transport Canada, Ottawa, Canada. Available from: http://www.tc.gc.ca/acts-regulations/GENERAL/m/mvsa/regulations/mvsrg/900/mvsr904.html. [Accessed: 4 July 2008]

Coleman, B.L., Sweatman, P.F. & Di Cristoforo, R. 2003. *Approval for a 16.6m (54.5ft) intermodal container semi-trailer*. Roaduser Systems Report RUS-03-837-01-03. Melbourne, Australia.

Committee of Land Transport Officials. 2000. *TRH11: Guidelines for granting of exemption permits for the conveyance of abnormal loads and for other events on public roads.* Bloemfontein, South Africa.

Corbin, G, Grandbois, J. and Richard, M.J. 1995. Evaluation of Self-steering Axles for Semitrailers. *Proceedings of the Fourth International Symposium on Heavy Vehicle Weights and Dimensions*, 525-536. Ann Arbor, Michigan, USA.

CSA. 1978. *Design of Highway Bridges*, Canadian Standards Association, CAN/CSA-S6. Published in 1922, 1929, 1938, 1952, 1966, 1974, 1978 and 1988. Mississauga, Ontario, Canada.

Delisle, G. and Pearson, J.R. 1986. Investigating Articulated Vehicle Roll Stability Using a Tilt Table Device, *CCMTA/RTAC Vehicle Weights and Dimensions Study Technical Report Volume 7*. Roads and Transportation Association of Canada, Ottawa, Canada

de Pont, J. J., Mueller, T. H., Baas, P. H. and Edgar, J. P. 2000. Performance measures and crash rates. *Proceedings of the Sixth International Symposium on Heavy Vehicle Weights and Dimensions*, 1-10. Saskatoon, Saskatchewan, Canada.

de Pont J.J., Baas P.H., Latto D.J. 2002a. Improving the safety of a log transport fleet, *International Large Truck Safety Symposium*, Knoxville, Tennessee, USA.

de Pont J.J., Baas P.H., Mueller, T. H. 2002b. "Quick and Dirty" methods for estimating heavy vehicle stability. *International Large Truck Safety Symposium*, Knoxville, Tennessee, USA.

de Pont, J.J., Baas, P.H. Hutchinson, D.N. and Kalasih, D. 2002c, Including performance measures in dimensions and mass regulations. *Proceedings of the Seventh International Symposium on Heavy Vehicle Weights and Dimensions,* 349-358. Delft, The Netherlands.

de Pont, J.J., Hutchinson, D.N., Baas, P.H. and Kalasih, D. 2004, Implementing a roll stability requirement: issues, problems and results. *Proceedings of the Eighth International Symposium on Heavy Vehicle Weights and Dimensions*. Johannesburg, South Africa.

de Pont J.J., Baas P.H. and Wilshier, W. 2006. Safety Gains in Log Transport in New Zealand, *Proceedings of the Ninth International Symposium on Heavy Vehicle Weights and Dimensions.* State College, Pennsylvania, USA.

Di Cristoforo, R. *et al.* 2003. *Performance assessment of intermodal container skels.* Roaduser Systems Report RUS-03-856-01-03. Melbourne, Australia.

Di Cristoforo, R. 2004. Innovative vehicles designed to Australian Performance-Based Standards. *Proceedings of the Eighth International Symposium on Heavy Vehicle Weight and Dimensions*. Johannesburg, South Africa.

ECE. 2001. *Uniform provisions concerning the approval of tank vehicles of categories N and O with regard to rollover stability*. Regulation No. 111, United Nations, Geneva, Switzerland.

Edgar, J. 1995. Regulating Heavy Vehicle Safety in New Zealand using Performance Based Standards, *Proceedings of the Fourth International Symposium on Heavy Vehicle Weights and Dimensions*, 115-120. UMTRI, Ann Arbor, Michigan, USA.

Edgar J. 2004. Development of Performance Standards for Australian Heavy Vehicles. *Proceedings of the Eighth International Symposium on Heavy Vehicle Weights and Dimensions*. Johannesburg, South Africa.

Ervin, R.D. and Guy, Y. 1986a. *The Influence of Weights and Dimensions on the Stability and Control of Heavy Duty Trucks in Canada - Volume I: Technical Report*. Report UMTRI-86-35/I. CCMTA/RTAC Vehicle Weights and Dimensions Study. University of Michigan Transportation Research Institute, Ann Arbor, Michigan, USA.

Ervin, R.D. and Guy, Y. 1986b. *The Influence of Weights and Dimensions on the Stability and Control of Heavy Duty Trucks in Canada – Volume II: Appendices A-B*. Report UMTRI-86-35/II. CCMTA/RTAC Vehicle Weights and Dimensions Study. University of Michigan Transportation Research Institute, Ann Arbor, Michigan, USA.

Fepke, E., Gopalakrishna, D. and Woodrooffe, J. 2006a. Performance-Based Oversize and Overweight Permitting System. *Proceedings of the 85th Transport Research Board Annual Meeting*. Washington, D.C., USA.

Fepke, E., Gopalakrishna, D. and Woodrooffe, J. 2006b. Conceptual Framework for a Performance-Based Oversize and Overweight Permitting System. *Proceedings of the Ninth International Symposium on Heavy Vehicle Weights and Dimensions*. State College, Pennsylvania, USA.

FERIC. 1998. *Western Log Truck Configurations Study.* FERIC Contract Report No. CR-98-03-15. Forest Engineering Research Institute of Canada, Pointe-Claire, Canada.

Gagne, R.E. 1986. Graphic Representation of Heavy Vehicle Computer Simulation Model Output: A 3-D Animation Package for Computer Models, *CCMTA/RTAC Vehicle Weights and Dimensions Study Technical Report Volume 15*. Roads and Transportation Association of Canada, Ottawa, Canada.

Good, D., Robinson, J.B.L., Sparks, G. and Neudorf, R. 1991. *The Effect of Vehicle Length on Traffic on Canadian Two-lane, Two-way Roads*. Roads and Transportation Association of Canada, Ottawa, Canada.

HMSO. 1972. *The Public Service Vehicles (Conditions of Fitness, Equipment and Use)*, Regulation No 6 Stability. London, United Kingdom.

Johnston, M. and Bruzsa, L. 2008. Development of an Innovative Steerable Double Extendable Trailer under Performance Based Standards (PBS). *Proceedings of the Tenth International Conference on Heavy Vehicles*, 97-108. Wiley. Paris, France.

Jung, F.W. 1969. *Simplified Design Live Load Patterns for Use in Controlling Vehicle Weights on Bridges.* Report RR 149. Ontario Department of Transportation and Communications, Toronto, Canada.

Jung, F.W. and Witecki, A.A. 1971. *Determining the Maximum Permissible Weights of Vehicles on Bridges.* Report RR 175. Ontario Department of Transportation and Communications, Toronto, Canada.

LTSA, 2002. *Land Transport Rule Vehicle Dimensions and Mass Rule 41001.* [Internet]. Land Transport Safety Authority, Wellington, New Zealand. Available from: http://www.ltsa.govt.nz/rules/vehicle-dimensions-and-mass-2002.html. [Accessed: 5 July 2008]

McIntyre, K., and Moore, B. 2002. *National Road Transport Compliance and Enforcement Reforms: On the Road to a New National Culture of Compliance.* Paper presented to the Australian Institute of Criminology's Current Issues in Regulation: Enforcement and Compliance Conference, Melbourne, Australia.

McIntyre, K. 2005. *Chain of Responsibility: Achieving Truck and Bus Compliance in Australia.* Paper presented to the International Truck and Bus Safety and Security Symposium. Virginia, USA.

Moore, B. 2007. An Integrated Approach to the Regulation of Heavy Vehicles. *Proceedings of the 23rd World Road Congress.* Paris, France.

Mueller, T. H., de Pont, J. J. and Baas, P. H. 1999. *Heavy vehicle stability versus crash rates.* TERNZ, Manukau City, New Zealand.

NCHRP. 2008. *Review of Canadian experience with large commercial motor vehicles*, NCHRP Project 8-63, Washington D.C., USA.

Nix, F.P. *et al*. 1996. *Assessment of the Impact of Changes in Vehicle Configurations on Ontario's Industry*, Report for Ontario Ministry of Transportation, Canada.

NRTC. 1999a. *Performance Based Standards for Heavy Vehicles in Australia: Field of Performance Measures*. Prepared by Sweatman, P, Ramsay, E, Lambert, J and Prem, H. National Road Transport Commission, Melbourne, Australia.

NRTC. 1999b. *Performance Based Standards for Heavy Vehicles: Assembly of Case Studies*. Prepared by Prem, H., Ramsay, E and McLean, J; ARRB Transport Research. National Road Transport Commission, Melbourne, Australia.

NTRC. 2000a. *Performance Based Standards Policy Framework for Heavy Vehicle Regulation*. Discussion paper. National Road Transport Commission, Melbourne, Australia.

NRTC. 2000b. *Specification of Performance Standards and Performance of the Heavy Vehicle Fleet*. Discussion Paper. NRTC/Austroads Project A3 and A4. National Road Transport Commission, Melbourne, Australia.

NRTC. 2000c. *Performance-Based Standards for Heavy Vehicle Regulation*. Working paper on legal, regulatory and compliance issues. National Road Transport Commission, Melbourne, Australia.

NRTC. 2001a. *Performance Based Standards Policy Framework for Heavy Vehicle Regulation: Regulatory Impact Statement*. National Road Transport Commission, Melbourne, Australia.

NRTC. 2001b. *Definition of Potential Performance Measures and Initial Standards*. Discussion paper prepared by Prem, H., Ramsay, E., McLean, J., Pearson, R.A., Woodrooffe, J. and De Pont, J. NRTC/Austroads Project A3 and A4. National Road Transport Commission, Melbourne, Australia.

NRTC. 2001c. *Report on Initial Selection of Potential Performance Measures*. Discussion paper prepared by Prem, H., Ramsay, E., McLean, J., Pearson, R.A., De Pont, J., Woodrooffe, J. and Yeo, D. NRTC/Austroads Project A3 and A4. National Road Transport Commission, Melbourne, Australia.

NRTC. 2001d. *Dimension and Mass Characterisation of the Australian Heavy Vehicle Fleet*. Prepared by Ramsay, E., Prem, H. and Pearson, R.A. NRTC/Austroads Project A3 and A4. National Road Transport Commission, Melbourne, Australia.

NRTC. 2001e. *Comparison of Modelling Systems for Performance-Based Assessments of Heavy Vehicles*. Working paper prepared by Prem, H., Ramsay, E., De Pont, J., McLean, J. and Woodrooffe, J. National Road Transport Commission, Melbourne, Australia.

NRTC. 2002a. *An Overview of Performance Based Standards Regulatory and Compliance processes*. National Road Transport Commission, Melbourne, Australia.

NRTC. 2002b. *Steerable axles to improve productivity and access*. Prepared by Coleman, B. and Sweatman, P. National Road Transport Commission, Melbourne, Australia.

NRTC. 2002c. *Performance Characteristics of the Australian Heavy Vehicle Fleet.* Working paper prepared by Prem, H., de Pont, J., Pearson, R.A. and McLean, J. NRTC/Austroads Project A3 and A4. National Road Transport Commission, Melbourne, Australia.

NRTC. 2002d. *Truck Safety Benchmarking Study.* Prepared by Harworth, N., Vulcan, P. and Sweatman, P. National Road Transport Commission, Melbourne, Australia.

NRTC. 2003a. *Performance-Based Standards: Regulatory and Compliance Processes.* Discussion Paper. National Road Transport Commission. Melbourne.

NRTC. 2003b. *PBS Safety Standards for Heavy Vehicles*. Discussion paper prepared by Prem, H., McLean, J. and Edgar, J. NRTC/Austroads Project A3 and A4. National Road Transport Commission, Melbourne, Australia.

NRTC. 2003c. *PBS infrastructure protection standards for heavy vehicles*. Discussion paper. NRTC/Austroads Project A3 and A4. National Road Transport Commission, Melbourne, Australia.

NRTC. 2003d. *Performance-Based Standards Phase A Standards and Measures Regulatory Impact Statement*. Prepared by Economic Associates Pty Ltd, Pearsons Transport Resource Centre Pty Ltd, RT Dynamics Pty Ltd. Project Managed by: ARRB Transport Research Ltd. National Road Transport Commission, Melbourne, Australia.

NRTC. 2003e. *Road Transport Reform (Compliance and Enforcement) Bill. Regulatory Impact Statement*. Prepared by Jaguar Consulting Pty Ltd. National Road Transport Commission, Melbourne, Australia.

NRTC. 2003f. *Road Transport Reform (Compliance and Enforcement) Bill. Model Provisions*. National Road Transport Commission, Melbourne, Australia.

NRTC. 2004a. *Interim PBS Road Classification Guidelines*. Prepared by ARRB Transport Research Pty Ltd. National Road Transport Commission, Melbourne, Australia.

NTC. 2005a. *Regulatory Impact Statement: Performance-Based Standards for Heavy Vehicle Regulation: Proposed Regulatory Framework and Processes.* Prepared by Economic Associates Pty Ltd, Pearsons Transport Resource Centre Pty Ltd in association with the National Transport Commission, Melbourne, Australia.

NTC. 2005b. *Rules for Assessment of Potential PBS Vehicles* – Discussion Paper and Draft Rules prepared by Pearsons Transport Resource Centre Pty Ltd, Mechanical System Dynamics Pty Ltd and ARRB Group Ltd. National Transport Commission, Melbourne, Australia.

NTC. 2006a. *Administrative Guidelines, Rules and Codes for Operation of Performance-Based Standards Vehicles: Vehicle Assurance and Operating Rules*. Prepared by Prem, H., Pearson, R.A. and Gardner, B. National Transport Commission, Melbourne, Australia.

NTC. 2006b. *Administrative Guidelines, Rules and Codes for Operation of Performance-Based Standards Vehicles: Operator Certification Guidelines*. Prepared by Pearson, R.A., Prem, H. and Gardner, B. National Transport Commission, Melbourne, Australia.

NTC. 2006c. *Administrative Guidelines, Rules and Codes for Operation of Performance-Based Standards Vehicles: Compliance Assurance Guidelines*. Prepared by Pearson, R.A., Prem, H. and Gardner, B. National Transport Commission, Melbourne, Australia.

NTC. 2006d. A*dministrative Guidelines, Rules and Codes for Operation of Performance-Based Standards Vehicles: Discussion paper*. Prepared by Pearson, R.A., Prem, H. and Gardner, B. National Transport Commission, Melbourne, Australia.

NTC. 2007a. *Performance Based Standards Scheme: The Standards and Vehicle Assessment Rules*. National Transport Commission, Melbourne, Australia.

NTC. 2007b. *Performance Based Standards Scheme: Network Classification Guidelines*. National Transport Commission, Melbourne, Australia.

NTC. 2007c. *Performance Based Standards Scheme: Assessor Accreditation Rules*. National Transport Commission, Melbourne, Australia.

NTC. 2007d. *Performance Based Standards Scheme: Vehicle Certification Rules*. National Transport Commission, Melbourne, Australia.

NTC. 2007e. *Performance Based Standards Scheme: Guidelines for Determining National Operating Conditions*. National Transport Commission, Melbourne, Australia.

NTC. 2007f. *Performance Based Standards Scheme: Review Panel Business Rules*. National Transport Commission, Melbourne, Australia.

NTC. 2008. PBS Case studies [Internet]. National Transport Commission, Melbourne, Australia. Available from: http://www.ntc.gov.au/viewpage.aspx?page=A023114004005800200. [Accessed: 15 July 2008]

OAG. 2005. *Progress in Implementing Key Recommendations of the 1996 Transport Committee Inquiry into Truck Crashes*. Office of the Auditor-General, Wellington, New Zealand.

OECD. 1997. *Report to Ministers on Regulatory Reform.* OECD, Paris, France.

OECD. 2005. *Performance-based standards for the road sector.* OECD, Paris, France.

OECD. 2007. *Working Group on Heavy Vehicles: Regulatory, Operational and Productivity Improvements: Draft Terms of Reference*. Joint OECD/ECMT Transport Research Committee. OECD, Paris, France.

Parker, S.P.S., Amlin, E.J. and Hart, D.V. 1998. *Steering Evaluations of a Tridem Drive Tractor in Combination with Pole Trailers*. Forest Engineering Research Institute of Canada, Pointe-Claire, Canada.

Pearson R.A. and Leyden P. 2004. Performance-Based Standards: Challenges in Developing Infrastructure Protection Standards. *Proceedings of the Eighth International Symposium on Heavy Vehicle Weights and Dimensions*. Johannesburg, South Africa.

Peters, R. and Stevenson, J. 2000. Regulating Heavy Vehicles in Australasia using a Performance-Based Standards approach. *Proceedings of the Sixth International Symposium on Heavy Vehicle Weights and Dimensions,* 289-300. Saskatoon, Canada.

Prem, H., Mai, L. and Atley, K. 2006a. Application of Trackaxle® to Multi-Combination Vehicles. *Proceedings of the Ninth International Symposium on Heavy Vehicle Weights and Dimensions.* State College, Pennsylvania, USA.

Prem, H., Mai, L. and Bruzsa, L. 2006b. Tilt Testing of Two Heavy Vehicles and Related Performance Issues. *Proceedings of the Ninth International Symposium on Heavy Vehicle Weights and Dimensions.* State College, Pennsylvania, USA.

Prem, H., Mai, L. and Davey, G. 2008. A New Steerable Wheel System for Road Transport Applications. *Proceedings of the Tenth International Conference on Heavy Vehicles,* 413-428. Wiley. Paris, France.

Rolland, D., Pearson, R.A. and Edgar, J. 2006. Performance-Based Standards – Recent Developments in Australia. *Proceedings of the Ninth International Symposium on Heavy Vehicle Weights and Dimensions.* State College, Pennsylvania, USA.

RTAC. 1980. *Vehicle Weights and Dimensions - Bridge Capacity Study*, Roads and Transportation Association of Canada, Ottawa, Canada.

RTAC. 1986. *Vehicle Weights and Dimensions Study Technical Steering Committee Report.* Roads and Transportation Association of Canada, Ottawa, Canada.

RTAC. 1987. *Recommended Regulatory Principles for Interprovincial Heavy Vehicle Weights and Dimensions*, CCMTA/RTAC Vehicle Weights and Dimensions Study Implementation Committee Report. Roads and Transportation Association of Canada, Ottawa, Canada.

RTAC. 1988. *Memorandum of Understanding on Interprovincial Heavy Vehicle Weights and Dimensions*. Roads and Transportation Association of Canada, Ottawa, Canada.

RTAC. 1992. *The Effect of Vehicle Length on Traffic on Canadian Two-lane, Two-way Roads*, Committee Report. Roads and Transportation Association of Canada, Ottawa, Canada.

Sweatman, P, Woodrooffe, J and Blow, P. 1998. Use of engineering performance in evaluating size and weight limits. *Proceedings of the Fifth International Symposium on Heavy Vehicle Weights and Dimensions*, 161-176. Queensland, Australia.

Sweatman, P.F., Di Cristoforo, R. and Kalasih, D. 2003a. *Benchmarking heavy vehicle productivity and safety performance*. Roaduser Systems Report RUS-03-898-01-01. Melbourne, Australia.

Sweatman, P.F., Coleman, M. and Di Cristoforo, R. 2003b. *Evaluation of an active-steering triaxle group (Trackaxle)*, Roaduser Systems Report RUS-03-1000-01-03. Melbourne, Australia.

TRB. 2002. *Regulations of Weights, Lengths, and Widths of Commercial Motor Vehicles.* Special Report 267. National Research Council, Transportation Research Board. Washington, D.C., USA.

US DoT. 2000. *Comprehensive Truck Size and Weight (CTS&W) Study.* FHWA, U.S. Department of Transportation, Washington, D.C., USA.

Vuong, B. Tepper, S. and Sharp, K. 2002. *Performance-Based Specifications for Heavy Vehicles. Evaluation of requirements for Vertical Loading*. ARRB Transport Research Ltd. Published as Appendix B in PBS Infrastructure Protection Standards for Heavy Vehicles, Discussion Paper. January 2003. National Road Transport Commission. Melbourne, Australia.

White, D. M. and Baas, P. H. 1993. Improving the safety of heavy vehicles in New Zealand through performance-based regulations. *Proceedings of the 26th ISATA International Symposium*, Aachen, Germany.

Winkler, C.B., Blower, D., Ervin, R. D. and Chalasani, R.M. 2000. *Rollover of heavy commercial vehicles*. The University of Michigan Transport Research Institute. SAE Research Report. Ann Arbor, Michigan, USA.

Wong, J.Y. and El-Gindy, M. 1986. A comparison of Various Computer Simulation Models for Predicting the Lateral Dynamic Behaviour of Articulated Vehicles, *CCMTA/RTAC Vehicle Weights and Dimensions Study Technical Report Volume 16*. Roads and Transportation Association of Canada, Ottawa, Canada.

Woodrooffe, J.H.F., LeBlanc, P.A. and El-Gindy, M. 1986. *Technical Analysis and Recommended Practice for the Double Drawbar Dolly Using Self-steering Axles.* Roads and Transportation Association of Canada, Ottawa, Canada.

Woodrooffe, J.H.F., LeBlanc, P.A. and LePiane, K.R. 1986. The Effect of Suspension Variations on the Dynamic Wheel Loads of a Heavy Articulated Vehicle, *CCMTA/RTAC Vehicle Weights and Dimensions Study Technical Report Volume 11*. Roads and Transportation Association of Canada, Ottawa, Canada.

Woodrooffe, J.H.F., Burns, N, Johnson, D, Palmer, J and Smith, D. 1998. Constructive use of performance measures for improved vehicle safety and productivity. *Proceedings of the Fifth International Symposium on Heavy Vehicle Weights and Dimensions*, 161-176. Queensland, Australia.