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Validation of the Performance of the proposed 23m 10-axle 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 two new pro-forma B-train designs that comply with the proposed new PBS requirements. The NZTA has approved the construction of two prototype vehicles – one built each of the two new pro-forma designs. The first of these was a 9-axle B1233 combination built by Roadmaster Trailers for Vowles Transport which came into service in December 2018. The second of these is a 10-axle B1243 combination built by Fruehauf Trailers for K&S Freighters which was completed in March 2019.

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 K&S Freighters 10-axle B-train in Morrinsville and Rotorua on Wednesday, 27th March and Thursday 28th March, 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 K&S Freighters 10-axle B-train is pictured in Figure 1. Figure 2 shows a layout drawing of this vehicle supplied by Fruehauf Trailers who built the vehicle.

Figure 1. K&S Freighters B-train.

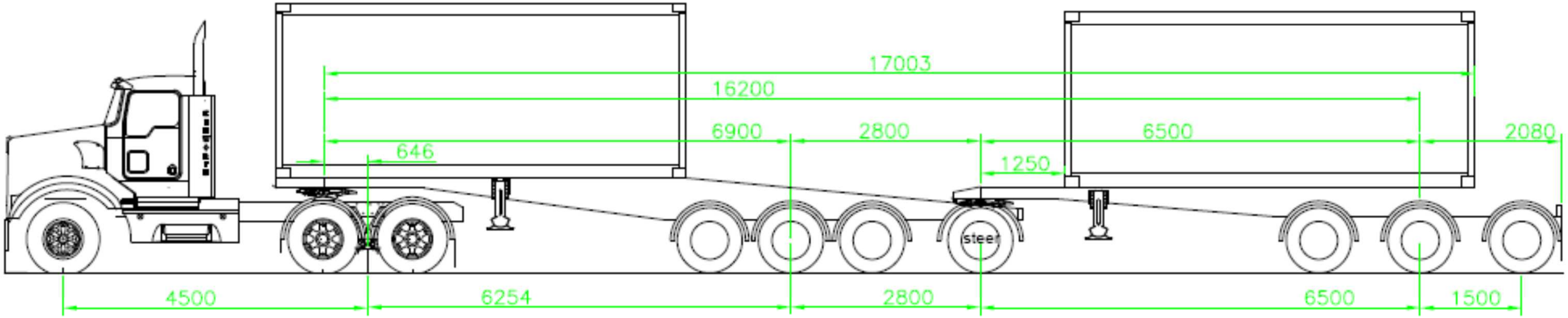

Figure 2. Layout drawing of K&S Freighters B-train supplied by Fruehauf Trailers.

The key vehicle dimensions were measured at the roadside with a tape measures. Within the accuracy that could be expected with this measurement technique the measured dimensions matched those shown in Figure 2.

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.

Testing in the unladen state did cause some complications when comparing the computer simulation results with the measured results. The caster steer axle fitted to the first trailer has some centring force applied to it to keep it stable. In developing the pro-forma design, the centring force data used in the computer model was based on an obsolete caster steer axle that was available to us.

When the vehicle is loaded, the cornering forces are quite large in relation to the centring force and so the vehicle's performance is not very sensitive to the centring force data. However, when the vehicle is unladen, the cornering forces are much less and so the contribution of the centring forces is significant. As a result the initial match between the computer simulation results and the measured results was not as good as we would like. To solve this we obtained the specific centring force data for the SAF axle which is fitted to the vehicle from the suppliers, Gough Transpecs. This significantly improved the match.

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.

Both of these manoeuvres were conducted with the test vehicle and the four performance measures were obtained. These could then be compared with the values obtained by computer simulation. The test facility used was the Morrinsville Saleyards which has a very large parking area for stock trucks. This is the same facility that was used for the previous B-train test.

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.

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 1 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.

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

Table 1. Summary of measurement results for 12.5m outside radius 90° turn.

Performance Measure	Measurement				Average
	1	2	3	4	
Low Speed Swept Width (m)	6.48	6.65	6.65	6.60	6.60
Tail Swing (m) - Load	0.00	0.00	0.00	0.00	0.12
Frontal Swing (m)	0.36	0.35	0.28	0.38	0.34

For the 25m outside radius turn, the only measurement taken was swept width. Eleven readings were taken and these are summarised in Table 2.

Table 2. Summary of measurement results for 25m outside radius steady state turn.

Performance Measure	Measurement											Average
	1	2	3	4	5	6	7	8	9	10	11	
Steady State Swept Width (m)	5.09	5.08	5.09	5.04	5.08	5.08	5.07	5.08	5.06	5.05	5.07	5.07

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 3.

Table 3. 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	6.75
Tail Swing (m) - Load	Less than 0.3	0.08
Frontal Swing (m)	Less than 0.75	0.33
Steer-Tyre Friction Demand	Less than 0.50	0.27
Steady State Low Speed Swept Width (m)	Less than 5.20	4.86
High Speed Offtracking at 0.2g (m)	Less than 0.46	0.46
High Speed Offtracking at 0.25g (m)	Less than 0.68	0.64
Static Rollover Threshold (g)	Greater than 0.35	0.40
Dynamic Load Transfer Ratio	Less than 0.6 (0.7)	0.25
Rearward Amplification	Less than 2	1.60
High Speed Transient Offtracking (m)	Less than 0.6	0.30
Yaw Damping Ratio (%)	Greater than 15	0.45

The test conditions for this simulation were slightly different from those at trial. Specifically, for the original simulation the vehicle was loaded to 59 tonnes while the trial was conducted with an unladen vehicle. The high speed off-tracking is quite close to the limit values but the modelling was done with the trailer steering active while the steering is configured to be locked at 70 km/h. Thus the actual high speed performance will be substantially better than shown in Table 3.

The vehicle was also modelled in the unladen state. The results of this modelling are shown in Table 4.

Table 4. Performance assessment of the test vehicle as tested using proposed new PBS.

Performance Measure	Unladen K&S B-train	Laden K&S B-train
Low Speed Swept Width (m)	6.98	6.75
Tail Swing (m) - Load	0.05	0.08
Frontal Swing (m)	0.32	0.33
Steady State Low Speed Swept Width (m) - 25m radius turn	5.11	4.86

Referring back to Table 1 and Table 2, we can compare these simulated results with the measured results. Initially, we modelled the vehicle with generic centring force data for the caster steer axle but, because the match between the measured and simulated results was not very good we obtained centring data for the specific axle from the suppliers which generated the results shown in Table 4.

The measured low speed swept width during the 90 degree turn was quite consistent but it was substantially better than the simulation result. The difference is 380mm, which is only 6% but we would hope to get closer. With the laden vehicle the swept width is only 150mm above the measured value which is just over 2%. It appears that the simulation model is generating more centring force than is occurring in practice, i.e. there was more steering from axle during the physical trial giving a smaller swept width.

The amount of tail swing generated by this vehicle is very small and we did not observe any significant tail swing during the trials. The simulations indicate that a tail swing of 50mm would have occurred. Given the uncertainty associated with our measurement technique and the precision of path following that was achievable. This represents a reasonable match.

For frontal swing the simulation results and the average measured value were within 20mm of each other. There was some variability between test runs but generally, the match between the measured values and the simulation value was very good.

The required path for the steady state low speed turn was relatively easy 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 swept width measurements from these turn were very consistent. The match between the measured and simulated results for this performance measure was excellent. The laden vehicle has a significantly lower swept width. This suggests that with the larger radius and an empty vehicle, the centring force is sufficient to suppress the steering action of the trailer but when the vehicle is loaded the steering becomes active.

Comparing the results for the 90 degree turn with the 360 degree turn we see that with the smaller radius turn the cornering forces are sufficient to overcome the centring forces and thus the axle steers while for the larger radius turn this does not occur when the vehicle is unladen. The simulation model is not currently representing this centring force response very accurately.

Overall the match between the measurements and the simulations is quite good. The results are conservative and so the vehicle was performing a little better in practice than predicted by the simulation model.

ON-ROAD PERFORMANCE

The vehicle was followed by car on a trip from Rotorua to the Kawerau turnoff on SH30. The route followed SH30A and then SH30 and finished at the junction with SH34. The total trip distance was approximately 50km. The first few kilometres of the trip were on urban roads through the city of Rotorua. After about 10km this became open road (100km/h speed limit). For the first 20km or so this was relatively straight with the occasional bend warranting an advisory speed sign while the last 20km or so was quite winding with numerous curves with advisory speeds. This is the same route that was used for the validation trial of the new log truck pro-forma design which was reported in a TERNZ report to the NZTA entitled "Validation of the Performance of a 23.4m Log Truck" and dated July 2018.

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 right hand 45 km/h curve while Figure 5 shows it on a right hand 35 km/h curve. These are the same curves that were used in the log truck report and thus the comparable log truck photo is shown for reference.

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. Furthermore the performance of the B-train is very similar to the of the log truck.

Figure 4. Traversing a 45 km/h advisory speed curve – pro-forma B-train compared to pro-forma log truck.

Figure 5. Traversing a 35 km/h advisory speed curve – pro-forma B-train compared to pro-forma log truck.

DRIVER PERCEPTIONS

In the validation test on the log truck pro-forma design we undertook 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 K&S B-train, on the other hand was only delivered to the company a few days before the trial and so there was almost no driver experience with the vehicle and there is no scope for any statistical analysis. Thus no formal driver survey was undertaken. During the trial the vehicle was driven by Baden Redman who is the supervisor of the Cambridge depot of K&S Freighters. A telephone interview with Mr Redman was conducted on 10th May when the truck had been in operation for approximately six weeks.

Mr Redman has had 28 years of experience driving heavy vehicles and has driven all of the combination vehicle configurations currently in use in New Zealand. In his view, the new K&S B-train tracks significantly better than a typical quad-axle semi-trailer combination. It also tracks markedly better that the 23m 50MAX truck and combinations that were created by fitting and additional axle to existing four-axle trailers and slightly better than the newer 23m truck and trailer combinations. He also thought that it off-tracked less than the current 23m B-trains and similar to or possibly slightly better than the old standard 20m B-trains. This last assessment is based on memory as K&S no longer operates any of these vehicles.

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 fair (low by 6%) and the tail swing result was inconsistent because the absolute level of tail swing is very low.

The reason that the match between the computer simulated swept width and the measured swept width for an empty vehicle is not better appears to be that we are not accurately modelling the centring forces of the caster steer under light loading. The swept width calculated for a laden vehicle is much closer to the measured value. For the 12.5m radius 90 degree turn the measured swept width is significantly less than the computer simulated value. In the simulation, the magnitude of the centring force is limiting the amount of steering by the caster steer axle whereas the measured results indicate that the steering is active. On the other, the match for the 25m radius turn with the empty vehicle is much better. This shows that for larger radius turns the steering was also limited on the actual vehicle. However, when the vehicle is loaded the steering does become active and the swept width reduces.

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 will 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 the test driver. He commented that the low speed turning performance of the B-train was significantly better than a 19m quad semitrailer combination and also better than the older 23m B-trains. He thought that its performance was a little better than the newer 23m truck and trailer combinations but noticeably better than the combinations that had been created by adding an axle to existing 4-axle trailers. Comparing the old standard 20m B-trains was a little more difficult because they have been phased out of the K&S fleet but he thought that the performance was similar and possibly slightly better.

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