SIMULATIONS AND FIELD TESTING OF SUPER-SINGLE TYRES FOR PBS



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Abstract
This paper provides a comparison study of a B-double vehicle simulated against the Performance Based Standards (PBS) with super single and dual tyres. The difference in passing load heights was determined. Additionally, the steering performance of self-steer axles fitted with duals and super-singles was investigated by both computer simulations and field testing.

Keywords: Super Single Tyres, Dual Tyres, Swept Path, Steering, Self-Steer, B-double, Heavy Vehicles

1. Background

There was no intention initially to write this paper, it occurred naturally as a result of the findings during a PBS assessment. Smedley's Engineers conducted a Performance Based Standards (PBS) assessment on a super B-double (axle configuration: 1244) for a client who desired increased load height and improved productivity. Super-single tyres were recommended as an option to accomplish this. Super-single tyres can improve the performance of a vehicle in the following ways:

1) Improved performance in SRT which is highly sensitive to effective track width, and the effective track width / tyre vertical stiffness outcome is typically better on vehicles fitted with wide super single tyres.
2) Improved suspension roll-stiffness through wider hanger and airbag spacings. This option is available to super-single tyre vehicles due to increased track clearance. Note that not all super-single tyres are used together with the improved suspension. Some are on offset wheels that can only be used with standard track width axles and suspensions, nullifying the benefit of the wider suspension.
3) Though not applicable in this instance, increased track clearance can also facilitate lower tank centroids on tankers.
4) Reduced tare (and unsprung) mass, potentially improving payload ratio and vehicle ride.

Wide super single tyres are commonplace in other developed road freight markets, however acceptance of their use by road managers at the same axle loadings as dual tyre sets has been contingent on further local research, due to Australia's high local prevalence of spray seal road construction and high per capita share of road freight transport. As wide super single tyre adoption grows, vehicle performance measures previously well understood with dual tyre sets – especially those of high relevance in Australia due to the PBS scheme - require re-evaluation in the context of wide super single tyres.

The client agreed to investigate super singles and the assessment covered dual tyres as well as single tyres with both the standard suspension and the wide suspension. The passing load heights for all three cases were determined.

During the assessment, the authors discovered a steering phenomenon that was not found previously addressed in a literature search. Where wide super-single tyres are fitted to self-steer axles, the axles self-steered less compared to when dual tyres were fitted; resulting in a worse low-speed swept path (LSSP). The difference was large enough to change the LSSP result from a pass to a clear failure. In the process of investigating this phenomenon, a method was identified by which the performance of the self-steer axles with super-single tyres can be brought back to similar levels to dual tyres.

2. Assessment Method

The vehicle was assessed by computer simulation using MSC Adams Car, a multi-body vehicle dynamics software package. Our assessment methods and software have been validated by the

National Heavy Vehicle Regulator (of Australia) (NHVR) to provide a reasonable representation of the real vehicle. Additionally, we are accredited as a PBS assessor by the NHVR.

In our models, longitudinal tyre forces and slip are simulated. It is worth noting that these forces do not need to be considered under the PBS rules. By default, our assessments take these into account to make them more realistic. The self-steer axle was assessed using actual geometry and self-align torque data supplied by the manufacturer rather than using assumptions.

The authors believe that diligence in incorporating the aforementioned assumptions and specifications is what led to detection of the steering phenomena during the computer simulations. If these factors were not considered (especially the first factor) then the phenomena would be missed or simulated to a different degree than reality. The current PBS rules specify that modelling longitudinal tyre forces is optional and they do not explicitly state self-steer axles should be modelled with their actual geometry and self-align torque. This conceivably creates an opportunity for an assessor to incorrectly model self-steer axle performance, especially when fitted with super-singles which are more sensitive.

Once the steering phenomena was identified, physical swept path field testing was undertaken to validate the findings. The field tests were conducted unladen and back-to-back with both super-single and dual tyres.

3. Vehicle specifications

The subject vehicle was a 30 m long ‘super’ B-double with axle configuration 1244, assessed at loads up to 77.5 t GCM. The multi-deck trailers had two self-steer axles on the rear of the lead trailer and one self-steer axle on the rear of the tag trailer, see Figure 1.

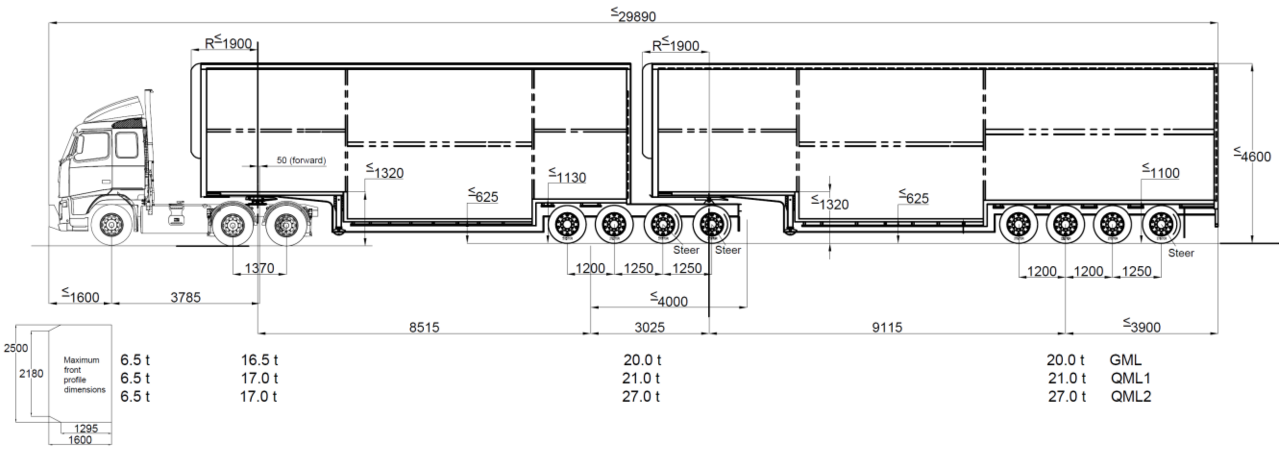

Figure 1: Vehicle dimensions with multi-deck trailers

The suspension, tyre and axle specifications were as per Table 1.

Table 1: Axle, suspension and tyre specifications

Specification	Wheels	Axle position			
		Lead trailer - fixed	Lead trailer - steerable	Tag trailer - fixed	Tag trailer - steerable
Axle track (mm)	Duals	1840	1840	1840	1840
	Singles with offset wheels	2023	2023	2023	2023
	Singles with wide track axle	2016	2023	2016	2023
Suspension hanger spacing	Duals	Standard	Standard	Standard	Standard
	Singles with offset wheels	Standard	Standard	Standard	Standard
	Singles with wide track axle	Wide	Standard*	Wide	Standard*
Tyre size	Duals	275/70R22.5	275/70R22.5	275/70R22.5	275/70R22.5
	Singles with offset wheels	385/55R22.5	385/55R22.5	385/55R22.5	385/55R22.5
	Singles with wide track axle	385/55R22.5	385/55R22.5	385/55R22.5	385/55R22.5
Tyre stiffness, per tyre, kN/m	Duals	800	800	800	800
	Singles with offset wheels	914	914	914	914
	Singles with wide track axle	914	914	914	914

* Steerable axles with wide track width were not available at the time the testing was undertaken

4. Results

We split the results into two sub-sections. First, we present a comparison of the load heights and PBS results with dual tyres vs super singles. Second, we look at the steering phenomenon identified in the comparison.

4.1 PBS results comparison

In this section the authors investigated how high we can make the load height and still pass the PBS standards. The load heights were determined solely from the computer simulations and were optimised so that the vehicle narrowly passed the PBS Static Rollover Threshold (SRT) standard (which was the main standard limiting the load height). The load heights were based on the vehicle carrying the maximum amount of mass (worst-case) allowed by the assessment which was 77.5 t GCM under QML2 axle loads.

Whilst this paper was based on a real PBS assessment, some of the assumptions for modelling undertaken for this paper were modified so that both the super single and dual tyre simulations used the same assumptions, to facilitate a direct comparison focused on the phenomenon. In the actual assessment, the dual tyre simulations and single tyre simulations were conducted at different times and the dual tyre simulations used previous generation assumptions for some parameters (most notably fifth wheel lash). For this paper the authors were interested purely in the difference between duals and singles and so all the assumptions were commonized, except for load heights and the specifications in Table 1. This means that some of the load heights in this paper no longer match the original assessment.

For the simulations, the duals and singles used the same make and model of tyre and additionally the tyre data was produced by the same test method. Unfortunately, in the field test the tyre model of the duals was different to the singles (but still the same make and similar model). In the original assessment there were multiple sizes and tyre makes and models simulated. The single make/model approach in this paper was chosen so that the effect of different tyre makes and models does not obfuscate the performance difference between the dual tyres and the super singles.

Based on Table 2 we found that a higher payload height is obtainable under PBS if the vehicle was fitted with super-single tyres. This was the case even if the standard suspension hanger width was used. The benefits were greater when the wide hanger suspension was used.

Table 2: Comparison of maximum passing load height, duals vs super-singles

Wheel/axle specification	Maximum load height from ground (mm)
Duals	3990
Offset singles with standard track axles	4070
Singles with wide track axles/suspension	4110

Load height improved by 80 mm with super-single tyres and 120 mm with super-single tyres and wide hanger suspension. In this study the load height is based on Uniform Density (UD) freight for which the load COG height is assumed to be 50% of the load height.
Using the load heights from Table 2 (for which the vehicle narrowly passed SRT) the authors also examined the PBS swept path and dynamic standards results for both the duals and singles. This comparison is shown in Table 3.

Table 3: Comparison of PBS swept path, SRT and dynamic results, duals vs super singles

PBS standard	Duals	Super singles	
		Offset wheels, standard suspension	Non-Offset wheels, wide suspension
TASP (m)	2.79	2.78	2.78
LSSP (m)	8.49	8.78	8.78
FS (m)	0.51	0.51	0.51
MoD (m)	0.31	0.36	0.36
DoM (m)	-0.05	-0.02	-0.02
TS (m)	0.08	0.07	0.07
STFD (%)	30	31	31
SRT (g)	0.351	0.350	0.350
HSTO (m)	0.28	0.27	0.27
RA	0.76	0.8	0.78
YDC	0.35	0.38	0.38

Most of the results with the super single tyres were very similar to the dual tyres however this was because load heights for each case were adjusted until the vehicle just passed SRT. There were some exceptions; Yaw Damping Coefficient (YDC), LSSP, Maximum of Difference (MoD) and Difference of Maxima (DoM):

- For YDC, super singles were better. But it should be noted that damping was extremely good and therefore only two yaw rate peaks were able to be used in the calculations, having only two peaks means that the YDC calculation is not very accurate.
- LSSP was noticeably worse with the super singles and failed the PBS Level 2 requirement of no more than 8.7 m. This was due to the self-steer axles with super singles steering less than with duals. The vehicle failing Level 2 LSSP (which did happen in the actual assessment) was a big issue for the operator and an investigation was conducted to find out why the super singles were producing this result and how to fix it.
- MoD and DoM were also worse with super singles for the same reason as LSSP.

4.2 Steering Phenomena

With super singles the swept path of the subject vehicle was worse than with duals because the self-steer axles with super singles did not turn as much as with duals. The cause was determined to be that the duals had a higher self-aligning moment which helped them steer better.

For axle groups with self-steer axles, the center of vehicle yaw rotation is near to the center of the fixed axles; in fact it is just behind. For example, for the lead trailer on the subject vehicle it would be near the center of the two fixed axles. See Figure 2. To track the radius of the turn (and improve swept path) the wheels need to steer about their kingpins as per the green lines. The pink lines show the actual orientation of the wheels (this has been exaggerated so the angle is more noticeable, the actual slip angle is only a few degrees depending on axle and wheel end). A higher self-aligning moment (Mz) exhibited by a tyre will try to turn the wheels (pink line) towards the green line, improving steering. It tries to make the axles turn as shown in Figure 3.

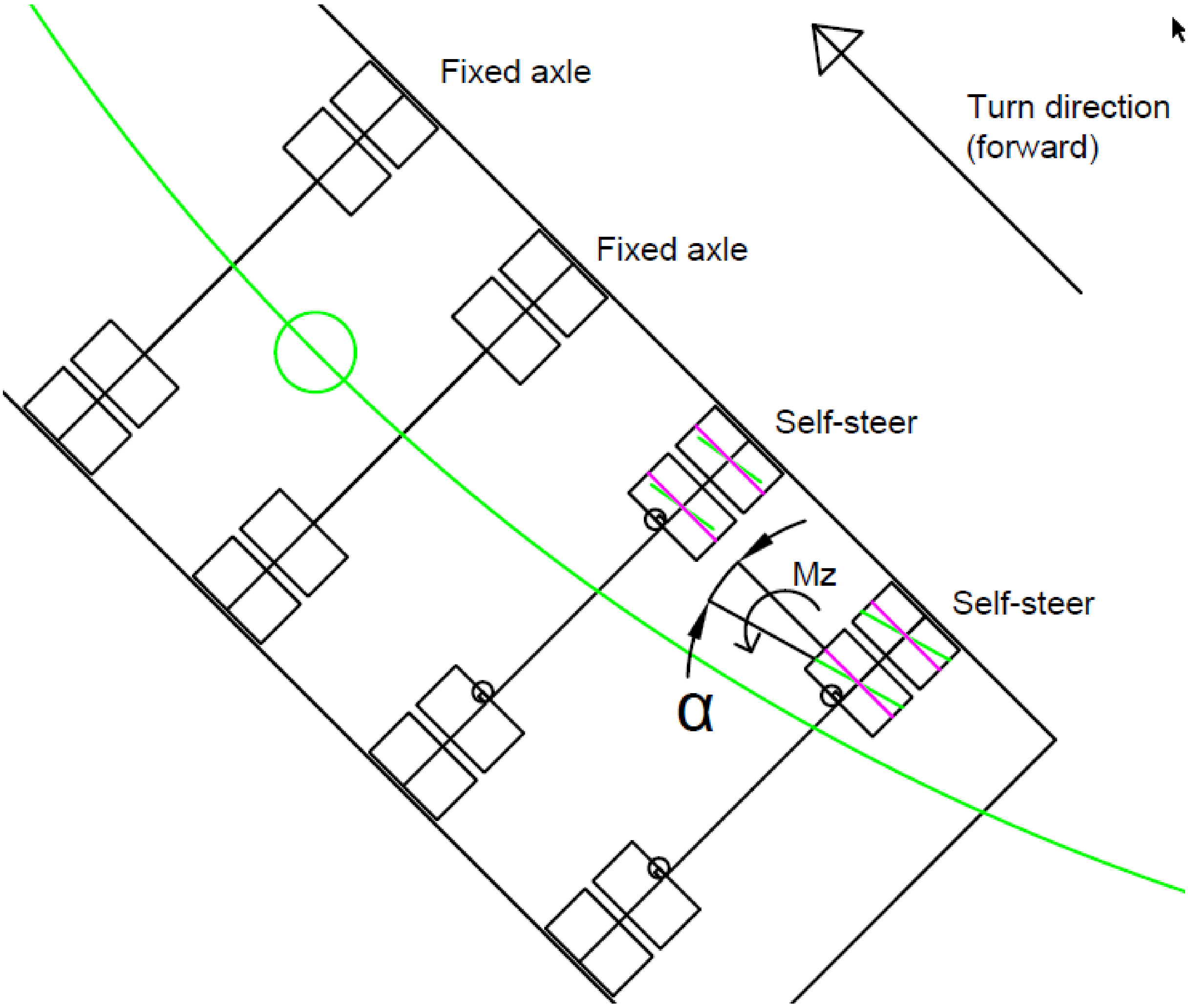

Figure 2: Bird's eye view of lead trailer showing exagerrated slip angle (α) in self steer axles when not steering well.

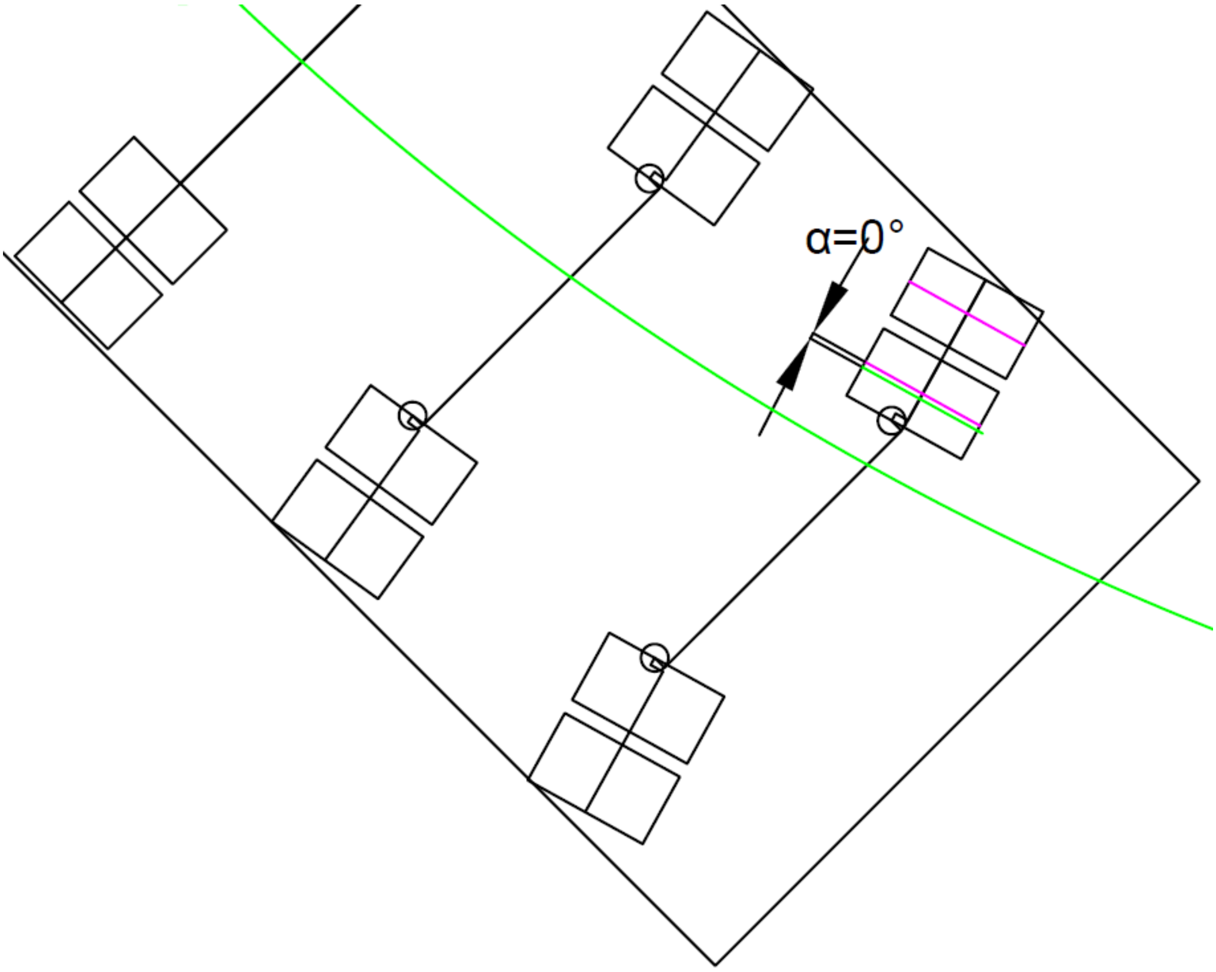

Figure 3: Bird's eye view of lead trailer showing self-steer axles steered to ideal position

The self-aligning moment of the singles was less than that of the dual tyres (due to a combination of differences in total effective contact patch width, and the lateral position of the centre of each tyre relative to the kingpin). Therefore, the singles don't turn as much towards the green line as the duals and cause the vehicle to have a wider swept path.

1.1.1. Steering Phenomena – Mitigation

With the cause identified, the authors needed to find a way for the super singles to turn the self-steer axles as effectively as the duals. The selected resolution was to reduce the pressure in the self-steer axles' self-centering airbags. Self-steer axles typically possess a mechanism to re-centre them after a turn. In the case of the subject vehicle this mechanism was an airbag at the front of the axle, an example of this is shown in Figure 4.

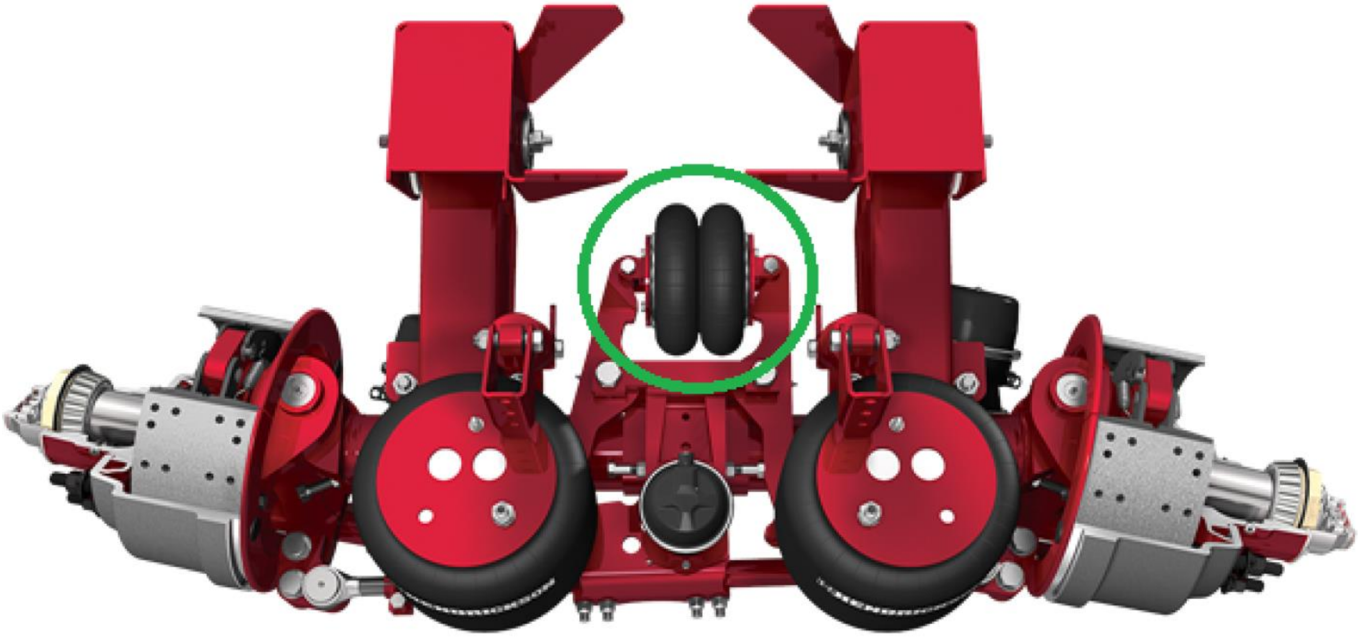

Figure 4: Plan view of example self-steer axle with an airbag centering mechanism

As the axle ends steer, they compress the airbag which tries to push them back to center. The higher the pressure in the airbag, the higher the return-to-centre force. In the case of the subject vehicle the pressure was 20PSI unladen and when laden it increased based on vertical load up to 80 PSI. This is the default manufacturer setting and by default the same setting is used for dual tyres and super singles. The centering moment vs airbag pressure vs vertical load was supplied to us by the manufacturer.

We found that reducing the pressure in the airbag with the super singles helped them match the dual tyre steering performance. Based on computer simulations, we found that by dropping the pressure to 20 PSI laden and 8 PSI unladen, the self-steer axles with super-single tyres exhibited equivalent LSSP performance to those fitted with dual tyres.

Field testing was performed to validate this finding. The field testing, see Figure 5, was only performed on the unladen vehicle due to budget and time constraints. The self-steer axles were fitted with string-pots (which measure displacement), see Figure 6, and this was converted into a steer angle, see Figure 7.

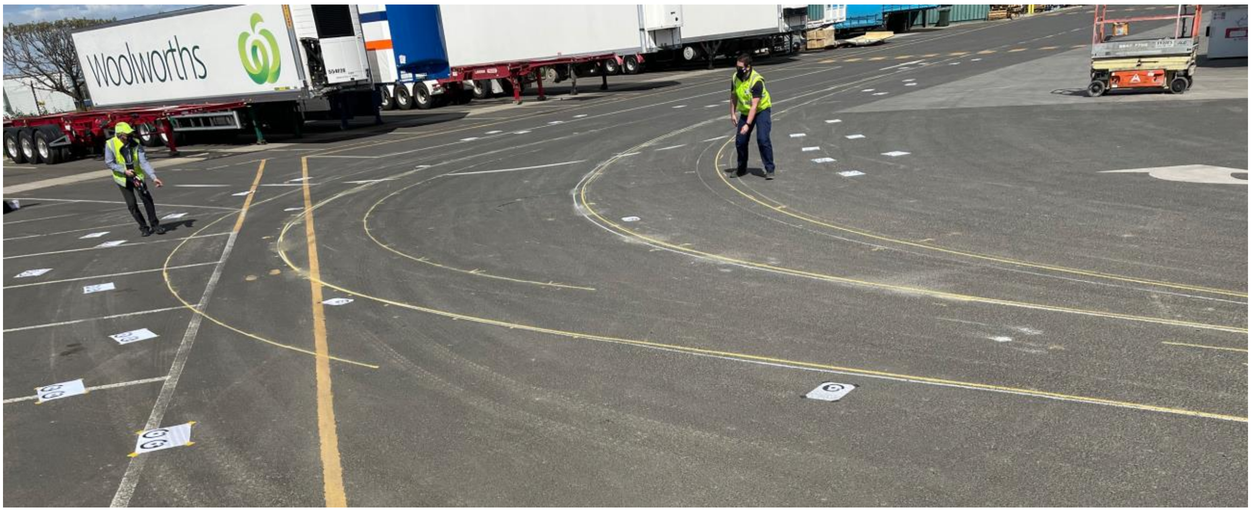

Figure 5: Trailer manufactuer and suspension/axle manufacturer helping out during the field tests.

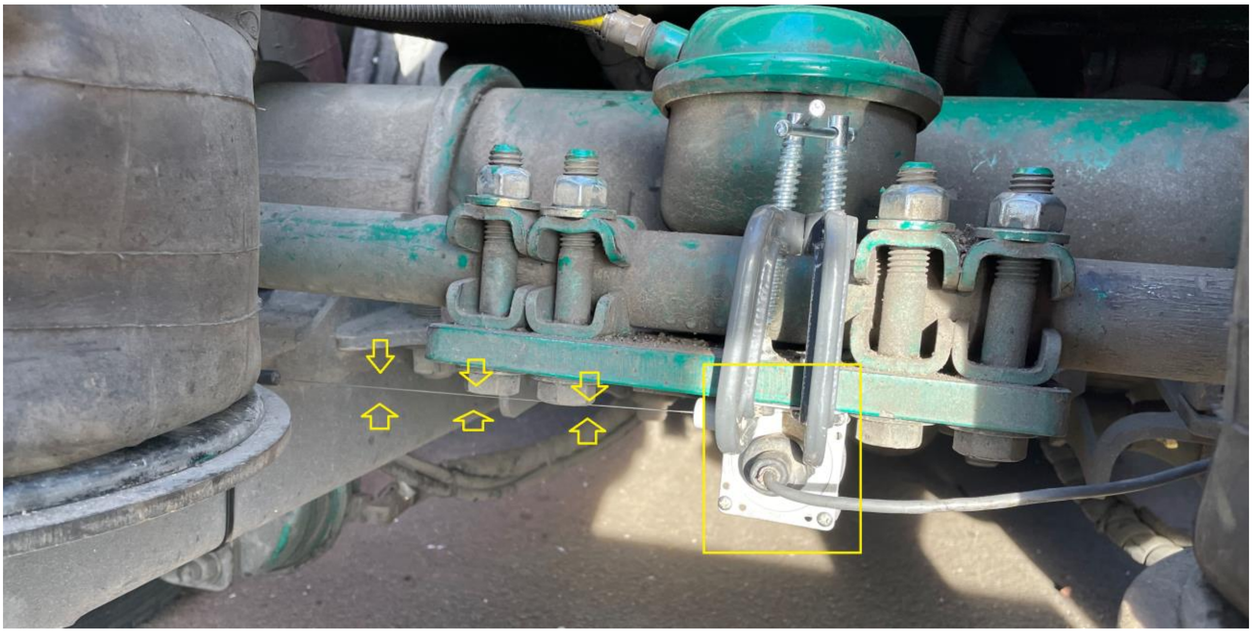

Figure 6: String pot placement

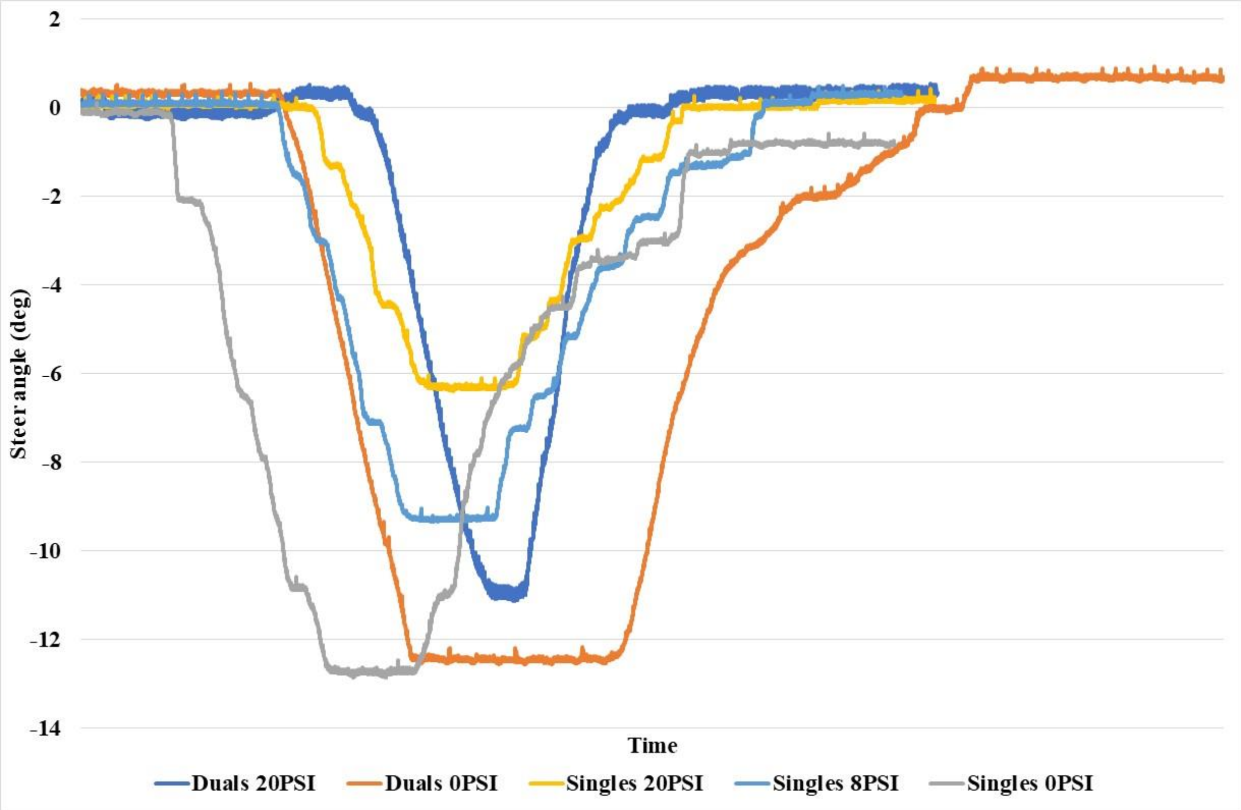

Figure 7: Steer angles of self-steer axles recorded during field tests

For dual tyres, increasing the pressure in the active-align airbag from 0 PSI to 20 PSI had a negligible effect on the peak steer angle. However, this was not true for the super-single tyres. For super-single tyres, when the pressure in the airbag was increased from 0 PSI to 20 PSI, the steering angle halved and therefore the self-steer axles would only be half as effective. When pressure was decreased down to 8 PSI (as used in the simulations), the steer angle increased to almost the same level as the dual tyres (83% effective).

The required pressure reduction was also determined for the laden case, however only by computer simulations, no laden field tests were done. The laden pressure with the singles needed to be set to 20 PSI to match the duals, normally it depends on the vertical load and can go up to 80 PSI. For this specific vehicle operating at QML2 axle loads it would have been around 62 PSI.

These findings only apply to the specific self-steer axle and suspension fitted to the subject vehicle. However, similar trends can be expected in other self-steer axles fitted with self-centering mechanisms. When the authors first identified this steering phenomenon, it was unknown to the suspension and axle manufacturer. Other vehicles which have super-single tyres fitted to self-steer axles may be under-performing in swept path if the active-align torque is not adjusted to compensate.

The effect of lowering the self-align torque on high-speed dynamic performance was not investigated because for these combinations the self-steer axles were locked at high speed (they are prevented from steering). This speed is usually 30 or 40 km/h. This is a common practice and means there should be no effect on high-speed standards provided the self-steer axles are locked.

5. Conclusion

When super-singles were fitted to the trailer axles the load heights improved by 80 mm with offset singles with standard track axles and by 120 mm with wide track axles (fitted with wide hanger suspensions).

It was also found that the self-steer axles steered significantly less with super singles than with duals. A lower pressure in the self-centering airbag was required to bring the steering performance with the super singles back to the same level as with the duals. In the laden case the pressure was reduced from 62 PSI to 20 PSI and in the unladen case from 20 PSI to 8 PSI. Lowering the pressure is important because if operators don’t lower it then the swept path of the vehicle would suffer defeating the whole point of self-steer axles. It is expected that the degree of pressure reduction depends on the specific make and model of the self-steer axles and the specifications of the vehicle.

Additionally, we are aware of self-steer axles that use other mechanisms to center the axle than airbags and, in these cases, lowering the pressure will not work. Investigating self-steer axles with other centering mechanisms was out of scope however we do have data for some of these axles and their self-centering force is much lower than axles with airbag centering. Therefore, it is expected the steering phenomenon would have less effect, however, this is based on just a few makes and models.

References

- National Transport Commission (NTC), (2020). “Performance-based standards scheme – the standards and vehicle assessment rules”.