

## DEVELOPMENT OF AN INNOVATIVE STEERABLE DOUBLE EXTENDABLE TRAILER UNDER PERFORMANCE BASED STANDARDS (PBS)

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### Abstract

Haulmark Trailers Australia Pty Ltd, in partnership with Queensland Transport initiated the development and introduction of an innovative, state of the art steerable extendable tri-axle semi-trailer under the framework provided by the Performance Based Standards (PBS) regulatory system. This project has clearly demonstrated the huge potential of a performance based regulatory system by the emergence of a significantly more productive and efficient heavy vehicle configuration with much improved dynamic performance and safety. The proposal was the first concept vehicle that has pushed the boundaries of both the PBS and prescriptive regulatory system to their limits and paved the way for other operators and manufacturers to "think outside the box" and develop new transport solutions for the growing freight tasks. This paper describes the technical, manufacturing, regulatory and operational challenges faced when developing this new vehicle concept for the transportation of long products.

**Keywords:** Computer Simulation, Heavy Vehicles, Vehicle Dynamics, Performance Based Standards (PBS), Australia.

### Résumé

Haulmark Trailers Australia Pty Ltd, en partenariat avec Queensland Transport a lancé le développement et l'introduction d'une semi-remorque extensible innovante à essieu tridem directeur dans le cadre des règles des normes de performance (PBS). Ce projet a clairement démontré le potentiel important d'un système de règles basé sur les performances avec l'émergence de configurations de poids lourds nettement plus productives et efficaces et avec des qualités dynamiques et une sécurité accrues. Cette proposition fut le premier concept de véhicule à repousser les limites des PBS et du système de prescriptions réglementaires, ouvrant la voie aux autres opérateurs et constructeurs à "jouer en dehors du pré carré" et à développer de nouvelles solutions pour répondre à l'accroissement du transport de fret. Cet article présente les défis techniques de fabrication, réglementaires et opérationnels relevés en développant ce nouveau concept de véhicule pour le transport de produits longs.

**Mots-clés:** simulation informatique, poids lourds, dynamique véhicule, normes de performance (PBS), Australie.

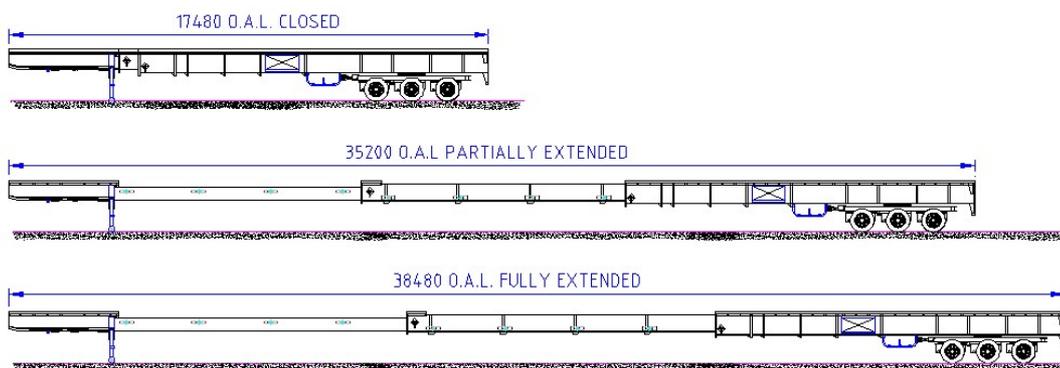
## 1. Introduction

Haulmark Trailers Pty Ltd (Haulmark), in partnership with Queensland Department of Transport (Queensland Transport) initiated the development and introduction of an innovative, state of the art steerable extendable tri-axle semi-trailer.

The particular freight task was to carry long roofing sheets up to 40 metres in length. These loads are considered to be overdimensional and such long loads are normally carried on extendable semi-trailers. These trailers are designed to be extended or shortened depending on the size of load but usually travel to the loading sites in a closed position. Accordingly, these combinations are operated under two distinctive regulatory regimes. When the extendable semi-trailers are operated in a closed form they have unrestricted access to the road network and they must comply with the requirements of the prescriptive regulatory system. These requirements limit the overall length of a semi-trailer to 14.6 metres, the maximum kingpin to rear of the trailer dimension to 12.3 metres and the maximum overall length of a 6-axle articulated vehicle combination to 19 metres.

During the transportation of long, indivisible loads, the extendable vehicle combinations are operated under the specific conditions of an oversize permit. These conditions for oversize require that any prime mover and extendable semi-trailer combination with an overall length greater than 30 metres has to be fitted with a full steering rear suspension group on the trailer and it must have the ability to be steered by remote control. The maximum rear overhang is also limited to 7.6 metres. Consequently, these extendable trailers must be designed to comply with the requirements of both operating schemes, which can significantly limit the flexibility of the trailer designs.

The recently introduced Performance Based Standards Scheme (PBS) is an innovative and optional regulatory system, which allows manufacturers to optimise the on-road performance of heavy vehicle combinations without specific dimensional limitations such as maximum length, height and maximum rear overhang. An innovative steerable extendable tri-axle semi-trailer for the transportation of long indivisible loads was developed.



**Figure 1** – Innovative steerable extendable semi-trailer.

The combination consists of a single steer tandem drive prime mover and a tri-axle extendable semi-trailer. When fully closed the semi-trailer has a deck length of 17.48 m, when extended to its maximum length the deck length is 39.62 m, and when carrying 35 m long roof sheeting

product it is operated at an overall deck length of 35.2 m (Figure 1). The trailer incorporates a trackaxle steerable tri-axle group with a manual override steering capability.

## **2. PBS Process**

PBS has introduced a new approach to the regulation of heavy vehicles in Australia as it encourages more productive outcomes from heavy vehicle operations and utilizes the existing infrastructure more efficiently. Under the performance-based approach, safety and infrastructure standards specify the performance required from vehicle operations rather than mandating how this level of performance is to be achieved. The concept is fundamentally based around how the heavy vehicle performs and interacts on the road instead of what it physically looks like as required under the prescriptive system.

In 2004, the Australian Transport Ministers approved the interim PBS package that was followed by the establishment of the PBS Interim Review Panel (IRP) in 2005. The PBS system requires compliance with 16 safety related performance standards and 4 infrastructure related standards relative to the specific level of on-road network access. The role of the IRP was to test the proposed assessment methods and arrangements for vehicles developed in accordance with the guidelines of the Performance Based Standards project. Although the IRP provided a nationally consistent assessment method for PBS case studies, it had only an advisory role to transport agencies on the PBS case study outcomes.

Under this interim process, the IRP considered PBS proposals that were submitted by the Case Study Lead Agencies (CSLA). The technical adequacy of the proposals has been assessed against the requirements of the assessment guidelines and a determination of the level of Performance Based Standards network access was decided. Although all jurisdictions were represented on the Panel, this endorsement did not extend to approval for access onto the road network in any jurisdiction. Even if a proposal was endorsed by IRP, the applicant had to return to each jurisdiction's road agency – including the case study lead agency – in order to seek access.

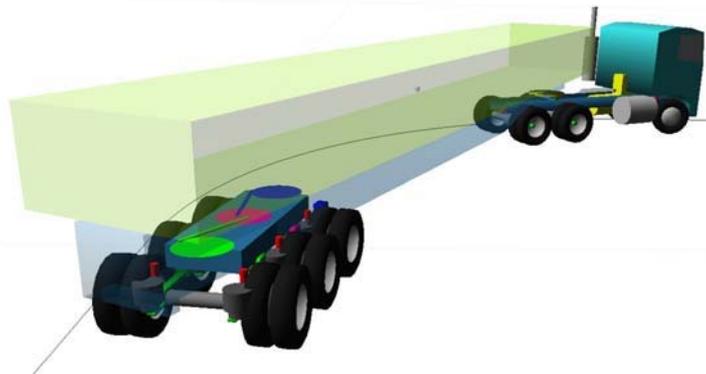
Queensland Transport considered the proposed concept to be a desirable combination and strongly supported this development by taking the proposal to the IRP run by the National Transport Commission (NTC).

## **3. Development of the extendable combination**

The development and the initial assessment of the Haulmark combination were carried out in 2006. As discussed earlier, when the semi-trailer is closed, it operates as a PBS vehicle on PBS Level 1 (L1) road class routes (general access) under general mass limit axle loads (GML). The Gross Combination Mass (GCM) of the combination is 42.5t with maximum axle load limits of 6t on the steer axle, 16.5t on the drive group and 20t on the treacle group. When the semi-trailer is extended it operates as a permit vehicle when over 30m in length. The PBS assessment only covered the operation of the combination in the fully closed operation. Mechanical System Dynamics Pty Ltd (MSD) was commissioned to carry out a formal PBS analysis of the proposed combination.

The performance of the combination has been assessed through computer simulation (Fig 2). For analysis of the safety performance of the extendable combination, numerical models were created using the ADAMS multi-body dynamics simulation software package (MSC Software,

2006) and MSD's *Atruck™* toolbox. Analysis of longitudinal performance was performed using MSD's *GradeSIM™* software.

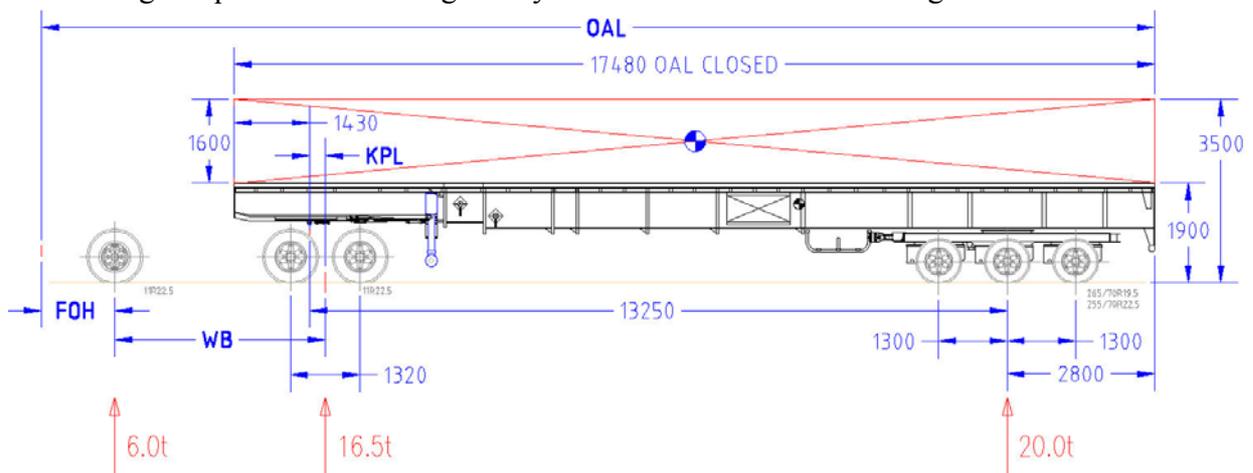


(source MSD)

**Figure 2** – Generic computer model of the innovative steerable extendable semi- trailer.

MSD obtained information and performance data from various sources including the manufacturers, Haulmark for the semi-trailer, Trackaxle Pty Ltd for the Trackaxle® steerable axle system, Hendrickson and BPW suspension suppliers for the semi-trailer suspension. Data for the prime movers was sourced from a previous major study of the performance of the Australian heavy vehicle fleet (Prem et al, 2002), and from MSD's heavy vehicle database and library. Mass properties were estimated from first principles and worst case loading was assumed (a uniform density load that fills the entire payload volume).

The development of this combination required a very close co-operation between the manufacturer, the regulator and the PBS assessor. Although, MSD has significant in-house developed modelling capabilities and expertise to estimate the likely performance of the proposed combination against the PBS standards the quality of the assessment was dependent on obtaining adequate advice on regulatory limitations and manufacturing constraints.



**Figure 3** – Dimensions of the innovative steerable extendable semi-trailer

The initial analysis considered only two different prime movers that will be coupled to the extendable semi-trailer during normal operation. In order to comply with the PBS regulatory principals and cover a wider range of prime movers that could tow the semi-trailer, additional assessments had to be carried out on a range of prime movers. These assessments analyzed the effects of potential changes in the critical prime mover dimensions including

wheelbase (WB), front overhang (FoH) and turntable position or king pin lead (KPL). The dimensions and axle loads of the combinations are illustrated in Figure 3.

Minimum and maximum values were selected for each of the three prime mover dimensions, consistent with the range that is expected to occur in-service. The parameter variations are summarised in Table 1.

**Table 1 – Variations of prime mover dimensions.**

<b>Parameter</b>	<b>Minimum</b>	<b>Maximum</b>
<b>Foh (mm)</b>	900	1500
<b>WB (mm)</b>	3530	4200
<b>KPL (mm)</b>	0	600

The Haulmark application has been through the PBS assessment and evaluation process a number of times as all design changes had to be reassessed. All these PBS assessments demonstrated that the performance of the extendable combinations meets the PBS Level 1 requirements. The proposal obtained national endorsement from the IRP which meant that a potential operator could have gained a permit for the operation of the combination from the jurisdictions.

The first trailer was manufactured in mid-2007. A PBS inspection was carried out by Queensland Transport to verify that the trailer was manufactured in accordance with the PBS specification. A low-speed swept path assessment was conducted by Queensland Transport and MSD to ensure the Performance of the combination complied with the performance predictions of the computer modelling. This assessment has been the basis of obtaining approvals in various jurisdictions for the operation of the semi-trailer.

The initial trailers performed on road as per the computer simulations suggested and in some cases the on road dynamic performance of the combinations have proven to be better than initially expected. The trailer significantly out-performed some shorter conventional prescriptive heavy vehicle combinations in the area of low speed turn manoeuvres at intersections and roundabouts. Following on-road testing and driver training the operation of the first combination commenced in Victoria in July 2007. There are now four units operating on the road network within Australia with more under construction.

**3.1 Performance of the combination**

*Safety standards*

The PBS standards correlate directly to the on-road performance of a heavy vehicle combination; therefore safety performance of the proposed combination can be quantified in absolute terms.

The PBS regulatory regime has four levels of route classification that specifies the route access for PBS vehicles. For a PBS vehicle to operate on a route having a Level 1 (L1) classification, it must meet the L1 performance requirements across all the applicable performance standards. Although the classification and establishment of the PBS network has not been completed by the time of the preparation of this paper, fundamentally the PBS route access categories are linked to the existing network categories. For instance, the

unrestricted access or PBS Level 1 network corresponds to the General Access network currently available for the operation of all heavy vehicle classes in Australia.

The safety performance of the combination vehicle was assessed by computer simulation against the specific PBS safety performance measures (NTC, 2007). The results of the PBS safety assessment are given in Table 2.

**Table 2** – PBS Assessment results...

<b>Performance Standard</b>	<b>PBS Level 1 requirement</b>	<b>Haulmark results</b>	<b>PBS compliance achieved</b>
<b>Startability (%)</b>	$\geq 15\%$	31.06%	Level 1
<b>Gradeability A (max. grade)</b>	$\geq 20\%$	31.06%	Level 1
<b>Gradeability B (max. speed on 1% grade)</b>	$\geq 80\text{km/h}$	90.5 km/h	Level 1
<b>Acceleration capability time to travel 100m (sec)</b>	$\leq 20.0$	16.9	Level 1
<b>Tracking Ability on a Straight Path (m)</b>	$\leq 2.9$	2.75	Level 1
<b>Low-Speed Swept Path Width (m)</b>	$\leq 7.4$	7.4	Level 1
<b>Frontal Swing A (prime mover) (m)</b>	$\leq 0.70$	0.57	Level 1
<b>Frontal Swing B (Semi trailer – MoD)(m)</b>	$\leq 0.40$	0.27	Level 1
<b>Frontal Swing C (Semi trailer – DoM)(m)</b>	$\leq 0.20$	-0.20	Level 1
<b>Tail Swing (m)</b>	$\leq 0.30$	0.27	Level 1
<b>Steer Tyre Friction Demand (%)</b>	$\leq 80$	37	Level 1
<b>Static Rollover Threshold</b>	$\leq 0.35\text{g}$	0.35g	Level 1
<b>Rearward Amplification</b>	$\leq 5.7\text{SRT}_{rrcu}$	0.98	Level 1
<b>High-Speed Transient Offtracking (m)</b>	$\leq 0.30\text{m}$	0.13	Level 1
<b>Yaw Damping Coefficient</b>	$\geq 0.15$	1.00	Level 1
<b>Directional Stability under Braking</b>	EBS/ABS and slack adjusters	Complies	Level 1

### ***Infrastructure Standards***

The pavement vertical loading standard limits the stress on the surface of the road. The axle group loads of the combination are consistent with General Mass Limits (GML) and the combination has a Gross Combination Mass (GCM) of 42.5 t. This complies with axle load limits for general access vehicles operating nationally. Consequently, the road wear values for the combination are acceptable and the combination complies with the PBS requirements.

The pavement horizontal loading standard controls road wear by limiting the impacts of horizontal tyre forces on the surface of the road. As the tyre forces could be critical in low-speed turns and during acceleration and up hill grades, the maximum axle spacing in an axle group is limited (i.e. if the axle spacing is larger than a set value a steerable axle must be used) and the distribution of attractive forces in a drive axle group - for a given GCM - is restricted (i.e. above a certain GCM equal torque distribution is required for a drive group). The Tyre Contact Pressure Distribution requirement of the PBS system limits the minimum tyre width and the maximum tyre pressure and pressure variations. Until further research can quantify the effects of tyre patch shape, maximum tyre pressure and tyre pressure differentials on road wear, the existing prescriptive requirements are used by PBS.

The bridge assessment has demonstrated that worst-case bridge loading from the combination for both the mid-span moment and end shear to be no greater than the corresponding Reference Vehicle across the entire range of spans considered. The combination complies with the PBS infrastructure requirements.

The PBS assessment has demonstrated that the performance of all of the combinations meet the PBS Level 1 requirements for Level 1 (L1) road network access.

#### **4. Discussions**

This project and the innovative steerable trailer developed by Haulmark Trailers and Queensland Transport has clearly demonstrated the huge potential of a performance based regulatory system by the emergence of a significantly more productive and efficient heavy vehicle configuration with much improved dynamic performance and safety.

If the extendable trailer was built to comply with the prescriptive system, the overall length of the closed trailer would have been limited to 14.6 meters and when fully extended it would have been only 30 metres long. This trailer length would require the employment of an additional 5 metre long pull out tail piece as the length of the roof sheets is approximately 35 metres. The load rating of this fully extended conventional trailer for uniformly distributed load (UDL) would be approximately 4.5t.

This PBS trailer could be built to a maximum closed length of 17.5 meters which then results in a fully extended length of almost 40 metres without having to resort to a pull out tail section. The trailer provides an additional 3 metres of deck space when closed and an additional 5 metres when fully extended without any increase in the rear overhang. The rear overhang of this trailer is only 2.8 metres. This is a significant safety benefit as similar vehicles carrying long loads normally have large rear overhangs that represent a road safety hazard.

Furthermore, due to the extra trailer length, the structural design of the trailer was optimized and it was possible to achieve a payload of 11 tonnes uniformly distributed load (UDL) at 35 metres. The trailer has a payload of 8 tonnes UDL at 40 metres, never before achieved. The payload increase of more than 50% means that for a given freight task the trip numbers can be reduced by 50%.

Although the concept has been developed for a specific freight task, it could be used for developing other applications and has the potential to improve the efficiency of heavy vehicles transporting volume-based products by approx. 20%.

## 5. PBS and Compliance Issues raised by the Manufacturer

Although a national framework was developed by the state jurisdictions for the approval of these PBS vehicles, on-going issues have made it difficult for operators and manufacturers to have flexibility within the parameters of the PBS approval.

Under the current rules of PBS system (NTC, 2007), if any one dimension or performance value alters from the value or dimension detailed in the original assessment (eg. wheelbase changes by 100mm) a complete new assessment is required and it has to be approved before the vehicle is allowed to operate. Although the current PBS system provides the ability to develop new vehicles, it lacks flexibility for variation even to the smallest degree. The process for re-evaluation and certification could be very costly and time consuming (approx A\$ 5000.00 and can take up to 12 weeks before approval is granted) which is not conducive for efficient transport operations or manufacturing processes.

As the PBS system has evolved and the state government jurisdictions have further understood the potential advantages and disadvantages of the PBS system, retrospective regulations have been placed on already approved vehicles. The original PBS system had no maximum overall length limits on vehicles relative to the level of access required, so as long as the vehicle complied with the required PBS safety and infrastructure standards (i.e. Swept path, frontal swing and tail swing) the vehicle could be designed as long as required for the freight task.

The extendable trailer developed under this proposal was approved, depending on the particular prime movers used, at up to 21.7 meters for PBS Level 1 access. Some five months later a length restriction was put in place for all PBS levels of access, in this case, a maximum overall length of 20 meters was imposed due to a perceived issue of stacking distances at intersections and railway level crossings. Consequently, the introduction of an overall length limit has significantly restricted the level of access within which this vehicle was originally designed and approved to operate.

The differences between the requirements of various permit systems could be significant and frustrating from an industry perspective. A good example is the operation of the extendable trailer. When the trailer is extended and operates as an extendable trailer (not a PBS vehicle) it has to comply with the requirements governing the operation of over dimensional vehicles. Under these rules, prime mover semi-trailer combinations up to 25 metres have access to the same network as the PBS Level 1 network with minimal restrictions (operating times, national holidays etc). This means that when the trailer is fully closed (i.e. not extended) and classified as a PBS vehicle it may not be longer than 20 meters. However when the trailer is extended and doesn't operate under the PBS requirements, it can be up to 25 meters long and operate on exactly the same road network. This anomaly has emerged due to the misalignment of operational regulations within the state regulatory system and a failure by the state jurisdictions to fully harmonize all the issues relating to operating of heavy vehicle combinations on the road networks.

In Australia there are three levels of Government: Federal, State and Local and it probably shouldn't surprise anyone that they don't always agree. The PBS system can potentially provide some very tangible efficiency gains and improved safety performance, but it could be exposed to being over-run with unnecessary operational requirements imposed by a state or local government if deemed necessary. Although the vehicles are approved nationally, the state or

local jurisdiction in which the vehicle will operate can and does impose further operating requirements on the transport operator or vehicle, sometimes with little or no justification. A further problem arises when these vehicles have to operate across borders and in these situations approval to operate must be granted by each jurisdiction; quite often they have different requirements which impose further restrictions and inefficiencies on the transport operator.

The PBS system has the potential to provide very real and necessary productivity gains and with it a significantly improved level of safety. However, there is also a very real danger of those benefits being lost due to over regulation and misalignment of government policy that will in fact potentially reduce the ability and desire of industry to embrace the PBS concept.

## **6. Conclusions**

The importance of the road freight industry to Queensland's and the national economy cannot be overstated. Australia has a significant reliance on road transport and has successfully addressed many technical issues related to the operation of innovative vehicle combinations.

Queensland Transport has pioneered the performance-based standards approach for the assessment of new heavy vehicle combinations and operations in Australia. PBS allows industry more innovation in vehicle configuration and design, whilst maintaining safety, increasing flexibility, productivity and network access for heavy and large vehicles.

The trailer is the result of the need to build a specific trailer for a very specific freight task and comply with pre-existing regulatory requirements. Although the trailer could have been built under the existing prescriptive regulatory system, utilising the new PBS Scheme, a significantly more productive and operationally safer trailer has evolved. Although the combination has been developed for a specific freight task, similar vehicle combinations can be also designed by using the concept that would deliver significant productivity and safety benefits to the road transport industry and the broader community alike.

The project has provided a unique opportunity to trial various elements of the PBS approval process and demonstrated that the PBS process can deliver innovative PBS heavy vehicle combinations with significant improvement over the conventional heavy vehicle combinations. This proposal was the first concept vehicle that has pushed the boundaries of both the PBS and prescriptive regulatory system to their limits and paved the way for other operators and manufacturers to "think outside the box" and develop new transport solutions for the growing freight tasks. This project also reflects Queensland's smart state priorities through the promotion of innovative freight vehicles and technological vehicle assessment and compliance techniques.

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