PRESCRIPTIVE LIMITS OR PERFORMANCE BASED STANDARDS?

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Abstract

Traditionally size and weight regulation has been based on prescriptive limits. Since the 1980s there has been increasing interest in using Performance-Based Standards as a mechanism for regulating size and weight. In this paper the two approaches are compared. One of the key findings is that even with a Performance-Based Standards approach it appears to be impossible to avoid including prescriptive requirements. Thus any practical regulatory system is likely to be a hybrid of the two approaches. The challenge is to find the appropriate balance.

Keywords: Performance Based Standards, Heavy Vehicles, Productivity, Size and Weight, Regulation, Freight Efficiency.

1. Introduction

Traditionally vehicle size and weight has been regulated using prescriptive limits. The Vehicle Weights and Dimensions study (RTAC 1986) sponsored by the Roads and Transportation Association of Canada (RTAC) led to the development of a set of performance measures for characterising safety-critical aspects of vehicle performance. The goal of the RTAC study was to achieve improved uniformity in interprovincial weight and dimension regulations. Performance measures were a means of developing these regulations rather than an end in themselves. The results of this RTAC study were presented at the first of these symposia.

The RTAC study led to the idea of regulating size and weight through performance-based standards (PBS). The basic concept was that we should regulate what the vehicle can do rather than what it should look like. Since then a number of jurisdictions have adopted the use of performance-based standards to varying degrees.

In this paper we review some of the relationships between the prescriptive and PBS regulation and discuss how the two systems interact in practice.

2. Historical Context

Although the concept of PBS as a system for regulating size and weight only evolved in the 1980s, the use of performance standards for regulating vehicles has been in place for much longer. Vehicle braking performance requirements have been specified in regulations in many jurisdictions since at least the 1920s. Rollover stability limits for buses have existed in the UK for just as long. These early performance standards were an adjunct to prescriptive requirements and not an alternative to them. A number of these standards are still in place today.

The main purpose of performance measures in the RTAC study was to inform the development of a set of harmonised vehicle size and weight limits that would be acceptable to all the Canadian provinces. An initial memorandum of understanding (MOU) between the provinces and the federal government was signed in 1988 and this has been extended and amended a number of times since then.

Similarly, in New Zealand, the performance measures developed in the RTAC study have been used to guide changes to the size and weight regulations since the late 1980s (Baas and White 1989). At that time the gross combination weight limit was increased from 39 tonnes to 44 tonnes. However, the higher weights were linked to improvements is safety performance and were not available to configurations that had been shown have poorer performance particularly in terms of high speed dynamics. Most notably, A-trains were held at the 39 tonnes weight limit and have gradually disappeared from the New Zealand fleet.

Performance measures and standards were also used to evaluate the performance characteristics of vehicles operating under permit outside the standard size and weight regulations. This approach has particularly been used in New Zealand and in some Canadian provinces. Examples of this approach have been presented at previous symposia (Edgar 1995, Woodrooffe at al 1998, Borbely et al 2000).

In 2002, New Zealand embedded some performance standards into its size and weight regulations; most notably a rollover stability requirement applying to most large heavy vehicles (de Pont et al 2004). The others were the low speed turning performance requirements for over-dimension vehicles to be exempted from travel time restrictions. Performance analysis was also used to inform the development of some of the prescriptive requirements. In particular a mass ratio limit for trailers was introduced as well as a maximum hitch offset (as a proportion of wheelbase) for trucks towing trailers. Both of these requirements were designed to manage high speed dynamic performance.

In 2010, the New Zealand size and weight regulations were amended to allow larger and heavier vehicles to operate on routes that could accommodate them. The regulator in implementing these changes used performance standards as a basis for determining whether vehicle designs would fit on the network but these designs are prescriptive dimensional envelopes.

In the late 1990s, the National Transport Commission (NTC) in Australia initiated a very ambitious programme to develop a comprehensive alternative size and weight compliance regime based completely on PBS. This scheme took a number of years to develop and involved an extensive research programme (Sweatman et al 1999, Prem et al 1999, Prem at al 2001a, 2001b, 2001c, Prem et al 2002, Pearson et al 2007) as well as stakeholder consultation. The scheme was finally implemented in 2008 (National Transport Commission 2007a). It is an optional alternative system that operates in parallel with the prescriptive regime. Vehicles approved under PBS operate under permit and are restricted to routes that have been approved for their use.

South Africa has adopted a PBS system similar to Australia's and based largely on the same performance standards. They began in 2007 by trialling the system on two demonstration vehicles in the forestry sector (Nordengen et al 2008, Nordengen 2010). This initial trial was deemed successful and the trial was expanded so that by 2012, some 58 vehicles were operating on PBS permits with a number of others at the design stage (Nordengen 2012).

In Europe in the 1990s jurisdictions were also developing more productive vehicles with the European Modular System (EMS) vehicles. This concept was originally developed in Scandinavia and was included in EC Directive 96/53 where they are referred to as modular concept vehicles. These vehicles are based on connecting standard length modules together in various combinations. The basic concept was that two of these vehicles could replace three current standard vehicles. The modular nature also meant that the vehicles could be split into component units if necessary for access to restricted parts of the network. The development of the concept was based purely on prescriptive dimension and mass limits without being based on performance assessment at all although some performance assessment has been done since (Aurell and Wadman 2007, Bózsvári et al 2008).

EC Directive 96/53 does not mandate the EMS for EU members nor does it explicitly specify and overall length and weight limit. EMS vehicles were originally implemented in Sweden and Finland with an overall length limit of 25.25m and a maximum weight of 60t. Subsequently the concept has been adopted in the Netherlands but at this stage they are not used elsewhere in Europe.

Sweden is currently undertaking an extensive cooperative research programme to evaluate the options for applying PBS there. This is motivated by a desire to introduce large more productive vehicles while ensuring that safety performance is maintained and environmental and infrastructure impacts are controlled.

3. How has it worked in practice?

The European modular concept vehicles have been quite successful where they have been implemented. In the Netherlands they have been extensively monitored and they have achieved significant productivity gains with good safety performance.

Some of the modular combinations that are possible within the EMS concept can have poor performance characteristics, although it appears that these particular configurations are not popular with operators and very few of them exist. There has, however, been considerable resistance in many European countries to permitting these modular concept vehicles and thus currently their operations are restricted to a relatively small proportion of the network. The opposition to these vehicles is based on a wide range of issues and it is unlikely that a PBS analysis showing their safety performance characteristics would make any difference to their acceptability.

At the opposite end of the scale, the Australian PBS system was envisaged as being totally performance-based with no prescriptive constraints at all but in practice this has not been able to be achieved. The performance measures and pass/fail criteria are shown in Table 1. Within the PBS system in Australia there are four primary levels of access broadly representing the different types of infrastructure access that exists under prescriptive limits.

Level 1 is aligned with general access. Under prescriptive limits the largest general access vehicles have a maximum length limit of 19m and a maximum gross combination weight of 42.5t. There are provisions for some types of vehicle such as B-doubles to go up 50t but there are some route restrictions on the higher weights. These gross weights are based on the so-called “general mass limits” and higher weights are permitted for qualifying vehicles on approved roads under provisions called “concessional mass limits” and “higher mass limits”. Each type of axle group has a maximum weight limit and there is a bridge formula which controls the axle spacings required to achieve particular weights. Vehicles are allowed a maximum width of 2.5m and a maximum height of 4.3m.

A level 1 PBS vehicle is limited to an overall length of 20m. Its height and width are constrained to the prescriptive limits, i.e. 2.5m and 4.3m respectively. The pavement vertical loading performance standard specifies that the axle group loads cannot exceed the prescribed limits for that type of axle configuration while the bridge formula constrains the axle weights and spacings. Thus the level 1 PBS vehicle is subject to a raft of prescriptive limits as well as having to meet the PBS standards.

Under prescriptive limits the truck and full trailer combination is limited to 19m and 42.5t. Under level 1 PBS a 3-axle truck and 3-axle full trailer can achieve 48t and 3-axle truck and 4-axle full trailer can achieve 50t. The PBS Rules specify a maximum gross weight of 50t for general access. Not surprisingly the majority of PBS permits that have been issued have been for truck and full trailer combinations.

Level 2 PBS access in Australia is broadly aligned with the B-double routes. B-doubles in Australia can operate at up to 26m long and 62.5t at general mass limits. B-double routes include the major inter-city links as well as access links to industrial and commercial zones. The Network Classification Guidelines (National Transport Commission 2007b) divide each of the Level 2, 3 and 4 road networks into two access classes designated “A” and “B”. Access to the level 2A network is limited to vehicles with an overall length of 26m or less as well as the standard height and width limits. Axle weights are limited by the standard mass limits and a bridge formula constrains the axle weights and spacings. Thus the level 2A PBS provisions effectively allow for other vehicle configurations to operate at the same weight and length as B-doubles on B-double routes if they have satisfactory performance. However, the B-double is a productive vehicle with good safety performance and so the scope for developing a better vehicle within the same mass and dimension parameters is limited.

Table 1. Performance standards and pass/fail criteria.

Performance Standards and Pass Criteria				
Performance Standard	Level 1	Level 2	Level 3	Level 4
Safety Standards				
1. Startability:	≥ 15%	≥ 12%	≥ 10%	≥ 5%
2. Gradeability:				
a) Maximum grade	≥ 20%	≥ 15%	≥ 12%	≥ 8%
b) Speed on a 1% grade	≥ 80km/h	≥ 70km/h	≥ 70km/h	≥ 60km/h
3. Acceleration capability (100m travel from rest)	≤ 20 sec	≤ 23 sec	≤ 26 sec	≤ 29 sec
5. Tracking Ability on a Straight Path	≤ 2.9m	≤ 3.0m	≤ 3.1m	≤ 3.3m
7. Low-Speed Swept Path	≤ 7.4m	≤ 8.7m	≤ 10.6m	≤ 13.7m
8. Frontal Swing:				
a) Maximum Frontal Swing	≤ 0.7m	≤ 0.7m	≤ 0.7m	≤ 0.7m
b) Maximum of Difference	≤ 0.4m	≤ 0.4m	≤ 0.4m	≤ 0.4m
c) Difference of Maxima	≤ 0.2m	≤ 0.2m	≤ 0.2m	≤ 0.2m
9. Tail Swing	≤ 0.30m	≤ 0.35m	≤ 0.35m	≤ 0.50m
10. Steer-Tyre Friction Demand	≤ 80%	≤ 80%	≤ 80%	≤ 80%
11. Static Rollover Threshold (Worst)	≥ 0.35g	≥ 0.35g	≥ 0.35g	≥ 0.35g
Static Rollover Threshold of last unit	≥ 0.35g	≥ 0.35g	≥ 0.35g	≥ 0.35g
12. Rearward Amplification	≤ 5.7 times SRT of last unit			
13. High-Speed Transient Offtracking	≤ 0.6m	≤ 0.8m	≤ 1.0m	≤ 1.2m
14. Yaw Damping Coefficient	≥ 0.15	≥ 0.15	≥ 0.15	≥ 0.15
16. Directional stability under braking				
Infrastructure Standards				
17. Pavement Vertical Loading	Existing prescriptive axle group load limits apply			
18. Pavement Horizontal Loading				
a) Maximum gross weight with one drive axle	35t	45t	45t	45t
b) Maximum gross weight with two drive axles	70t	85t	110t	150t
19. Tyre Contact Pressure Distribution	Existing prescriptive limits on min. tyre width and max. pressure apply			
20. Bridge Loading	M = 3L + 12.5 for M <= 42.5 t; and M = L + 32.5 for M >= 42.5 t	M = 3L + 12.5 for M <= 46.5 t; and M =1.5L + 29.5 for M >= 46.5 t	M = 3L + 12.5 for all M	

Level 2B access allows for vehicles up to 30m in length. This does offer some opportunities for larger vehicles than the existing prescriptive B-trains and there are A-double vehicles that have been developed for level 2B access (Johnston 2012).

Level 3 and level 4 access is based on road train routes which are typically in more remote areas of Australia. The prescriptive vehicles are various forms of A-train. These can have relatively poor high speed dynamics. The PBS system has opened the way for various innovative combinations which incorporate more "B" couplings and have better high speed dynamics.

The length limits for PBS access quoted above are not absolute. The PBS rules provide for vehicles to be longer than these limits on specific routes but this requires a route assessment to be undertaken. This increases the cost and complexity of obtaining the PBS approval and imposes more restrictive operating conditions and so, in effect, each PBS access level has an associated overall length limit.

There are also still prescriptive limits for height and width. The pavement loading criteria and the bridge formulae also constrain the allowable weight to the same limits as prescriptive vehicles. Because of the rigor of the system, the PBS approval process is quite involved and costly for the operator and as a result the initial uptake has been slow. As at June 2012, after nearly five years, 308 PBS applications had been received and about 750 PBS vehicles had been built (Arredondo 2012). The regulators are working to improve the accessibility of the system.

One of the ways that they are doing this is through the development of "blueprint" vehicles. These are effectively design envelopes for particular configurations that would be expected to achieve the PBS standards. Vehicles complying with these blueprint designs can be submitted PBS approval without having to go through the assessment process.

This blueprint vehicle process is similar to that used in New Zealand where performance standards were used to create prescriptive dimensional envelopes for high productivity motor vehicles (HPMVs) (de Pont 2012). In New Zealand these are called pro-forma designs. With this approach the cost of implementation has been lower and the uptake has been stronger. In the first two years of the scheme over 1000 HPMV permits were issued which represents about 5% of the combination vehicle fleet. However, infrastructure limitations have constrained increases in weight. Currently there are also issues where length limits are being imposed on the basis of the limitations of the infrastructure rather than the performance of the vehicle.

4. Discussion

Increasing truck size and weight is a politically sensitive issue. Productivity improvements reduce fuel consumption and environmental impacts as well as reducing the amount of truck traffic needed for a particular freight task. On the other hand there is a perception that improving the efficiency of truck transport will result in a modal shift from rail and water towards road transport and hence increase truck traffic volumes. There is also the perception that larger trucks pose a greater safety risk.

The use of PBS in determining the parameters for the larger trucks can be used to help to demonstrate that there is no loss of safety performance associated with the size and weight increases. However, this does not address perceived issues such as modal shift. The European EMS vehicles were developed without using PBS and some of the possible configurations do not have the best possible safety performance, but, in practice, these vehicles have a reasonably good safety track record. Nevertheless they have not become widespread across Europe. There is a significant organised lobby group called "No Mega Trucks" opposing the more widespread use of these vehicles. It seems unlikely that the use of PBS to demonstrate the safety performance of the vehicles would make much difference to this opposition.

As shown in the previous section, even when a full PBS approach is applied there are still a number of prescriptive requirements that cannot be avoided. These include length, height and weight, axle group weight limits and bridge formula compliance. These prescriptive requirements are driven primarily by the infrastructure and associated traffic engineering issues rather than vehicle safety performance. This is the reason that they are unavoidable. For example, vehicle height affects rollover stability but a height limit is also needed to avoid collisions with overhead structures such as bridges. We cannot rely on the rollover stability requirement to restrict the vehicle height because it will not guarantee that the height is low enough to avoid collisions.

The infrastructure has evolved to accommodate the existing vehicle fleet. Stacking distances at intersections, sight distances, signal timings, overtaking requirements etc are all based on the length of existing vehicles. Road structures are designed to accommodate existing axle group weight limits and bridges are designed for existing axle spacings and weights. Most of these elements are not built to the minimum possible requirements and thus can often tolerate small increases but this incremental creep approach to size and weight regulation is something PBS was designed to avoid.

The first three performance standards in the Australian PBS system relate to the performance of the vehicle's engine and transmission. These measures are startability, gradeability (at low speed and high speed) and acceleration capability. Although these measures are typically evaluated by computer simulation, this involves a number of assumptions and seems unnecessarily complicated for what the standards are aiming to achieve. The purpose of these standards is to ensure that the engine and transmission can generate sufficient tractive force to deliver acceptable performance at both low speed and high speed. For the first two standards this can be achieved quite simply through prescriptive requirements. The engine and transmission has to be able to deliver sufficient tractive force to the wheels for the weight of the vehicle and there has to be sufficient weight on the drive axles to transmit the tractive force to the road surface.

For example, the level 1 low speed gradeability requirement specifies a slope of 20%. This means that we require a tractive force equal to, at least 0.2 times the weight of the vehicle to overcome the slope. Rolling resistance will add a further 1%-1.5% to this so we need a tractive force of about 22% of the vehicle weight. If we assume that the friction coefficient between the tyres and the road is 0.8, then the drive axles must carry at least 27.5% of the gross combination weight. A similar assessment can be applied to the startability criterion. In the Australian PBS system low speed gradeability is the critical measure for determining the minimum drive axle loads as a proportion of gross combination weight.

For startability, the level 1 requirement is that the vehicle can start on a 15% grade which means that the tractive force must exceed 15% of the total vehicle weight. Again we have to add a force component for overcoming rolling resistance and a force to gently accelerate the vehicle. As the vehicle is stationary when the force is initially applied it will not start moving if there is no accelerating force. The magnitude of this accelerating force is somewhat arbitrary but let us assume that the rolling resistance coefficient is 0.015 and the minimum acceleration is 0.015g. This means that, with the engine generating clutch engagement torque, the tractive force at the wheels must exceed 18% of the gross combination weight. The tractive force can easily be calculated as the product of the engine torque, the ratio of the lowest gear, the final drive ratio, a transmission efficiency factor and the rolling radius of the drive tyres. Thus it is relatively simple to define a prescriptive requirements for meeting the startability performance.

The same approach can be applied to the gradeability criteria. In this case the engine can operate at maximum torque rather than clutch engagement torque. For the high speed gradeability measure it is also necessary to include aerodynamic drag forces. With simulation methods this involves assumptions which may vary from assessor to assessor. It is more reliable to make some conservative assumptions and embed them in a prescriptive requirement.

The third engine and transmission performance standard is acceleration capability. In the simulation approach a vehicle's performance in this measure depends strongly on the time taken for each gear change. The manoeuvre takes 20s and there are typically seven or eight gear changes required. During each gear change the vehicle is decelerating. For manual gearboxes there is limited data on gear change times and so the simulation inputs are rather arbitrary. However, the gradeability criteria cover both low speed and high speed operation and a vehicle that meets both those standards will achieve the acceleration capability standard unless its intermediate gears are so badly spaced that it cannot stay in the peak torque band. While this is theoretically possible, it is difficult to imagine a truck manufacturer fitting such a gearbox and even more difficult to imagine an operator buying such a vehicle.

Thus these first three performance standards could be replaced with prescriptive requirements which would be easier and cheaper to evaluate and less sensitive to assumptions.

5. Conclusions

Virtually all regulatory systems for dimensions and mass contain a mix of prescriptive requirements and performance requirements.

The PBS approach can effectively address the safety performance of the vehicle but the vehicle also has to fit on existing infrastructure and interact with traffic. These latter issues are most simply addressed through prescriptive requirements.

Where performance issues can be addressed by prescriptive requirements it is often simpler and more effective to do so. This can be at the performance standard level as discussed for the engine and transmission performance standards or at the whole vehicle level through "blueprint" or "pro-forma" designs.

A system that is more heavily weighted toward prescription is less flexible but generally involved less cost to operate. Conversely a system that is more heavily based on performance standards has greater flexibility but is more cumbersome and costly.

The challenge is to find the appropriate balance between the two.

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