VEHICLE INNOVATION IN A PBS ENVIRONMENT

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Abstract

An innovative trailer design that can be used as an alternative to a semi-trailer has been developed. The trailer features two axle groups with a steering mechanism which improves its low speed turning performance and increases its weight and volume capacity compared to a conventional semi-trailer. The Australian Performance-Based Standards system provides an alternative approach for regulating size and weight based on how the vehicle performs rather than what it looks like. This paper describes the process of applying for a permit to operate an innovative unconventional vehicle under the PBS system.

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

1. Introduction

In 2008 after a number of years of research and development Australia introduced a Performance Based Standards system for regulating vehicle size and weight as an optional alternative to the prescriptive regime. One of the fundamental tenets of the PBS approach is that the PBS system defines what the vehicle should be able to do rather than what it should look like. A corollary of this principle is that the PBS system was expected to facilitate innovation in vehicle design.

In practice to date, the Australian PBS system has not been used extensively for developing innovative vehicles. The largest number of vehicles approved under the scheme have been conventional truck and dog trailer combinations operating at increased gross combination weights.

In this paper we describe the development of an innovative vehicle design and our experiences in applying for approval for this vehicle to operate under the Australian PBS system.

2. The EasySteer Innovative Trailer

In the log transport industry in New Zealand, Australia and Canada, a configuration known as a jinker pole trailer is reasonably widely used for transporting long logs. With this configuration the towing forces are transmitted from the towing vehicle to the trailer through the logs. The trailer is also connected to the towing vehicle by a sliding pole which acts to steer the trailer wheels. The trailer wheels may be a single axle group in which case the pole steers the whole group or they may be two axle groups in which case the pole steers the front group. An example of this latter configuration is shown in Figure 1.

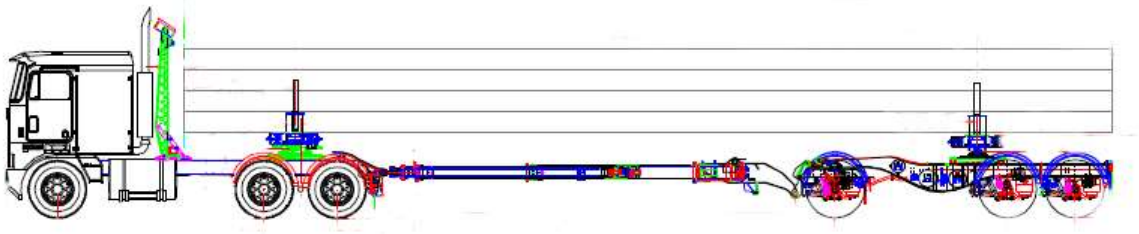

Figure 1. Logging jinker full trailer.

Although the vehicle appears to be similar to a semi-trailer, the steering pole improves the low speed turning performance so that this vehicle is more manoeuvrable than a semi-trailer of the same dimensions.

The Easysteer trailer takes this concept a step further by connecting the pole to the trailer itself rather than to the towing vehicle and applying this to a general purpose vehicle. The proposed vehicle is shown in Figure 2. The example shown is a flat deck trailer but the configuration can be used for container transport, refrigerated transport or general freight.

Figure 2. Easysteer trailer.

By connecting the steering pole to the trailer itself, the vehicle can be towed by a standard tractor unit and thus the trailer can simply be substituted for a conventional semi-trailer. The steering mechanism results in improved low speed turning performance which means that the vehicle can potentially be longer than the conventional semi-trailer with more deck length and a greater load volume. At the time that the Easysteer concept was developed, the maximum allowable length for a semi-trailer combination was 19m while level 1 PBS vehicles could be up to 20m long. Since then a new blueprint PBS semi-trailer has been introduced (NHVR 2014), which allows semitrailers to be up to 20m long. Although it would be quite possible to configure an Easysteer vehicle that is longer than these 20m semi-trailers while retaining better low speed turning performance, the level 1 PBS requirements limit the vehicle length to 20m and a longer vehicle would not be approved. Thus the introduction of the 20m blueprint PBS semi-trailer option has effectively eliminated the payload volume gains associated with the Easysteer vehicle at PBS level 1 but an Easysteer vehicle will have better low speed turning performance than a semi-trailer of the same length. The Easysteer trailer axle configuration consists of two axle groups (in the same configuration as a 3-axle dog trailer) and thus the trailer axles have greater weight capacity (25.5 tonnes) than a conventional tridem axle group (20 tonnes) on a semi-trailer. The Easysteer vehicle concept has been patented by Elphinstone Engineering.

The vehicle can be visualised as being a hybrid cross between a B-train (known as a B-double in Australia) and a conventional semi-trailer. If the front of the pole were connected to the trailer at the fifth wheel position, the pole would have no steering effect and the vehicle would behave like a B-train with a single-axle first trailer and a tandem axle second trailer. If the pole were connected to the trailer chassis in line with the front axle of the trailer bogey, the steering would be such that the first axle of the bogey was always aligned with the trailer chassis. In this case the vehicle would behave like a 3-axle semi-trailer. Note that neither of these pole positions is physically possible but the visualisation is useful for understanding how the steering mechanism works. The performance characteristics of this vehicle are expected to be between those of a B-train and semi-trailer. For low speed turning performance this will mean that the vehicle is superior to the semi-trailer which is how we can achieve increased overall length. On the other hand the B-train-like steering on the bogey enables the trailer axles to be spread more widely to give increased weight capacity without causing excessive scuffing forces.

3. Vehicle Performance Characteristics

The Easysteer trailer was not designed as a one-off vehicle for a specific application but rather as a new category of vehicle that will have widespread application for a number of transport tasks. Because of this it was expected that a range of tractor units might be used to tow the trailer and that the trailer dimensions might also vary. To keep the options manageable, the dimensions of the trailer axle sub-assembly were fixed. However, the distance between the

coupling point on the tractor and the turntable connecting the trailer deck to the trailer axle sub-assembly was allowed to vary as was the attachment point of the pole to the trailer deck (i.e. the length of the pole). Similarly the tractor wheelbase and tractor front overhang could vary to allow for different makes and models of tractor.

The Australian PBS system provides for four primary levels of network access with different PBS acceptability limits for each level. The widest access is provided by level 1 which is effectively general access and consequently has the most restrictive PBS requirements. The Easysteer trailer was designed with the intention of achieving level 1 access. The performance standards and pass/fail criteria for level 1 access are shown in **Table 1**. Full details of the performance standards and the procedures for evaluating them can be found in NTC (2008). As noted previously the requirements for level 1 access also restrict the vehicle's maximum overall length to 20m.

Table 1. Performance standards and pass/fail criteria.

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

The first three performance standards are there to ensure that the vehicle's engine and transmission can generate sufficient tractive force at both low and high speed and that there is sufficient weight on the drive axles to transmit that tractive force to the pavement. The PBS application forms are designed for individual vehicles and thus expect that assessment is done on the basis of a specific engine with a specific gearbox and a specific differential. In our case we were applying for approval for a generic vehicle which would be able to be used with a range of tractor units. However, the maximum weight and axle weight distributions of the proposed vehicles is known and so it was relatively straightforward to determine the minimum engine power and torque and the transmission ratios needed to achieve satisfactory performance.

The vehicle was modelled using multibody simulation software. Some ten different vehicle configurations with variations of tractor front overhang, tractor wheelbase, trailer wheelbase (defined as the distance from the kingpin to the rear pivot point where the deck connects to the bogey), pole length and trailer rear overhang were modelled and assessed. From the results the limit values of these dimensional parameters were determined. The critical performance standards were those relating to low speed turning performance with the different aspects of low speed performance trading off against each other. For example, lengthening the pole reduces the low speed off-tracking but increases the tail swing. For all the other safety performance standards except Static Rollover Threshold (SRT) the vehicle easily satisfied the level 1 requirements.

SRT depends on the height of the centre of gravity of the vehicle, the tyre track width and the roll stiffness of the suspension and tyres. Thus almost any vehicle can have a satisfactory or an unsatisfactory SRT depending on how it is loaded. In order to achieve a satisfactory SRT it was necessary impose some restrictions on the vehicle. Specifically we required the vehicle to be fitted with dual tyres with a nominal section width between 265mm and 295mm inflated to the manufacturer's recommendations. The trailer was required to have a minimum tare weight of 7900kg and a maximum deck height of 1620mm. The suspension was required to have a minimum roll stiffness of 17,800Nm/deg per axle. With these constraints we determined the maximum allowable load height for a uniform density load and for a mixed freight load with 70% of the weight in the lower half of the load space and 30% of the weight in the upper half of the load space.

For the infrastructure standards, the proposed axle loadings were all in line with the existing legal limits which gave the vehicle a potential gross combination weight limit of 48 tonnes compared to 42.5 tonnes for a conventional semi-trailer combination at standard mass limits. The proposed geometry and axle weights comply with the requirements of the bridge loading shown as performance standard 19 in **Table 1**. The vehicle also complies with the other two infrastructure standards.

At this point we had developed a dimensional envelope for the vehicle with limits for all the key dimensions and for the critical parameters. Staying within these limits ensures that the vehicle can achieve all of the performance standards for level 1. We were now ready to submit our application.

Because the concept represents a significant departure from existing vehicle configurations, Elphinstone Engineering did not rely solely on the computer simulation results to satisfy themselves that the vehicle would work. A prototype vehicle was built which is shown in Figure 3. This vehicle was used to confirm the low speed turning performance characteristics of the

vehicle and to reassure Elphinstone that its high speed dynamic behaviour was safe. It was also taken to two major industry shows for demonstration and marketing purposes.

Figure 3. Prototype Easysteer trailer configured for log transport.

4. The Application Process

During the development of this proposal the administration of the PBS system was transferred from the National Transport Commission (NTC) to a new agency called the National Heavy Vehicle Regulator (NHVR). However, there was no fundamental change to the process through this change. There are two standard forms to be completed for a PBS application and these are submitted to the administrator in the agency. The administrator reviews the applications and resolves any issues that he sees with the applicant before submitting them to the PBS review panel. The review panel decides whether or not to approve the application based on whether they believe the vehicle complies with the PBS requirements.

If the application is approved, the applicant can build the vehicle. Once built, it is required to go through an inspection by a PBS certifier who checks that the actual vehicle as built is the same as the design that was originally approved. In parallel with this there is also a process where the operator who is planning to use the vehicle has to get approval from the relevant road controlling authorities for the routes he wishes to use. When the PBS system was first developed it was envisaged that the four levels of access would simplify this process. It was expected that all roads would be classified as being level 1, 2, 3, or 4 and thus a level 4 PBS vehicle would have access to all level 4 roads, a level 3 PBS vehicle would have access to level 3 and level 4 roads and so on. To date, gaining access has not been that simple but the regulators are working to improve this. This paper is focussing on the vehicle approval and so the issues of route access are outside its scope.

Although the PBS system is intended to promote innovation, the application forms have been formulated towards one-off designs with a specific powered vehicle, fixed dimensions for the trailer(s), specific suspensions, tyre size and makes etc. Part of the reason for this is that it simplifies the task for the certifier when he comes to check the actual vehicle. But it does mean that the forms are not well-suited to a class of vehicle like the Easysteer trailer with dimensional envelopes that have a range of acceptable values, options for tyre sizes and generic tractors etc.

However, the NTC had previously developed the concept of blueprint vehicles to facilitate a greater uptake of PBS. One of these blueprint vehicle designs was for a quad-axle semi-trailer (NTC 2007). This design provided for a range of tractor units and included a dimensional envelope rather than fixed dimensions. Thus we based our application on the approach used for defining the blueprint quad-axle semi-trailer. As much as possible we defined generic characteristics of the key vehicle parameters without specifying details like make and model.

On this basis the application forms were completed and submitted to the NHVR. We had had discussions with the NHVR administrator during the process and he was very supportive of the proposal. Anecdotally we also received feedback that the some members of the review panel had been canvassed and viewed the concept favourably.

The reason for this favourable view was that when PBS was first introduced it was seen as a pathway for developing innovative vehicle designs which would result in productivity and safety benefits. However, in practice, it has been extensively used as a mechanism for achieving weight increases for truck and dog trailer combinations and relatively few truly innovative designs have been approved. The Easysteer trailer is an innovative design which could help to showcase the benefits of PBS.

5. The Crunch

The PBS application forms for the Easysteer trailer were submitted to the NHVR on the 20th March 2013 at the same time as an application for another vehicle. Some confusion occurred with these two applications and we were asked to resubmit a month later on 24th April. A further month on we were asked to prepare tracking curves showing the path of each axle during the standard 12.5m radius 90° low speed turning manoeuvre. These were submitted and the application was considered by the PBS review panel on the 29th May, 2013. We were informed on the 6th October, 2013 that the application was not approved.

The PBS review panel found that the vehicle meets all of the PBS safety standards but that it does not meet the requirements of the pavement vertical loading standard. This standard says that the individual axle group loads must not exceed those that currently apply under the prescriptive limits. Although the finding that the Easysteer trailer does not comply seems extraordinary because all the proposed axle group weights were based on the legal limits for the type of axle group, the reasoning was based on the way that the review panel's business rules, which are defined in legislation, have been applied. Essentially the Easysteer trailer was deemed to be a semi-trailer by the review panel. The legal definition of a semi-trailer in Australia says that a semi-trailer has only one axle group. Therefore, the three trailer axles were regarded as being part of the same axle group and as such are limited to a maximum axle group weight of 20 tonnes. The axle spacing of the Easysteer trailer axles is also greater than the allowed spacing for a tridem group. If the Easysteer trailer axles were limited to a total weight of 20 tonnes, the vehicle would no longer have any productivity advantage and does not make economic sense. Nobody would buy one.

However, the axle configuration of the Easysteer trailer is identical to that of a 3-axle truck and 3-axle dog trailer as illustrated in Figure 4. The axle weights applied for the Easysteer vehicle are identical to those that have been approved for a number of truck and dog combinations like the one shown. These weights are specified in the prescriptive limits and the axle spacings meet the bridge formula requirements. This is the basis on which we determined that the Easysteer trailer met the PBS infrastructure standards. It is possible to configure an Easysteer vehicle and a truck and dog trailer vehicle so that all the axles on each vehicle are in exactly the same relative position and carry the same weight. From the point of view of the infrastructure, the vertical loading from these two vehicles would be identical.

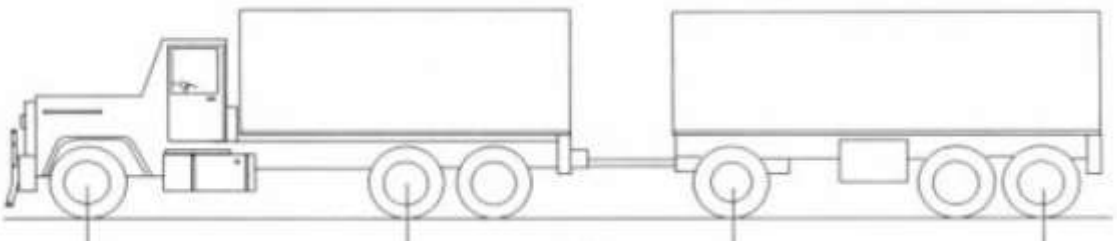

Figure 4. Three-axle truck and three-axle dog trailer.

To try to resolve the issue we presented an argument to the review panel that the Easysteer trailer is not a semi-trailer but rather is its own category of vehicle. As we pointed out earlier in this paper, the Easysteer trailer is effectively a hybrid of a B-train and a semi-trailer and its performance characteristics fit somewhere in between these two vehicle configurations. Furthermore, as the legal definition of a semi-trailer says that it has one axle group, our argument was that, because the Easysteer trailer has two axle groups, it is not a semi-trailer.

The NHVR has considered this argument and came back to us with a request that we calculate the pavement wear implications of the Easysteer vehicle compared to that of the alternative vehicles that it might replace. The measures used to characterise pavement wear in Australia are Standard Axle Repetitions (SAR) or Equivalent Standard Axles (ESA). For each axle group the SAR is the axle group weight divided by the reference weight for that type of axle group and then raised to a power. The most widely used value for the exponent is four and a SAR calculated using the fourth power is called an ESA. To get a rating for the vehicle the ESA or SAR values of all the axle groups are summed.

In our response we noted that a simple ESA or SAR value for a vehicle is not very meaningful because it fails to take productivity into account. For example, a 2-axle rigid truck at maximum legal weights in Australia generates about 3 ESA while a 6-axle semi-trailer combination at maximum legal weights generates 5 ESA. However, the semi-trailer combination can carry about three times as much payload as the rigid truck. Therefore, one semi-trailer trip would need to be replaced by three rigid truck trips which would incur a total of about 9 ESA. Based on ESA the semi-trailer option would cause less pavement wear. To incorporate productivity in the measure we calculated the ESA/payload tonne. Determining the payload weight involves making assumptions about the vehicle tare weight which can vary significantly for different freight tasks. Modifying the tare weights can change the relativities between different vehicle configurations. An alternative is to use ESA/gross tonne as the measure. This measure is not as directly related to productivity as ESA/payload tonne but it eliminates any debate about the validity of the tare weight assumptions.

The pavement wear analysis showed that the Easysteer trailer combination generates the same ESA/payload tonne and ESA/gross tonne as the 6-axle truck and dog trailer combination. We assumed that the two configurations had the same tare weight. At general mass limits the Easysteer vehicle generates about 18% more ESA/payload tonne than the 6-axle semi-trailer combination but significantly less than a rigid truck. At higher mass limits the Easysteer vehicle generates about 13% more ESA/payload tonne than the semi-trailer. Thus the productivity gain from using an Easysteer trailer in place of a conventional semi-trailer is at the expense of a modest increase in pavement wear from vertical loading. However, there is a reduction in horizontal scuffing forces because of the steering mechanism, which has a beneficial effect on pavement wear at intersections and roundabouts where tight turning manoeuvres are required.

As mentioned above, in addition to getting a PBS approval to operate the vehicle from the NHVR it is also necessary to obtain permission for the relevant road controlling authority for access to the road network. Thus, in parallel with the vehicle application, an application was made to the VicRoads for access to the level 1 PBS network in Victoria. There was some initial concern from them regarding the bridge loadings but as of 21st May 2014, they have said that they will grant the vehicle access to the Level 1 PBS network in Victoria at 48.5 tonnes gross combination weight providing it complies with the PBS standards.

We have now (June 2014) received a verbal notification from NHVR that the Easysteer vehicle has been approved. The official written confirmation should arrive soon. The permitting process has taken 15 months.

6. Conclusions

Although the PBS system was intended to facilitate innovation, in this case, it struggled to cope. This is not through any lack of goodwill from either the PBS administrator or the review panel. Both parties have been very supportive of the application and have tried to assist wherever possible. Most of the problems have arisen because of the way that the business rules were written. Innovative designs that are significantly different from existing vehicles were not really anticipated and are not covered adequately by the business rules.

7. References

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