



# Validation of the Performance of the proposed 23m B-train Pro-forma Design

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## INTRODUCTION

As part of the process of developing the New Zealand Performance Based Standards system for managing vehicle size and weight, the Truck Trailer Manufacturers Federation (TTMF) commissioned the development of a new pro-forma B-train design that complies with the proposed new PBS requirements. The NZTA has approved the construction of two prototype vehicles built this new pro-forma design. The first of these was built by Roadmaster Trailers for Vowles Transport and came into service in December 2018.

One of the purposes of permitting the prototypes to be built was to enable them to be physically tested with the measured response able to be compared to the computer simulation results. The focus of this validation testing is the low speed turning performance. One of the main concerns with allowing longer vehicles to operate on the network is that they might require additional road space when cornering which would be a safety issue on narrow winding roads.

The pass/fail criteria for low speed turning performance in the new PBS scheme have been set at levels where the PBS vehicles should be superior in performance to the worst case standard legal vehicles. The current pro-forma designs are based on the vehicles being equal in performance to the worst-case standard legal vehicles so the new PBS scheme is more demanding on low speed turning performance.

This report describes the validation testing undertaken on the Vowles Transport B-train in Morrinsville on the Thursday, 21<sup>st</sup> February, 2019. The validation trial consisted of three components:

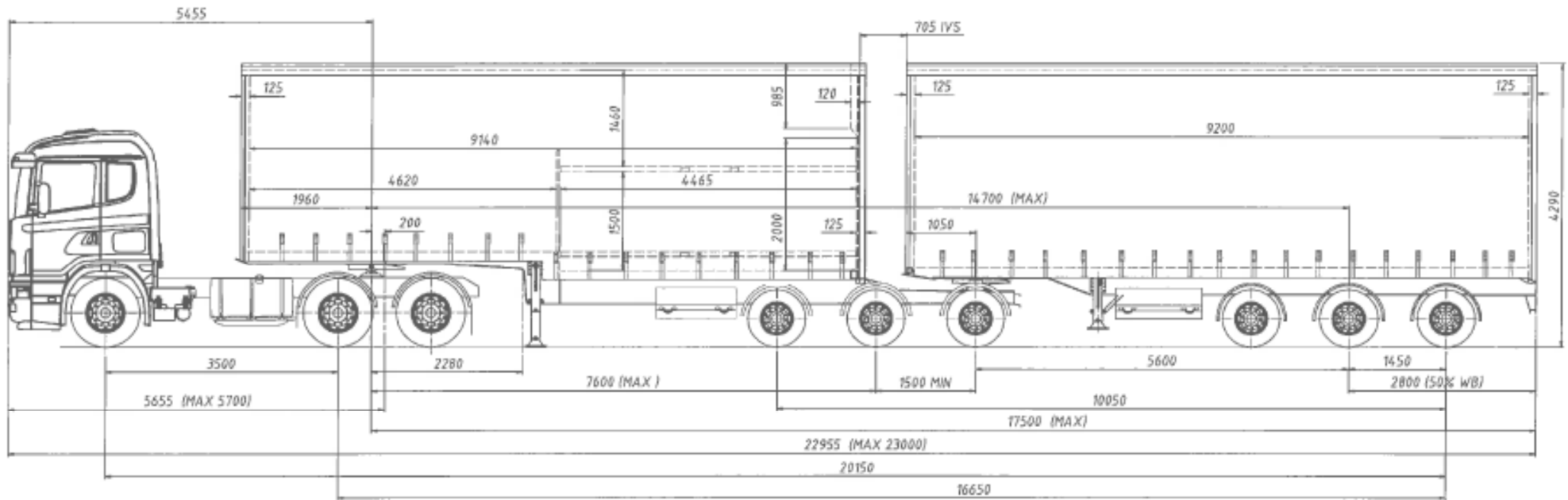
- Low speed turning performance measurements
- On-road observations with video recording of the vehicle in a mix of road environments including some tight curves
- Informal interviews with the drivers on their experience with the new vehicle.

## THE TEST VEHICLE

The Vowles Transport B-train during the low speed steady turning manoeuvre is pictured in Figure 1. Figure 2 shows a layout drawing of this vehicle supplied by Roadmaster Trailers who built the vehicle.



Figure 1. Vowles Transport B-train.



NOTE: Limited maximum wheelbase ratio :-  $7600 / 5600 = 1.36$

Figure 2. Layout drawing of Vowles Transport B-train supplied by Roadmaster Trailers.

The layout drawing is based on using a Scania tractor. The validation tests were undertaken with a Kenworth tractor which has a similar forward length but this is comprised of a longer wheelbase and a shorter front overhang. The differences in the key tractor dimensions are shown in Table 1. Note that both tractors meet all of the requirements of the proposed pro-forma design. The trailer dimensions were also checked and these were exactly as shown in the drawing (Figure 2).

**Table 1. Differences in dimensions between tractor shown in the drawing and the actual tractor used.**

Dimension	Scania tractor as shown in Figure 2	Kenworth tractor as measured
Forward length	5655mm	5680mm
Front overhang	1455mm	940mm
Wheelbase	4200mm	4740mm

The vehicle was tested in an unladen state. For low speed turning performance and for lower speed highway curves this is conservative. The off-tracking experienced by a vehicle is the combined effect of the low speed off-tracking generated by the vehicle's geometric configuration which is on the inboard side of the turn and the high speed off-tracking which is generated by the lateral acceleration of the vehicle due to cornering forces. High speed off-tracking occurs on the outboard side of the turn. This high speed off-tracking component increases with vehicle weight and so is at a minimum when the vehicle is unladen

The PBS low speed turning manoeuvres are undertaken at very low speeds so that the high speed off-tracking component is very small anyway. Thus the difference in low speed off-tracking between a laden and an unladen vehicle is very small but the unladen vehicle will have slightly greater low speed off-tracking. For the lower speed highway curves, the low speed turning effect dominates but the high speed effect is not negligible and it will be less for the unladen vehicle so the off-tracking will be worse.

## LOW SPEED TURNING TESTS

The draft New Zealand PBS system includes two low speed turning manoeuvres. One is the standard 12.5m outside radius 90° turn used in the Australian PBS system where the path is followed by the outer face of the outside steer tyre (kerb-to-kerb turn). Three main performance measures are determined from this manoeuvre; low speed swept width, tail swing and frontal swing. The second manoeuvre is a 25m outside radius 360° turn where the path is followed by the outermost front corner of the truck (wall-to-wall turn). One performance measure, steady state low speed swept width, is evaluated during his manoeuvre.

The original intention was to conduct both these manoeuvres with the test vehicle and to measure the four performance measures. These could then be compared with the values obtained by computer simulation. The test facility proposed by Vowles Transport was the Morrinsville Saleyards which has a very large parking area for stock trucks. This would have been large enough but unfortunately there was a stock sale being held on the day that Vowles were unaware of and a number of stock truck and trailer vehicles were parked in the yard. The remaining available space was not large enough to undertake the 25m radius turn and thus the 25m radius turn was replaced by a 20m radius turn.

The truck was fitted with pressurised water sprayer units on the right front corner and in line with the outside edge of the left rear trailer axle group. These sprayers were activated during each test and traced out the path followed by the respective points on the vehicle. In addition a wand was strapped to the outside right edge of the rear corner of the vehicle to indicate the tail swing. The location on the ground of the projection of the wand during the turn was marked manually with pavement chalk. Figure 3 shows the two sprayers and the wand during a test.



Figure 3. Sprayer units and tail swing wand fitted to the test vehicle.

The driver initially had some difficulty in following the target path accurately particularly on the exit of the 90° turn. This mostly affects the frontal swing measurement which is measured relative to the target path. The swept width measurement records the distance between the inner and outer vehicle tracks and thus is less affected by small deviations from the target path. Like frontal swing, tail swing is measured relative to the target path but tail swing occurs at the start of the turn.

In all five runs of the 12.5m radius 90° turn were undertaken but the first one was discarded due to poor path following. The results of these measurements are summarised in Table 2 below. The swept width values are all well within 1% of the average. The frontal swing values are more variable because of the difficulties in following the path at the exit of the turn. The tail swing results also show some variability. In part this is because the driver was lining up the path using the outside edge of the right steer tyre but the steer axle is at least 100mm narrower than the trailers and so the corner of the trailer was typically already 50mm over the edge of the path at the start of the manoeuvre. Part of the problem was that he had work around the stock trucks that were parked in the yard.

**Table 2. Summary of measurement results for 12.5m outside radius 90° turn.**

Performance Measure	Measurement				Average
	1	2	3	4	
Low Speed Swept Width (m)	6.69	6.78	6.76	6.69	6.73
Tail Swing (m) - Load	0.00	0.18	0.11	0.20	0.12
Frontal Swing (m)	0.52	0.60	0.54	0.40	0.52

For the 20m outside radius turn, the only measurement taken was swept width. Eight readings were taken and these are summarised in Table 3.

**Table 3. Summary of measurement results for 20m outside radius steady state turn.**

Performance Measure	Measurement								Average
	1	2	3	4	5	6	7	8	
Steady State Swept Width (m)	5.70	5.75	5.80	5.82	5.76	5.77	5.79	5.78	5.77

## COMPUTER SIMULATION MODELLING

In order to get its HPMV permit the test vehicle had already been modelled using the Yaw-Roll multibody simulation package and had been assessed using the proposed new NZ PBS system. The results of this performance assessment are shown in Table 4.

**Table 4. Performance assessment of the test vehicle at full load using proposed new PBS.**

Performance Measure	Acceptability Level	
Low Speed Swept Width (m)	Less than 6.95	6.88
Tail Swing (m) - Load	Less than 0.3	0.05
Frontal Swing (m)	Less than 0.75	0.52
Steer-Tyre Friction Demand	Less than 0.50	0.29
Steady State Low Speed Swept Width (m)	Less than 5.20	5.00
High Speed Offtracking at 0.2g (m)	Less than 0.46	0.40
High Speed Offtracking at 0.25g (m)	Less than 0.68	0.58
Static Rollover Threshold (g)	Greater than 0.35	0.39
Dynamic Load Transfer Ratio	Less than 0.6 (0.7)	0.39

Rearward Amplification	Less than 2	1.75
High Speed Transient Offtracking (m)	Less than 0.6	0.40
Yaw Damping Ratio (%)	Greater than 15	20

The test conditions for this simulation were slightly different from those at trial. Specifically, for the original simulation the vehicle was loaded to 57 tonnes while the trial was conducted with an unladen vehicle. Furthermore the Steady State Load Speed Swept Width measure is based on a 25m radius turn while at the trial we could only undertake a 20m radius turn.

Thus, for validating the test, the model data was adjusted to match the test conditions and the relevant performance measures were evaluated. For simulations of on-road behaviour we generally assume that the tyre-road friction coefficient is 0.8. Because the trial was conducted on an unsealed surface we also simulated a lower friction coefficient of 0.6. The results of this assessment are shown in Table 5. As can be seen the effect of reducing the friction coefficient was minimal.

**Table 5. Performance assessment of the test vehicle as tested using proposed new PBS.**

Performance Measure	Unladen Vowles B-train	
	Friction 0.8	Friction 0.6
Low Speed Swept Width (m)	6.91	6.93
Tail Swing (m) - Load	0.04	0.04
Frontal Swing (m)	0.53	0.53
Steady State Low Speed Swept Width (m) - 20m radius turn	5.76	5.77

Referring back to Table 2 and Table 3, we can compare the simulated results with the measured results.

The simulated result for low speed swept width is 2.6% higher than the measured result. This is reasonably close and the simulation result is conservative. This is consistent with other validation trials that we have conducted in the past where generally the vehicle's measured performance has been slightly better than predicted by the simulation.

For tail swing the simulation and the measurements differ by about 80mm but the absolute values are quite small. Because of the constraints of the test venue, the alignment of the vehicle at the start of the test manoeuvre was not always ideal and this will have introduced some error.

For frontal swing the simulation result and the average measured value were within 10mm of each other. There was quite a bit of variability between test runs which was the result of difficulties in following the prescribed path in a constrained environment. However, the match between the average measured value and the simulation value was very good.

The required path for the steady state low speed turn was easier for the driver to achieve because once he had the steering wheel position right, very little adjustment was needed to maintain the constant radius turn. The match between the measured and simulated results for this performance measure was excellent.

Overall the match between the measurements and the simulations is quite good. For the 90° turning manoeuvre, we were somewhat constrained by the presence of parked trucks and the entry and exit paths which determine tail swing and front swing respectively were not able to be followed as precisely as we would have liked.

## ON-ROAD PERFORMANCE

The vehicle was followed by car on a trip from the Morrinsville Saleyards via Studholme St and Morrinsville-Tahuna Rd to Tahuna. From Tahuna, it followed Pioneer Rd to State Highway 27 and then north to the roundabout at the junction of State Highway 2 and State Highway 25. The vehicle completed a full circle of the roundabout and returned to Morrinsville the way that it came via State Highway 2 and State Highway 27 with a minor variation in that rather than taking Pioneer Rd to Tahuna, we continued and turned right at the roundabout at the junction of State Highway 27 and the Paeroa-Tahuna Rd in order to re-join the Morrinsville-Tahuna



Rd just south of Tahuna. The total trip distance was approximately 100km. The route was chosen because it included a winding hilly section at Kaihere on State Highway 27 as well as the two roundabouts.

The vehicle was videoed throughout the trip using a Panasonic NV GS400 video camera. It tracked extremely well with no trailer sway at any time. On the curves, it was able to stay well within its lane and provided good clearance to the centreline. Figure 4 shows a still taken from the video of the vehicle in a left hand 35 km/h curve while Figure 5 shows it on a right hand 35 km/h curve. As can be seen the lanes are quite narrow but the vehicle had no difficulties in staying well within them and allowing adequate clearance for any similar oncoming vehicle.



Figure 4. Traversing a left hand 35 km/h advisory speed curve.



Figure 5. Traversing a right hand 35 km/h advisory speed curve.

Figure 6 shows the vehicle meeting an oncoming truck and trailer while travelling through a 35 km/h curve. The driver has positioned the vehicle so that the trailers have crossed the fog-line on the left hand side of the road but they are still comfortably on the hard shoulder. The clearance between the two trucks is comfortable and there was no indication from either the path taken or the vehicle speeds that either driver had any concerns.



Figure 6. Traversing a 35km/h curve with an oncoming truck and trailer.

Figure 7 shows the vehicle on a moderate curve with an oncoming car. The curve had no posted advisory speed but it immediately followed a 35 km/h curve and is on an uphill gradient. The criteria for posting an advisory speed sign are based on both the severity of the curve and the 85<sup>th</sup> percentile vehicle approach speed. Thus the fact that there is no advisory speed sign does not mean that it is a high speed curve. What is notable about this image is that the car is giving the truck an unnecessarily wide berth. This may simply be the car driver cutting the corner to reduce the effective curvature or it may be excessive caution.



Figure 7. Traversing a moderate curve with an oncoming car.

. Figure 8 shows the vehicle undertaking a right turn on roundabout and again there are clearly no issue with road space.



Figure 8. Undertaking a right turn on the roundabout at the junction of SH27 and Paeroa-Tahuna Rd.

## DRIVER PERCEPTIONS

In the previous validation test on the log truck pro-forma design we undertake a formal survey of the drivers who had been driving the vehicles. However, in the case of the log trucks a number of these vehicles had been operating for over a year and thus there were a significant number of drivers with experience in using them. The survey had eight respondents and although this is not a large sample it is big enough to get a range of views.

The Vowles B-train, on the other hand was only delivered to the company in December so the amount of driver experience with the vehicle is much less and there is no scope for any statistical analysis. Thus no formal driver survey was undertaken. Instead informal interviews with the drivers were undertaken and their perceptions of the vehicle are reported here.

The driver for the trial was not the regular driver of the vehicle and had not previously driven it. Thus his perceptions are based on his experience on the day which involved about 100km of driving. This driver had eight years of heavy driving experience but four years of that was on buses. His truck driving experience includes all the common types on combination vehicles (tractor-semitrailers, truck and full trailer and B-trains). His perception of the low speed turning performance of the test vehicle was that it was very good. He rated it as better than a quad-axle semi-trailer, better than the older 20m B-trains, similar to a 23m bulk truck and trailer and better than a 23m curtainsider truck and trailer. The other comment that he made was that with many of older vehicles you need to watch the mirrors through low speed turns to watch where the trailers were going while this vehicle tracked so well that this was not necessary.

Subsequently I undertook a telephone interview with the regular driver of the vehicle. This driver has 21 years of professional driving experience and has driven all of the common combination vehicle configurations. His view was that the low speed turning performance of this vehicle was markedly better than a quad semi-trailer. He thought that the off-tracking was probably slightly worse than the old 20m B-trains due to the additional length but slightly better than the current 23m B-trains. When I asked him for a comparison with 23m truck and trailer curtainsiders, he thought that it might be slightly worse but that there was very little difference. He thought that the high speed tracking was excellent. The vehicle does two Auckland-Christchurch return trips per week and thus it travels through some of the more challenging curves on State Highway 1 including the Kaikoura coast road and around Lake Taupo. In his opinion the vehicle tracks well through these curves. He also noted that he has been monitoring the tyre wear and this is very good. He had thought that the larger spreads on the tridem groups might increase tyre wear but this does not appear to have happened.

## CONCLUSIONS

The match between the computer simulation results and the measured results for low speed turning performance was excellent for the swept width during the steady state turn. For the 90° turn, the frontal swing result was very good, the low speed swept width result was reasonably good (low by 2.6%) and the tail swing result was inconsistent although the absolute level of tail swing is very low.

Because of the constraints of the test venue, there were some difficulties for driver in following the path of the 90° turn which will have affected the tail swing results. For low speed swept width in the 90° turn the result is conservative with the measured value being lower than the computer simulation result. This is consistent with previous testing that we have undertaken. Interestingly the steady state turn results were close to a perfect match. Thus, it seems likely that the computer simulation modelling does not exactly model the development of off-tracking perfectly. This may be related to how tyre properties are modelled. Fortunately the computer simulation is conservative and thus the actual performance of the vehicles will be slightly better than predicted. Note that the difference was only 2.6% for this vehicle.

The on-road video monitoring showed excellent tracking performance. The vehicle was tested in an unladen state which would be expected to increase the inboard off-tracking on tight corners and might make the vehicle track less well. In terms of the straight line tracking there was no visible effect. The tracking was excellent. On the tight corners, the vehicle's tracking was also very good. It was able to stay well within its lane on 35 km/h corners and leave ample space for oncoming vehicles.

The driver perception part of this validation exercise was based on informal interviews with two drivers. One of these drivers was the driver who undertook the validation testing with us. Although he has had experience with the full range of combination vehicles he had not previously driven this vehicle. The other driver interviewed was the regular driver of the vehicle. He was considerably more experienced and like the first has had experience with all configurations of combination vehicle.

There were some minor differences in the perceptions of the two drivers but overall they were very similar. Both commented that the low speed turning performance of the B-train was significantly better than a 19m quad semitrailer combination and a little better than the older 23m B-trains. The comparisons with 20m B-trains and 23m truck and trailer combinations were a little less consistent but the differences between the new vehicle and these combinations were considered small. Both drivers commented on how well the vehicle tracked at speed and both had a very positive view of the vehicle and its performance. It should be noted of course that this was a new vehicle and so everything was in very good condition so a degree of positivity is to be expected.

Overall the vehicle appears to be performing well. Overall the match between the computer simulation results and the measured results is quite good. Where there is a difference, the computer simulation results are conservative.