EFFECT OF HEADWAY DISTANCE ON TRUCK PLATOON DYNAMIC ON-ROAD PERFORMANCE

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Abstract

This research investigates how heavy vehicle headway distance affects on-road dynamic performance of truck platoons. Computer simulation was used to investigate the effects in both high-speed and low-speed scenarios with platoons consisting of two vehicle combinations. It was found that without complex steering controls, platoons performed significantly worse than individual vehicle combinations. It was also found that increased headway distance affected high-speed and low-speed performance similarly to increased drawbar length in multi-combination heavy vehicles. It was also found that at headway distances above 9 metres, high-speed performance was similar to that of general access Australian heavy vehicles, suggesting complex steering control may not be necessary for high-speed operation.

Keywords: heavy vehicle, platoon, PBS, dynamic performance, headway distance

1. Introduction

Heavy vehicle platooning involves the use of multiple vehicles travelling in a column with each vehicle separated by a specific distance (headway). The differences between modern platoons and traditional heavy vehicles travelling in a column is that vehicle-to-vehicle communication can allow for much smaller distances to be maintained safely through simultaneous braking and vehicle automation (Bergenhem et al, 2012). Current platooning trials involve the lead unit being manually driven while follower vehicles will instead be partially or fully autonomously driven. The benefits of platooning include improved fuel economy, lane capacity increases, driver efficiency improvements and driver range increases (Jacob and Arbeit De Chalendar, 2018). Alongside the steering and acceleration/braking control system of each of the units, an important factor when determining performance for a heavy vehicle platoon is controlling the headway between each of the combinations in the platoon. This headway distance has safety implications, for both the platoon vehicles themselves as well as interactions with other road users, especially in the case of sufficient braking distance and avoiding cut in from other road users (Bergenhem et al, 2012).

To date, research has already been completed on the effect that varying headway can have on heavy vehicle efficiency, driving performance and bridge loading (Browand, McArthur, & Radovich, 2004 and Jacob and Arbeit De Chalendar, 2018) however the current study is specifically looking at dynamic on-road performance of a platoon. Existing research into Performance Based Standards (PBS) for connected automated vehicles (de Pont, 2018) has been used as the basis for this research. The research by de Pont modelled a specific vehicle in both low-speed and high-speed tests using a fixed headway distance between two prime mover and semi-trailer combinations. The lead and follower combinations in the platoon were modelled as either connected via a drawbar (high-speed) or the lead combination’s trailer path was input as a steer path for the follower prime mover (low-speed). All test procedures were based on the proposed New Zealand PBS scheme. It was found that in both high-speed and low-speed tests, the performance was significantly worse than that of a single combination’s performance.

When using a simple steering control system, such as that modelled in the research by de Pont wherein the follower unit does not take into account additional lane information, it is expected that the performance of a platoon can be considered similarly to an articulated combination. As such, it is expected that the headway distance may follow the drawbar length performance trends as outlined in the Australian PBS fleet report (Prem, de Pont, Pearson & McLean, 2002). This study may then identify headway distances which reach a balance between optimum high-speed and low-speed performance. This assessment was completed using the Australian PBS scheme, which offers advantages in both being a relatively mature system for modelling heavy vehicle performance but can also be directly related to suitability for the Australian heavy vehicle network, linking performance to real-world applicability.

2. Materials and methods

All heavy vehicle simulation was completed using the heavy vehicle dynamics simulation package TruckSim. TruckSim is a multi-body heavy vehicle dynamics simulation package which is can be used as part of the Australian PBS scheme to accurately model the performance of heavy vehicles as part of the scheme.

2.1 Subject vehicle

For this study, the Austroads 19-metre prime mover and semi-trailer was selected as the subject vehicle. This subject vehicle consists of a single steer, tandem drive tractor unit towing a tri-axle semi-trailer. This combination was modelled as being 4.3 metres high and with axle loads up to the maximum allowed under the Australian PBS scheme. Under normal circumstances this vehicle can be legally operated and is used as a reference vehicle for road design in Australia. A diagram of the Austroads semi-trailer is shown in Figure 1 with key dimensions shown.

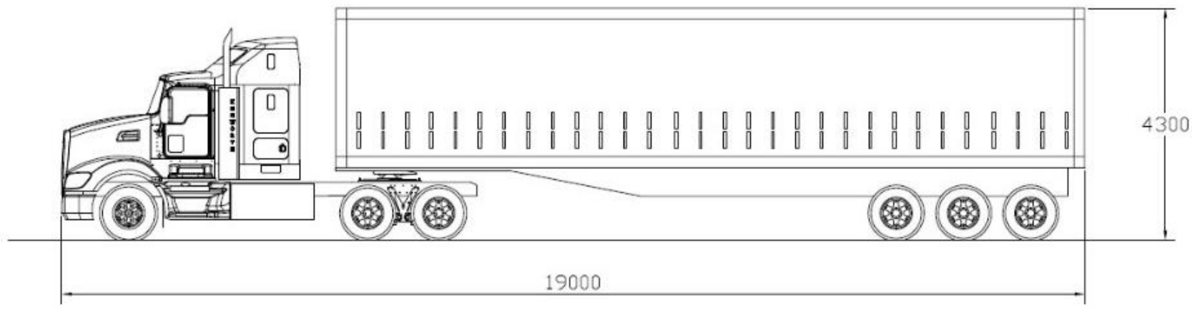

Figure 1 - Austroads 19-metre prime mover and semi-trailer combination

The vehicle was modelled with single tyres on the front steer axle and dual tyres on all other axles. The front suspension includes leaf springs fitted while all other axle groups were fitted with airbag suspension.

The axle loads for the different groups were as follows:
- Steer axle – 6.5 tonnes
- Drive axle group – 17.0 tonnes
- Tri-axle semi-trailer group – 22.5 tonnes.

2.2 Driver and headway control method

The platoon consisted of two units, a lead prime mover and semi-trailer unit, and a follower prime mover and semi-trailer unit.

The platoon follower unit's steering control was modelled using a simplified driver control approach wherein it followed a specific point on the lead unit and maintained a specified headway distance. More advanced steering systems are possible for implementation but may not be applicable when input information is limited, typically due to reduced headway distances (de Pont, 2018).

Within TruckSim, each assessment was completed in two steps. In the first step, the lead unit was simulated performing the procedure in isolation. A reference point was placed at the rear of the lead unit's trailer and the longitudinal and lateral coordinates of the reference point at each timestep in the simulation environment were exported to a list. When the follower unit was modelled in the next step, the driver control model was given a single target location to drive towards and a headway distance to be maintained. Every few timesteps within the simulation, the target location point was updated to the next relevant point exported from the rear of the lead unit. In this manner, the driver of the follower unit continuously updated its path trajectory based on new data.

The primary reason for using this method is to create more realistic driver control models, wherein the follower unit has no influence on the lead unit in the platoon, and the driver of the follower unit has no future knowledge of the driver path so they cannot optimize the path with future knowledge.

2.3 High-speed performance assessment

High-speed performance was found by performing the ISO lane change manoeuvre (ISO, 2000) with three performance factors measured, Rearward Amplification (RA) and High-Speed Transient Offtracking (HSTO) as per the Australian PBS Scheme (NTC, 2008) as well as Load Transfer Ratio (LTR).

Two of the lane-change manoeuvres' animated runs have been overlaid and shown in Figure 2 to show the two-unit platoon visually. The target reference point for the follower combination can be seen under the rear of the lead unit, as a small blue sphere on the ground.

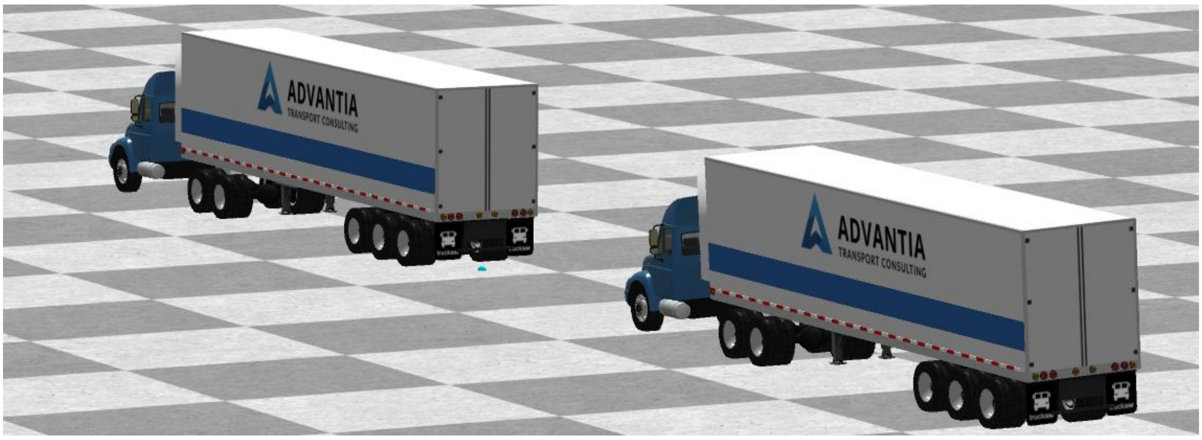

Figure 2 – The platoon in the TruckSim environment

2.3.1 Rearward Amplification

RA is measured as a ratio between the input (at the steer axle) lateral acceleration of the hauling unit and the lateral acceleration of the Rearmost Roll Coupled Unit (RRCU). When measuring the rearward amplification of a platoon, the follower unit's lateral acceleration is divided by the lead unit's input acceleration. Rearward amplification is an important measure of performance with articulated multi-unit combinations due to the propensity for rollover of the rear unit during evasive manoeuvres. Rear-most units receive a larger magnitude of lateral acceleration which can exceed the rollover threshold of the RRCU.

2.3.2 High-Speed Transient Offtracking

The second high-speed performance measure recorded is HSTO, which represents the maximum relative lateral displacement of the rear axle compared to the steer axle during the lane change manoeuvre. In this type of evasive manoeuvre, rear units in an articulated combination may 'swing out' farther than the path of the steer axles, possibly encroaching on adjacent lanes or road furniture. A visual example of the HSTO, taken from the PBS Assessment Rules (NTC, 2008) is shown in Figure 3.

HSTO is typically measured on a per combination basic, however, when measuring the HSTO of a platoon, the maximum lateral distance of the lead unit's steer axle was compared to the maximum lateral distance of the follower unit's rearmost axle.

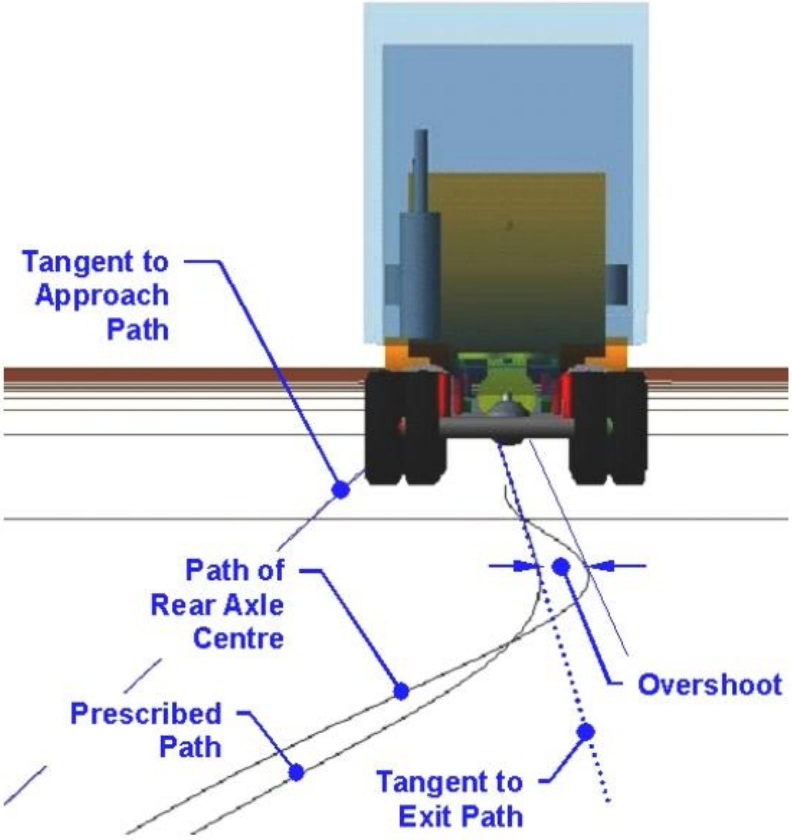

Figure 3 – The overshoot (i.e. HSTO) of a heavy vehicle

2.3.3 Load Transfer Ratio

LTR is the third performance measure which was recorded during the lane change manoeuvre in this assessment. LTR is a measure of how much of a heavy vehicle's weight has shifted from the tyres on one side of the combination to the tyres on the other side of the combination. LTR is zero when the heavy vehicle is driving in a straight line on a flat road (i.e. equal weight on each side), and a value of one when the heavy vehicle has experienced wheel-lift at every axle down one side of the vehicle (i.e. all weight on one side, imminent rollover). This measure has been included in the Western Australian implementation of PBS and is also recommended for inclusion in the European FALCON project (de Saxe et al, 2019). In this case the RRCU was considered as the critical unit due to the aforementioned RA. Within the platoon, this meant that the left and right-hand-side axle loads of the entire follower unit were considered to calculate the LTR.

LTR is significant due a strong correlation with overall crash safety of a heavy vehicle, with lower LTR linked to lower crash rates; research shows significant increases in crashes once LTR exceeds approximately 0.6-0.8 (Woodrooffe et al, 2010).

2.4 Low-speed performance assessment

Low-speed performance was determined via a 12.5-metre radius 90 degree turn as per the Australian PBS Scheme (NTC, 2008). Reference points were positioned at critical locations on each of the units. The traces of each critical point were then overlaid to show the complete swept path envelope of the platoon. The maximum distance was then determined by finding the maximum swept path width, i.e. the Low-Speed Swept Path (LSSP). A visual example of LSSP is shown in Figure 4 for an example articulated combination, with total swept path envelope shown by the green trace, the left steer axle's path by the blue trace and the maximum LSSP shown in red (seen from overhead).

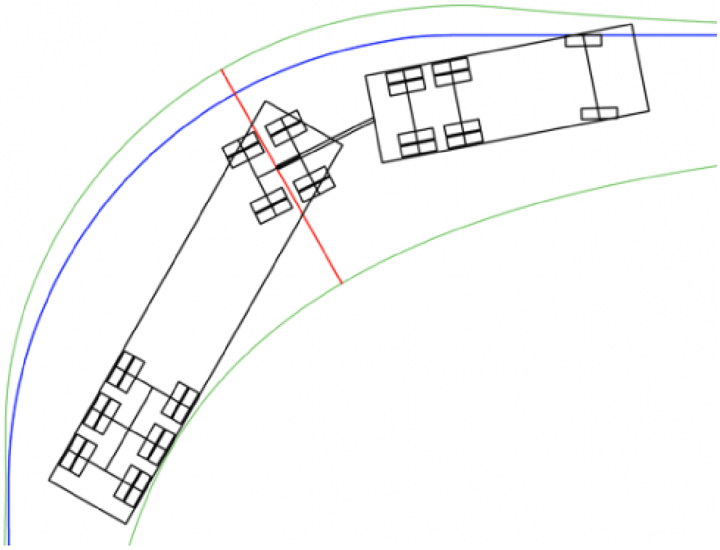

Figure 4 – The swept path of a heavy vehicle

LSSP is highly relevant when considering low-speed maneuvering of a combination and can provide a measure of whether a combination can complete a small-radius turn when considering the available road geometry.

3. Results

The results from the high-speed and low-speed performance tests are shown in Table 1 with varying headway between the combinations.

Table 1 – Platoon dynamic performance results

Headway (m)	Platoon RA	Platoon HSTO (m)	RRCU LTR	Platoon LSSP (m)
3	1.91	0.69	0.74	10.34
6	1.77	0.65	0.69	10.87
9	1.57	0.54	0.61	11.63
12	1.35	0.43	0.52	12.52
15	1.16	0.32	0.45	13.49
Lead unit only	1.14*	0.16*	0.45*	7.17*

*results for the single lead prime mover and semi-trailer combination only

4. Conclusion and discussion

The results of the high-speed and low-speed performance tests were consistent with those found by de Pont and also aligned with the Australian PBS fleet report (Prem et al, 2002) when considering the platoon as a multi-articulated combination. This includes the following findings:

1. Both the low speed turning and high-speed evasive performance of the platoon was significantly worse than that of the lead unit itself
2. Increased headway improved dynamic performance and worsened LSSP.

The second finding in particular supports the assertion by de Pont that the platoon can be generally modelled through consideration of the headway as a drawbar, rather then solely relying on more complex simulation methods such as used in this assessment.

While some of the configuration results indicate relatively poor performance, there are a number of promising results with respect to two-combination prime mover and semi-trailer platoons.

Firstly, the platoon's overall RA performance was below 1.995 for all headway values tested. This indicates that if the rear unit can have an acceptable static rollover threshold to meet the Australian PBS scheme, then the RA will also be acceptable (NTC, 2008) for operation on Australian roads. Moreover, when the headway was increased to at least 9 metres, the HSTO was also within the acceptable Australian limits for the best performing PBS level (≤0.6 metres), PBS Level 1 (equivalent to general access in some jurisdictions). Even at a headway of 3 metres, the HSTO was within the acceptable Australian limit for PBS Level 2 (≤0.6 metres), which is generally equivalent to performance of a 26-metre B-double and would provide access to many of the countries arterial road networks. LTR was also approximately at a commonly considered safe value of 0.6 when the headway was at least 9 metres, and when at a reduced headway (i.e 3 metres) the LTR did not exceed 0.8. This means that LTR remained within the range of acceptable headway distances, depending on the level of conservatism applied (Woodrooffe et al, 2010). It is also worth noting that at a headway distance of approximately 9 metres, the combination would be expected to be able to achieve some of the fuel savings due to reduced aerodynamic drag, with approximately 6% and 10% fuel reduction for the lead and follower unit respectively (Browand et al., 2004).

Nevertheless, at all headway distances tested, all LSSP values were found to be well above the PBS Level 1 requirement of 7.4 metres and falling within PBS Level 3 (≤10.6 metres – similar to a 36.5-metre double road train) and PBS Level 4 (≤13.7 metres – similar to a 53.5-metre triple road train).

The results indicate that with sufficient headway, two-unit prime mover and semi-trailer platoons may be acceptable for operation at high-speed with simple steering control technology. Due the reduced complexity of the steering control, it would be expected that this could be more easily implemented and retrofitted to existing equipment. However, at low speed, turning performance was such that more advanced steering control methods or that separation of the platoon may be required. Considering that platoons will be primarily used for highway use, this limitation may be acceptable for more widespread application of platoons in long haul transport scenarios.

An example application may include two tractor semi-trailers being independently driven to a staging point at the beginning of a highway in one city, the platoon being driven by a single driver for an extended distance along the highway to a second staging point at the other end of the highway in a second city after which the two units in the platoon are independently driven again for final delivery, possibly to different locations within the second city.

5. References

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