Evaluation of the Dynamic Performance of Extended Length B-trains

Prepared for

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ABSTRACT

This work has evaluated the dynamic performance of tridem-tandem and tandem-tridem B-trains with a box length from about 18 to 20 m (59 to 65 ft 7 in), pulled by tractors with a wheelbase from 4.06 to 7.16 m (160 to 282 in), and an overall length up to 27.5 m (90 ft 3 in), against the RTAC performance standards.

EXECUTIVE SUMMARY

The national Memorandum of Understanding on Interprovincial Weights and Dimensions ("the M.o.U.") allows a box length up to 20 m (65 ft 7 in) for double trailer combinations, but restricts their overall length to 25 m (82 ft). The M.o.U. allows a tractor wheelbase up to 6.20 m (244 in), but the 20 m (65 ft 7 in) box length within 25 m (82 ft) overall length restricts the tractor pulling a double trailer combination to a maximum wheelbase of about 5.28 m (208 in). A longer wheelbase is possible for a tractor pulling a B-train with a box length less than 20 m (65 ft 7 in). The front axle setback of particular tractor models, the need for a sleeper berth, environmental control equipment, longer fuel tanks for natural gas, or a moose bumper, further restricts the choice of tractor model and wheelbase, or B-train, for carriers who run B-trains.

The Canadian Trucking Alliance (CTA) has determined that an overall length of 27.5 m (90 ft 3 in) would allow any tractor up to 6.20 m (244 in) wheelbase to pull any B-train with a box length up to 20 m (65 ft 7 in). A number of provinces now allow a tractor with a wheelbase up to 7.2 m (282 in) to pull a semitrailer as long as the semitrailer wheelbase is less than a specified value, less than 12.5 m (41 ft). An overall length of 27.5 m (90 ft 3 in) would also allow a tractor up to 7.2 m (282 in) wheelbase to pull a B-train up to 20 m (65 ft 7 in) box length, though there might be some minor restrictions on the internal dimensions of either tractor or B-train. An overall length of 27.5 m (90 ft 3 in) would allow carriers more flexibility in choice and assignment of tractors to pull B-trains, without any change to the current 20 m (65 ft 7 in) box length of the B-train, or any of its internal dimensions. It would allow any tractor that can currently pull a semitrailer also to pull a B-train.

The CTA is therefore proposing that the overall length of a B-train be increased to 27.5 m (90 ft 3 in), and in support of this, requested an assessment of the dynamic performance of four tractor options:

1. Tractors that can currently pull a 20 m (65 ft 7 in) box length B-train within the current overall length of 25 m (82 ft);
2. Tractors up to 6.20 m (244 in) wheelbase pulling a reduced box length B-train within the current overall length of 25 m (82 ft);
3. Tractors up to 6.20 m (244 in) wheelbase pulling a 20 m (65 ft 7 in) box length B-train within an overall length of 27.5 m(90 ft 3 in); and
4. Tractors up to 7.16 m (282 in) wheelbase pulling a B-train up to 20 m (65 ft 7 in), box length within an overall length of 27.5 m (90 ft 3 in).

The first two options are within the current M.o.U., and the regulations of all provinces, so establish the baseline performance of existing B-trains. The third addresses full use of tractors up to 6.20 m (244 in) wheelbase with B-trains with a box length up to 20 m (65 ft 7 in). The fourth addresses use of longer tractors that may combine some or all of a long front axle setback, a moose bumper, a more spacious sleeper berth, space for new environmental equipment and technology, and longer fuel tanks for natural gas, with B-trains with a box length up to 20 m (65 ft 7 in).

A tractor up to 6.20 m (244 in) wheelbase that pulls B-trains with a box length up to 20 m (65 ft 7 in) and exceeds 25 m (82 ft) overall length would not have materially different dynamic performance than other tractor-B-train combinations that can currently operate freely within the regulations of the provinces within 25 m (82 ft) overall length.

A tractor from 6.20 to 7.16 m (244 to 282 in) wheelbase that pulls B-trains with a box length up to 20 m (65 ft 7 in) and exceeds 25 m (82 ft) overall length would exceed the low-speed offtracking performance standard only for tridem-tandem B-trains with the longest lead semitrailer and shortest rear semitrailer, but otherwise would meet the performance standard, and would exceed the high-speed offtracking of the current legal B-train with the highest high-speed offtracking by about 0.03 m (1 in). Otherwise, there would be no materially different dynamic performance than other tractor-B-train combinations that currently operate freely within the regulations of the provinces within 25 m (82 ft) overall length.

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1. INTRODUCTION

The 8-axle B-train became the principal heavy haul truck configuration when all provinces adopted the Memorandum of Understanding on Interprovincial Weights and Dimensions (“the M.o.U.”) in 1989 [1]. The M.o.U. allows a box length up to 20 m (65 ft 7 in) for double trailer combinations, but restricts the overall length to 25 m (82 ft) [1]. The M.o.U. allows a tractor wheelbase up to 6.20 m (244 in), but the 20 m (65 ft 7 in) box length within 25 m (82 ft) overall length restricts the tractor pulling a double trailer combination to a maximum wheelbase of about 5.28 m (208 in). A longer wheelbase is possible for a tractor pulling a B-train with a box length less than 20 m (65 ft 7 in). The front axle setback of particular tractor models, the need for a sleeper berth, environmental control equipment, longer fuel tanks for natural gas, or a moose bumper, further restricts the choice of tractor model and wheelbase, or B-train, for carriers who run B-trains.

The Canadian Trucking Alliance (CTA) provided the following formal position statement as the basis for this work:

> "In 2011, CTA approved a position to extend the maximum overall B-train combination length to 27.13 metres (89 ft) in order to accommodate a 6.2 metre wheel base tractor (244") with a 20 metre box length (65 ft 7 in). It was deemed this was necessary to allow for new environmental control equipment and larger sleeper berths.
>
> In 2012, after discussions with various provincial governments, CTA further amended its position to an overall B-train combination length of 27.5 metres. This was the result of two additional issues emerging amongst carriers:
>
> (a) the desire of those carriers moving steel, lumber, cement and other bulk commodities to operate shorter box length (less than 20 metres) vehicles with longer wheelbase tractors (greater than 6.2 metres), again to provide flexibility for environmental control equipment and larger sleeper berths), so long as they fit within the proposed new maximum overall combination length and
>
> (b) the desire to operate B-trains where the tractor has a moose bumper (a key safety feature for trucking operations in many regions of Canada). Moving forward on a 27.5 metre b-train would accommodate CTA's 2011 initial position, but also the additions in the amended 2012 position; the longer wheelbase tractors operating a shorter B-train configuration and moose bumpers. (Note: The moose bumper must fit within the 27.5 metre overall B-train combination length). The go forward on this issue of course would of hinge on demonstrating all safety parameters could be met, hence the reason for this analysis.
>
> This analysis serves a twofold purpose:
>
> 1. To provide information for all provincial associations in the CTA federation and

government representatives at the National Weights and Dimensions Task Force on this issue and the need for the MoU to be updated accordingly and

2. To provide reference points specific to the dynamic performance of these vehicles for governments to further develop internal communications and processes to bring about regulatory changes."

The CTA has subsequently added the two following clarifications:

“The 27.5 metre window also ensures that regardless of the specifics of how a carrier may spec b-train trailer equipment in terms of some of the vehicles internal dimensions (e.g. king pin settings, 5th wheel off-sets), that no existing trailer configurations would be excluded by the addition of longer wheel-base tractors or overall length.

The overall length of 27.5 metres in this work does not include provisions for rear mounted aerodynamic devices known as boat tails. These devices are typically excluded from overall length measurements and CTA sees no reason why boat tails would be viewed differently on B-trains.”

CTA’s position statement is clear that this work is about allowing carriers more flexibility in choice and assignment of tractors to pull B-trains, and does not contemplate any change to the current 20 m (65 ft 7 in) box length of the B-train, or any of its internal dimensions. Beyond anything else, it would allow any tractor that can currently pull a semitrailer also to pull a B-train.

This work assessed the dynamic performance of four tractor options:

1. Tractors that can currently pull a 20 m (65 ft 7 in) box length B-train within the current overall length of 25 m (82 ft);
2. Tractors up to 6.20 m (244 in) wheelbase pulling a reduced box length B-train within the current overall length of 25 m (82 ft);
3. Tractors up to 6.20 m (244 in) wheelbase pulling a 20 m (65 ft 7 in) box length B-train within an overall length of 27.5 m(90 ft 3 in); and
4. Tractors up to 7.16 m (282 in) wheelbase pulling a B-train up to 20 m (65 ft 7 in), box length within an overall length of 27.5 m (90 ft 3 in).

The first two options are within the current M.o.U., and the regulations of all provinces, so establish the baseline performance of existing B-trains.

The third addresses full use of tractors up to 6.20 m (244 in) wheelbase with B-trains with a box length up to 20 m (65 ft 7 in).

The fourth addresses use of longer tractors with a long front axle setback, a moose bumper, and a longer wheelbase for a more spacious sleeper berth and space for new environmental equipment and technology, with B-trains with a box length up to 20 m (65 ft 7 in).

2. B-TRAIN CONFIGURATIONS

2.1 Scope

The M.o.U. allows a box length of 20 m (65 ft 7 in) for a double trailer combination, but restricts overall length to 25 m (82 ft) [1]. The M.o.U. allows a tractor wheelbase up to 6.20 m (244 in), but a 20 m (65 ft 7 in) box length within 25 m (82 ft) overall length restricts the tractor pulling a B-train to a wheelbase no more than about 5.28 m (208 in), with the exact value determined by tractor front axle setback, fifth wheel setting, tractor BBC dimension (including any sleeper berth), and lead semitrailer kingpin setback.

The need for a sleeper berth, and the front axle setback of particular models of tractor, can restrict the choice of tractor available to carriers who run B-trains. Fitting a moose bumper may further restrict wheelbase. Current and possible future needs for emissions technology or larger fuel tanks for alternative fuels might result in a general increase in tractor wheelbase.

This work examines the dynamic performance of M.o.U. B-trains pulled by a tractor with a wheelbase up to 7.16 m (282 in), with an overall length up to 27.5 m (90 ft 3 in).

The CTA identified the following 13 factors to be considered:

- Tractor wheelbase;
- Front axle setback;
- Fitment of a moose bumper;
- Tractor drive axle spread;
- Tandem axle allowable weight;
- Tractor fifth wheel setting;
- Lead semitrailer length;
- Lead semitrailer kingpin setback;
- Lead semitrailer fifth wheel setting;
- Rear semitrailer length;
- Rear semitrailer kingpin setback;
- B-train axle arrangement, tridem-tandem, or tandem-tridem; and
- Gross weight.

2.2 Tractors

This work used a generic tandem drive tractor with a day cab, typically equipped, with a gross combination weight rating of at least 63,500 kg (139,992 lb).

The principal factor in this work was the effect of tractor wheelbase on the dynamic performance of B-trains within the practical box length from about 18 m (59 ft) to 20 m (65 ft 7 in). The tractor was considered with a wheelbase of 4.06, 4.37, 4.67, 4.98, 5.28, 5.59, 5.89, 6.20, 6.50, 6.73 or 7.16 m (160, 172, 184, 196, 208, 220, 232, 244, 256, 265 or 282 in). The front axle setback was 0.76 m (30 in), and the tandem drive axle had a spread of 1.37 m (54 in).

The tractor had a tare weight of 8,391 kg (18,500 lb) and a tare front axle load of 4,762 kg (10,500 lb), regardless of wheelbase, full of fuel, with the driver and normal equipment. This is a representative weight for a tractor in the shorter ends of the wheelbase range considered. Tractors with a longer wheelbase will generally be heavier than the weight assumed here, especially when equipped with a sleeper berth, and/or a moose bumper.

The tractor fifth wheel was placed forward of the centre of the drive tandem by an amount that transferred about 544 kg (1,200 lb) of kingpin load to the front axle, with the setting rounded to the nearest 0.03 m (1 in). This resulted in a fifth wheel from 0.18 to 0.30 m (7 to 12 in) ahead of the centre of the drive tandem, depending on the tractor wheelbase, and retained sufficient front axle capacity that a 100 kg (220 lb) moose bumper could be fitted without overloading the front axle.

The front axle was assumed to weigh 544 kg (1,200 lb), with a rating of at least 5,500 kg (12,125 lb). Each drive axle was assumed to weigh 1,134 kg (2,500 lb). Moments of inertia were generated for the tractor in the same way as during the CCMTA/RTAC Vehicle Weights and Dimensions Study [2].

2.3 B-trains

Six of the 13 factors to be considered related to the B-train trailer configuration:

- B-train axle arrangement, tridem-tandem, or tandem-tridem;
- Lead semitrailer length;
- Lead semitrailer kingpin setback;
- Lead semitrailer fifth wheel setting;
- Rear semitrailer length; and
- Rear semitrailer kingpin setback.

Tridem-tandem and tandem-tridem axle arrangements were different B-train configurations, so were considered separately. The other five factors were intimately related with each other and the payload weight and distribution, and were considered together for each of the two axle arrangements.

The rear semitrailer swing clearance, allowable weights, and payload weight were the same for each axle arrangement, so are discussed here.

2.3.1 Rear Semitrailer Swing Clearance

The box length is the two semitrailer lengths plus the gap between them. Table 1 shows the minimum gap between the semitrailers, and the rear semitrailer swing clearance. These values were based on square corners on the rear semitrailer, and 0.15 m (6 in) minimum actual clearance. Rounded or chamfered corners slightly reduce the clearance required, so the values shown are slightly conservative. Useable semitrailer length is the greatest, and aerodynamic drag is least, when the gap between the semitrailers is a minimum, which suggests a deep (high) rear semitrailer kingpin setback. However, this would increase the load transferred to the lead semitrailer axle group, and would make it difficult to load fully the rear semitrailer axle group.

Table 1: Rear Semitrailer Swing Clearance

Rear Semitrailer Kingpin Setback	Minimum Gap between Semitrailers	Rear Semitrailer Swing Clearance
0.30 m (12 in)	1.19 m (47 in)	1.50 m (59 in)
0.46 m (18 in)	1.09 m (43 in)	1.55 m (61 in)
0.61 m (24 in)	0.99 m (39 in)	1.60 m (63 in)
0.76 m (30 in)	0.91 m (36 in)	1.68 m (66 in)
0.91 m (36 in)	0.84 m (33 in)	1.75 m (69 in)

2.3.2 Allowable Weights

The allowable axle and gross weights are shown in Table 2, by province. All provinces now allow 24,000 kg (52,910 lb) on the centre tridem, so there is sufficient axle capacity for an allowable gross weight of 63,500 kg (139,992 lb) in all provinces. However, the allowable gross weight is 62,500 kg (137,787 lb) in Québec and the four Atlantic provinces. A front axle weight higher than 5,500 kg (12,125 lb) is possible in a number

Table 2: Allowable Weights (kg)

Province	Steer Axle Load	Tandem Axle Load	Tridem Axle Load	Sum of Axle Loads	Gross Weight
BC	5,500	17,000	24,000	63,500	63,500
AB	5,500	17,000	24,000	63,500	63,500
SK	5,500	17,000	24,000	63,500	63,500
MB	5,500	17,000	24,000	63,500	63,500
ON	5,500	18,000	24,000	65,500	63,500
QC	5,500	18,000	24,000	65,500	62,500
NB	5,500	18,000	24,000	65,500	62,500
NS	5,500	18,000	24,000	65,500	62,500
PE	5,500	18,000	24,000	65,500	62,500
NF	5,500	18,000	24,000	65,500	62,500

of provinces, but Table 2 suggests there would be little incentive to use it, except maybe for a specialized application outside the scope of this work, so it was not considered here.

2.3.3 Payload Weight

The allowable gross weight of 63,500 kg (139,992 lb) that pertains in Ontario and the four western provinces was used for the bulk of this work. By assumption, all B-train combinations had a tare weight of 19,278 kg (42,500 lb), which allowed a maximum payload of 44,222 kg (97,492 lb). This was rounded down to 43,999 kg (97,000 lb) so that the vehicle could be loaded without exceeding any allowable axle group weight. The allowable gross weight of 62,500 kg (137,787 lb) in Québec and the four Atlantic provinces restricted the payload to 43,222 kg (95,287 lb), which is less critical, and was considered separately.

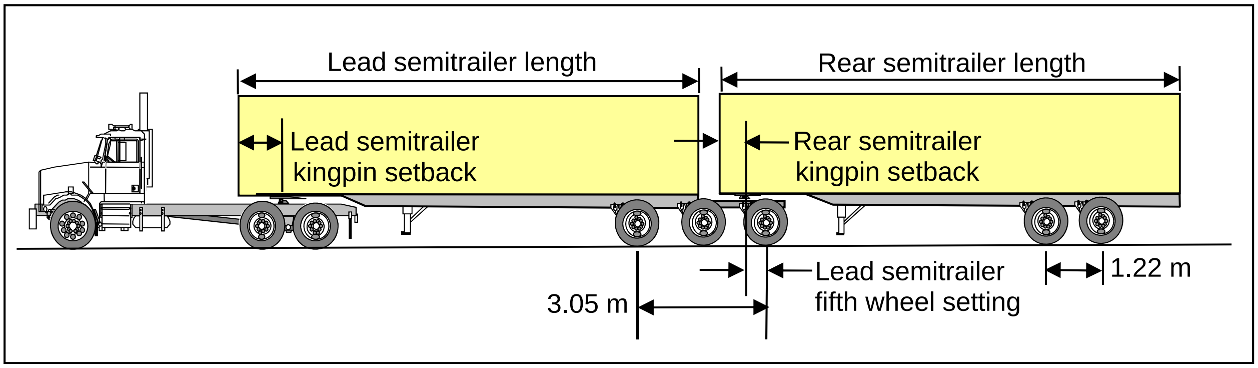
This work assumed the same tare weight for all B-trains, and used a weight appropriate for a box length around 18 m (59 ft). A B-train with a box length of 20 m (65 ft 7 in) would be about 454 kg (1,000 lb) heavier than the weight assumed here. So, with a gross vehicle weight capped at 62,500 or 63,500 kg (137,787 or 139,992 lb) by regulation, as shown in Table 2, the actual payload of a B-train with a tractor with a wheelbase longer than 4.06 m (160 in), and/or semitrailers with a box length longer than 18 m (59 ft), would be less than that assumed, and the centre gravity of the semitrailer sprung masses (body plus payload) would be lower than assumed. If the dynamic performance computed for the longer vehicles is in fact satisfactory, then the actual dynamic performance of an actual longer (and heavier) vehicle should be slightly better than that computed. This was therefore a conservative assumption, which was also a significant simplification to the work.

The work statement specified a payload density of 545 kg/cu m (34 lb/cu ft). This density represents a payload like dressed lumber, products packed 1.52-1.83 m (60-72 in) high on a pallet weighing 1,000-1,500 kg (2,204-3,306 lb), and many other commodities of moderate density. The CCMTA/RTAC Vehicle Weights and Dimensions Study used the same payload density [2], and it has also been included in many other studies. Use of this density for this work allowed comparison of these results back to those of the Vehicle Weights and Dimensions Study, and other studies.

2.4 Tridem-tandem B-trains

This work considered a generic dry van B-train with a tridem lead semitrailer and a tandem pup semitrailer, as shown schematically in Figure 1. The dimensions shown are the variables considered in this analysis. Values for internal dimensions were chosen so that each semitrailer could be loaded with the half the total payload weight, distributed over its entire length. This B-train was pulled by a generic tandem tractor, as described in Section 2.2 above.

Figure 1: Tridem-tandem B-train Van Configuration



The lead semitrailer was a dry van with a length of 8.53, 9.14, 9.75 or 10.36 m (28, 30, 32 or 34 ft), with a kingpin setback of 0.91 m (36 in), regardless of length. The lead semitrailer had a sliding tridem bogie with a 3.05 m (120 in) spread, where the centre axle of the tridem was set 0.61 m (24 in) behind the rear of the body. The lead semitrailer wheelbase was therefore fixed as the semitrailer body length less the kingpin setback plus 0.61 m (24 in). The lead semitrailer dimensions are presented in Table 3 for the various semitrailer lengths. The fifth wheel was positioned 0.58 m (23 in) ahead of the rearmost axle of the tridem, for minimum gap. The tare weight of the lead semitrailer was 6,350 kg (14,000 lb), regardless of length.

The rear semitrailer was a dry van with a length of 8.53, 9.14, 9.75 or 10.36 m (28, 30, 32 or 34 ft), with a fixed tandem axle with 1.22 m (48 in) spread. The rear semitrailer dimensions are presented in Table 4 for the various semitrailer lengths. The tare weight of the rear semitrailer was 4,536 kg (10,000 lb), regardless of its length.

Table 3: Tridem-tandem B-train Lead Semitrailer Dimensions

Length	Body Length	Kingpin Setback	Wheelbase
28 ft	8.53 (336 in)	0.91 (36 in)	8.23 (324 in)
30 ft	9.14 (360 in)	0.91 (36 in)	8.84 (348 in)
32 ft	9.75 (384 in)	0.91 (36 in)	9.45 (372 in)
34 ft	10.36 (408 in)	0.91 (36 in)	10.06 (396 in)

Table 4: Tridem-tandem B-train Rear Semitrailer Dimensions

Length	Length	Kingpin Setback	Wheelbase
28 ft	8.53 (336 in)	0.46 (18 in)	6.71 (264 in)
30 ft	9.14 (360 in)	0.46 (18 in)	6.78 (267 in)
32 ft	9.75 (384 in)	0.46 (18 in)	7.09 (279 in)
34 ft	10.36 (408 in)	0.46 (18 in)	7.59 (299 in)

Table 5: Tridem-tandem B-train Box Length

Lead Length	Rear Semitrailer Length			
	28 ft	**30 ft**	**32 ft**	**34 ft**
28 ft	18.16 m (715 in)	18.77 m (739 in)	19.38 m (763 in)	20.00 m (787 in)
30 ft	18.77 m (739 in)	19.38 m (763 in)	20.00 m (787 in)	20.00 m (787 in)
32 ft	19.38 m (763 in)	20.00 m (787 in)		
34 ft	20.00 m (787 in)			

The box length for all combinations of these lead and rear semitrailers is presented in Table 5. Combinations where the box length would exceed the maximum of 20 m (787 in) were omitted, as they were not considered in this work. These dimensions ensured the tandem-tridem inter-axle spacing exceeded 5.50 m (217 in), and the effective rear overhang of the rear semitrailer was less than 35% of its wheelbase.

A high payload is the critical case for dynamic performance, and typically occurs with payload loaded the full length of each semitrailer, such as the vans considered here, flatbeds loaded with logs or dressed lumber, or grain hoppers. The 0.91 and 0.46 m (36 and 18 in) kingpin setbacks used here were necessary to balance the axle loads of the B-train vans considered here that were loaded uniformly along their length. Shorter kingpin setbacks are often used on B-trains that carry very dense payloads, like steel coils and metal billets, and some grain hoppers, and others, as the payload does not occupy the entire length of either semitrailer and is positioned to balance the axle loads. Semitrailer kingpin setbacks less than 0.91 and 0.46 m (36 and 18 in) would increase the overall length if the same semitrailer lengths would be used, but B-trains that are designed for such payloads are generally built as short as possible, with near-minimum wheelbases and inter-axle spacing's, to reduce tare weight.

Each fixed axle on either semitrailer was assumed to weigh 680 kg (1,500 lb). Moments of inertia for these semitrailers and their axles were generated in the same way as during the CCMTA/RTAC Vehicle Weights and Dimensions Study [2].

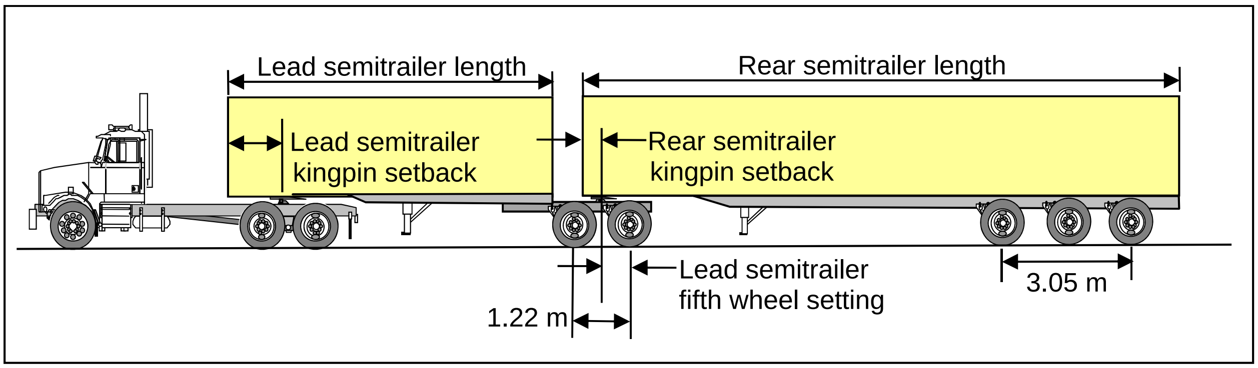
Half of the total payload weight of 43,999 kg (97,000 lb) was loaded in each semitrailer, as a solid block placed 0.07 m (3 in) from the front of the semitrailer running to 0.23 m (9 in) from the rear of the semitrailer, with a width of 2.44 m (96 in). Minor variations in payload front setback and length were necessary to ensure that no axle group was overloaded for an allowable tandem axle weight of 17,000 kg (37,787 lb), for every combination of tractor, lead and rear semitrailer. In fact, the payload was distributed so that the front axle load was within about 200 kg (441 lb) of its limit, and the drive and each semitrailer axle load was within about 100 kg (441 lb) of its limit. The height of a block of payload was determined from its weight, density of 545 kg/cu m (34 lb/cu ft), width and length, and varied from about 2.21 to 1.65 m (87 to 65 in), from the shortest to the longest semitrailer, respectively.

2.5 Tandem-tridem B-trains

Tandem-tridem B-trains are not common, and seem to have been used mostly as fuel tankers or log haulers, though may now be gaining popularity amongst carriers moving containers. Tandem-tridem B-trains generally have a lead semitrailer with a relatively short load bed, and a longer rear semitrailer. This arrangement does not work particularly well for vans, as it is difficult to load close to the front of the rear semitrailer.

This work considered a generic dry van B-train with a tandem lead semitrailer and a tridem pup semitrailer, as shown schematically in Figure 2. The dimensions shown are the variables considered in this analysis. This B-train was pulled by a generic tandem tractor, as described in Section 2.2 above.

Figure 2: Tandem-tridem B-train Van Configuration



The lead semitrailer was a dry van with a nominal length of 6.71, 7.32, 7.92 or 8.53 m (22, 24, 26 or 28 ft), but an actual length 0.05 m (2 in) less in each case. The lead semitrailer had a kingpin setback of 1.22 m (48 in), regardless of length. The lead semitrailer had a sliding tandem bogie with a 1.22 m (48 in) spread, where the lead axle of the tandem was set 0.53 m (21 in) behind the rear of the body. The lead semitrailer wheelbase was therefore fixed as the semitrailer body length less the kingpin setback plus 1.14 m (45 in). The lead semitrailer dimensions are presented in Table 6 for the various semitrailer lengths. Its fifth wheel was positioned 0.61 m (24 in) ahead of the rearmost axle of the tandem, so the gap between the semitrailers was minimized. The tare weight of the lead semitrailer was 4,990 kg (11,000 lb), regardless of length.

The rear semitrailer was a dry van with a nominal length of 10.36, 10.97, 11.58 or 12.19 m (34, 36, 38 or 40 ft), but an actual length 0.05 m (2 in) less in each case. The rear semitrailer had a fixed tridem axle with 3.05 m (120 in) spread, and a 0.30 m (12 in) kingpin setback, regardless of length, as shown in Table 7. The tare weight of the rear semitrailer was 5,897 kg (13,000 lb), regardless of its length.

The box length for all combinations of these lead and rear semitrailers is presented in Table 8. Combinations where the box length would exceed the maximum of 20 m (787 in) are left empty, and were not considered in this work.

Table 6: Tandem-tridem B-train Lead Semitrailer Dimensions

Length	Body Length	Kingpin Setback	Wheelbase
22 ft	6.71 (264 in)	1.22 (48 in)	6.63 (261 in)
24 ft	7.32 (288 in)	1.22 (48 in)	7.19 (283 in)
26 ft	7.92 (312 in)	1.22 (48 in)	7.80 (307 in)
28 ft	8.53 (336 in)	1.22 (48 in)	8.41 (331 in)

Table 7: Tandem-tridem B-train Rear Semitrailer Dimensions

Length	Length	Kingpin Setback	Wheelbase
34 ft	10.36 (408 in)	0.30 (12 in)	7.90 (311 in)
36 ft	10.97 (432 in)	0.30 (12 in)	8.31 (327 in)
38 ft	11.58 (456 in)	0.30 (12 in)	8.71 (343 in)
40 ft	12.19 (480 in)	0.30 (12 in)	9.14 (360 in)

Table 8: Tandem-tridem B-train Box Length

Lead Length	Rear Semitrailer Length			
	34 ft	**36 ft**	**38 ft**	**40 ft**
22 ft	17.91 (705 in)	18.52 (729 in)	19.13 (753 in)	19.74 (777 in)
24 ft	18.52 (729 in)	19.13 (753 in)	19.74 (777 in)	
26 ft	19.13 (753 in)	19.74 (777 in)		
28 ft	19.74 (777 in)			

Each fixed axle on either semitrailer was assumed to weigh 680 kg (1,500 lb). Moments of inertia for these semitrailers and their axles were generated in the same way as during the CCMTA/RTAC Vehicle Weights and Dimensions Study [2].

The total payload weight of 43,999 kg (97,000 lb) was split, with 17,690 kg (39,000 lb) in the lead semitrailer, and 26,309 kg (58,000 lb) in the rear semitrailer, regardless of the length of each of these semitrailers. Payload in the lead semitrailer was loaded as a solid block placed 0.07 m (3 in) from the front of the semitrailer running to 0.23 m (9 in) from the rear of the semitrailer, with a width of 2.44 m (96 in). Payload in the rear semitrailer was loaded as a solid block placed 2.03 m (80 in) from the front of the semitrailer running to 0.23 m (9 in) from the rear of the semitrailer, with a width of 2.44 m (96 in). This was a less than desirable arrangement, as it elevated the payload centre of gravity, but it was necessary to avoid overloading the centre tandem. The vehicle was configured precisely for every combination of tractor, lead and rear semitrailer so that no axle group was overloaded for an allowable tandem axle weight of

17,000 kg (37,787 lb). In fact, for every combination of tractor, lead and rear semitrailer, the payload was distributed so that the front axle load was within about 200 kg (441 lb) of its limit, and the drive and each semitrailer axle load was within about 100 kg (441 lb) of its limit. The height of a block of payload was determined from its weight, density of 545 kg/cu m (34 lb/cu ft), width and length, and varied from about 2.16 to 1.85 m (85 to 73 in), from the shortest to the longest lead semitrailer, and from about 2.47 to 1.98 m (97 to 79 in), from the shortest to the longest rear semitrailer respectively.

2.6 Overall Length

Four box lengths arose from the assumptions made, as shown in Table 5 for tridem-tandem B-trains, and in Table 8 for tandem-tridem B-trains. The box lengths were the same for corresponding combinations of short and long semitrailers for the two B-train configurations. Table 9 presents the overall length of tridem-tandem B-trains for these four box lengths, for the eleven tractors, each with 0.76 m (30 in) front axle setback. All combinations were within the proposed overall length of 27.5 m (90 ft 3 in, 1,083 in). Tandem-tridem B-trains would be 0.30 m (12 in) shorter, because the lead semitrailer kingpin was 0.30 m (12 in) deeper than for the tridem-tandem B-train.

Table 10 presents the overall length for a tridem-tandem B-train with 20 m (65 ft 7 in) box length for the nominal front axle setback of 0.76 m (30 in) used here, the largest common front axle setback of 1.40 m (55 in), and that setback with a moose bumper with a depth of 0.36 m (14 in). The proposed overall length of 27.5 m (90 ft 3 in, 1,083 in) was only exceeded for the tractor with the longest wheelbase of 7.16 m (282 in), and by only about 0.15 m (6 in), due to the moose bumper. This case is highlighted in bold in the Table. Minor adjustments to the many parameters within the

Table 9: Tractor Wheelbase and Overall Length for Tridem-tandem B-trains

Tractor Wheelbase	B-train Box Length			
	18.16 m (715 in)	18.77 m (739 in)	19.38 m (763 in)	20.00 m (787 in)
160 in	21.89 m (862 in)	22.50 m (886 in)	23.11 m (910 in)	23.72 m (934 in)
172 in	22.17 m (873 in)	22.78 m (897 in)	23.39 m (921 in)	24.00 m (945 in)
184 in	22.48 m (885 in)	23.09 m (909 in)	23.70 m (933 in)	24.31 m (957 in)
196 in	22.76 m (896 in)	23.37 m (920 in)	23.98 m (944 in)	24.59 m (968 in)
208 in	23.06 m (908 in)	23.67 m (932 in)	24.28 m (956 in)	24.89 m (980 in)
220 in	23.34 m (919 in)	23.95 m (943 in)	24.56 m (967 in)	25.17 m (991 in)
232 in	23.65 m (931 in)	24.26 m (955 in)	24.87 m (979 in)	25.48 m (1003 in)
244 in	23.93 m (942 in)	24.54 m (966 in)	25.15 m (990 in)	25.76 m (1014 in)
252 in	24.23 m (954 in)	24.84 m (978 in)	25.45 m (1002 in)	26.06 m (1026 in)
265 in	24.43 m (962 in)	25.04 m (986 in)	25.65 m (1010 in)	26.26 m (1034 in)
282 in	24.87 m (979 in)	25.48 m (1003 in)	26.09 m (1027 in)	26.70 m (1051 in)

Table 10: Front Axle Setback and Overall Length for 20 m Box Length Tridem-tandem B-trains

Tractor Wheelbase	Front Axle Setback		
	0.91 m (30 in)	**1.40 m (55 in)**	**1.75 m (69 in)**
160 in	23.72 m (934 in)	24.36 m (959 in)	24.71 m (973 in)
172 in	24.00 m (945 in)	24.64 m (970 in)	24.99 m (984 in)
184 in	24.31 m (957 in)	24.94 m (982 in)	25.30 m (996 in)
196 in	24.59 m (968 in)	25.22 m (993 in)	25.58 m (1007 in)
208 in	24.89 m (980 in)	25.53 m (1005 in)	25.88 m (1019 in)
220 in	25.17 m (991 in)	25.81 m (1016 in)	26.16 m (1030 in)
232 in	25.48 m (1003 in)	26.11 m (1028 in)	26.47 m (1042 in)
244 in	25.76 m (1014 in)	26.39 m (1039 in)	26.75 m (1053 in)
252 in	26.06 m (1026 in)	26.70 m (1051 in)	27.05 m (1065 in)
265 in	26.26 m (1034 in)	26.90 m (1059 in)	27.25 m (1073 in)
282 in	26.70 m (1051 in)	27.33 m (1076 in)	**27.69 m (1090 in)**

tractor and B-train could bring this within the proposed overall length of 27.5 m (90 ft 3 in, 1,083 in). Tandem-tridem B-trains were 0.30 m (12 in) shorter, because the lead semitrailer kingpin was 0.30 m (12 in) deeper than for the tridem-tandem B-train, and all tractors were within the proposed overall length of 27.5 m (90 ft 3 in, 1,083 in).

The results in Table 9 and Table 10 were based on the assumptions for internal dimensions of the B-trains presented in sections 2.3 through 2.5. Consequently, the overall lengths shown in Table 10 are not necessarily the absolute maximum overall length for any particular tractor wheelbase and front axle setback.

For B-trains with a box length of 20 m (65 ft 7 in), the overall lengths shown in Table 10 change if the lead semitrailer kingpin setback differs from the assumed value of 0.91 m (36 in). The minimum practical value is around 0.30 m (12 in), so the overall length could be up to about 0.61 m (24 in) more than the values shown in Table 10. However, there would be no change in overall length for a change in either the rear semitrailer kingpin setback, or the lead semitrailer fifth wheel setting, because any such change would be compensated by another change to maintain the box length at 20 m (65 ft 7 in). It is presumed that any such change in lead semitrailer kingpin setback would allow the axle loads to be balanced for the payloads for which the B-train was being designed.

For B-trains with a box length less than 20 m (65 ft 7 in), the overall lengths shown in Table 10 change if the either semitrailer kingpin setback differs from the assumed value, or the lead semitrailer fifth wheel setting differs from its assumed value. In this case, the maximum overall length would arise if the rear semitrailer kingpin setback and the lead semitrailer fifth wheel setting were changed to bring the box length to 20 m

(65 ft 7 in), and the lead semitrailer kingpin setback was changed to its minimum practical value around 0.30 m (12 in), when again the overall length could be up to about 0.61 m (24 in) more than the values shown in Table 10.

The tractor fifth wheel setting is an additional variable in the overall length. The tractor fifth wheel was placed forward of the centre of the drive tandem by an amount that transferred about 544 kg (1,200 lb) of kingpin load to the front axle, as described in section 2.2. If a particular tractor needs greater transfer of kingpin load, it will require a more forward fifth wheel, and an additional allowance of 0.15 m (6 in) is reasonable for this, though not necessarily an absolute maximum.

So, possible increases in overall length due to a reduced lead semitrailer kingpin setback and a more forward tractor fifth wheel together could result in an overall length up to about 0.76 m (30 in) more than the values shown in Table 10. For a tractor with 6.20 m (244 in) wheelbase, front axle setback of 1.40 m (55 in), and a moose bumper with a depth of 0.36 m (14 in), this would result in an overall length right on CTA's proposed limit of 27.5 m (1,082 in). A carrier needing a tractor with a wheelbase from 6.20 to 7.16 m (244 to 282 in) has a considerable number of parameters that can be adjusted to stay within an overall length of 27.5 m (1,082 in), whether it would be a new tractor to pull an existing B-train, or an existing tractor to pull a new B-train. There should be few tractors in Canada with a wheelbase over 6.20 m (244 in), and the likelihood that one such with a particular existing B-train would be longer than 27.5 m (1,082 in) should be rather low.

2.7 Other Factors

The principal factors in this study were the tractor wheelbase, the first factor identified in Section 2.1, and the B-train arrangement, which encompassed six of the other 12 factors identified there. The remaining six factors were:

- Front axle setback;
- Fitment of a moose bumper;
- Tractor drive axle spread;
- Tandem axle allowable weight;
- Tractor fifth wheel setting; and
- Gross weight.

These were dealt with individually, as outlined below.

2.7.1 Front Axle Setback

The work statement identified front axle setback as a factor to be considered, with a range from 0.76 to 1.40 m (30 to 55 in).

The driver model used in the computer simulation caused the front axle to be steered to follow a specific path, or to provide a specified steer input. Front axle setback is not a factor in the dynamic performance of these vehicles, because how much of the vehicle is ahead of the front axle when the vehicle is steered through a manoeuvre does not affect where the vehicle goes. In practical terms, front axle setback does affect the tare weight distribution of the tractor, so may slightly affect weight distribution on the semitrailers, but this work was done with a fixed and conservative tractor tare weight distribution.

Front axle setback within a fixed overall length may limit the tractor wheelbase, or may limit the B-train box length. This will be addressed in a general discussion of vehicle internal dimensions, box length, and overall length.

2.7.2 Fitment of a Moose Bumper

The work statement identified fitment of a moose bumper as a factor to be considered.
A moose bumper would either be fitted, or not fitted. If fitted, it would add about 100 kg (220 lb) to the tare weight of the tractor, and a little more to the tare front axle weight. The tractors were configured so that a moose bumper could be added without overloading the front axle. It would also effectively add about 0.35 m (14 in) to the front axle setback of the tractor.

The driver model used in the computer simulation caused the front axle to be steered to follow a specific path, or to provide a specified steer input. The presence of a moose bumper is not a factor in the dynamic performance of these vehicles, because how much of the vehicle is ahead of the front axle when the vehicle is steered through a manoeuvre does not affect where the vehicle goes.

In practical terms, a moose bumper does affect the tare weight distribution of the tractor, so may slightly affect weight distribution on the semitrailers, but this work was done with a fixed and conservative tractor tare weight distribution.

Fitment of a moose bumper within a fixed overall length may also limit the tractor wheelbase, or may limit the B-train box length. This will be addressed in a general discussion of vehicle internal dimensions, box length, and overall length.

2.7.3 Tractor Drive Axle Spread

The work statement identified tractor drive axle spread as a factor to be considered, either the current typical value of 1.37 m (54 in), or 1.83 m (72 in).

The current typical drive axle spread has an allowable load of 17,000 kg (37,478 lb) in the four western provinces, or 18,000 kg (39,683 lb) in Ontario, Québec and the four Atlantic provinces, as shown in Table 2. Ontario still allows 19,100 kg (42,108 lb) for a 1.83 m (72 in) tractor drive axle spread. Ontario already allows an excess of 2,000 kg (4,409 lb) of axle capacity over allowable gross weight with a typical drive axle spread, as shown in Table 2, and a 1.83 m (72 in) drive axle spread would add another 1,100 kg (2,425 lb) to this. This additional axle capacity would most likely be useful only for a special application, such as when the tractor had a permanently mounted crane.

The effect of a 19,100 kg (42,108 lb) tandem axle load was evaluated by reducing the lead semitrailer payload length to achieve a drive tandem load close to this, without causing an overload on the front axle.

This change was run for only the worst performing B-train combination.

2.7.4 Tandem Axle Allowable Weight

The work statement identified tandem axle allowable weight as a factor to be considered, either 17,000 or 18,000 kg (37,478 or 39,683 lb). The former is the limit in the four western provinces, while the latter prevails in Ontario, Québec and the four Atlantic provinces, as shown in Table 2. The vehicle weight distribution was set up based on a tandem axle load of 17,000 kg (37,478 lb) for the drive or rear semitrailer axle groups. This weight distribution would also work for a tandem axle load of 18,000 kg (39,683 lb).

The effect of a tandem axle load of 18,000 kg (39,683 lb) was evaluated by:

1. Reducing the lead semitrailer payload length to achieve a drive tandem load very close to 18,000 kg (39,683 lb); or.
2. Reducing the rear semitrailer payload length to achieve a rear semitrailer tandem load very close to 18,000 kg (39,683 lb); or
3. Reducing both semitrailer payload lengths to achieve a load very close to 18,000 kg (39,683 lb) on both the drive and rear semitrailer tandems, in each case, without causing an overload on any other axle group.

These changes were run for only the worst performing B-train combination.

2.7.5 Tractor Fifth Wheel Setting

The work statement identified tractor fifth wheel setting as a factor to be considered.

Fifth wheel setting should not be a factor for a tractor set up to haul a B-train, where the allowable gross weight is generally close to the sum of allowable axle loads. A fully loaded B-train lead semitrailer should have sufficient kingpin load, and the tractor fifth wheel should be appropriately positioned, so that the drive tandem and the front axle are both loaded close to, but not over, their allowable axle loads. This work encompassed a wide range of tractor wheelbases, with the same tare front and drive axle loads for each wheelbase. A tare front axle load was used for all tractors, and the fifth wheel was automatically positioned to transfer about 544 kg (1,200 b) of kingpin load to the front axle, to avoid overloading the drive axle. Any deviation from this would limit the payload weight, or restrict weight distribution in the four western provinces, where the sum of axle weights equals the allowable gross weight. If the fifth wheel is not set close to the ideal location, the payload weight would be reduced, which would result in an improvement in dynamic performance.

There was therefore no need to examine this factor.

2.7.6 Allowable Gross Weight

The work statement identified allowable gross weight as a factor to be considered.

Table 2 shows that the allowable gross weight is 62,500 kg (137,787 lb) in Québec and the four Atlantic provinces, and 63,500 kg (139,992 lb) in Ontario and the four western provinces. The work evaluated the high-speed performance measures at 63,500 kg (139,992 lb) for all tractor and B-train combinations.

If the dynamic performance is satisfactory at payloads for a gross weight of 63,500 kg (139,992 lb), there would be no need to evaluate the high-speed performance measures at 62,500 kg (137,787 lb). Removing 1,000 kg (2,205 lb) of payload reduced both payload weight and centre of gravity height, which individually and together would result in an improvement in dynamic performance. If a vehicle performed satisfactorily at 63,500 kg (139,992 lb), it would perform better at 62,500 kg (137,787 lb).

There was therefore no need to examine this factor in detail. This change was run for only the worst performing B-train combination.

3. COMPUTER SIMULATION

3.1 Simulation Procedure

This work evaluated the following customary performance measures:

- Static roll threshold;
- High-speed offtracking;
- Load transfer ratio;
- Transient offtracking;
- Low-speed offtracking
- Front outswing; and
- Rear outswing.

The performance measures, the related performance standards, and the simulation procedures are described in Appendix 3.

The CCMTA/RTAC Vehicle Weights and Dimensions Study evaluated the high-speed performance measures at 100 km/h (62.1 mi/h), so this serves as the baseline speed [2]. Some provinces allow a speed of 110 km/h (68.3 mi/h) on certain highways, while the speed of LCVs is limited 90 km/h (55.9 mi/h) where they are allowed to operate. For this work, the high-speed performance measures were evaluated at 90, 100 and 110 km/h (55.9, 62.1 and 68.3 mi/h).

The low-speed performance measures were evaluated at 8.8 km/h (5 mi/h).

There were 11 tractors, 2 B-trains each with 4 lead semitrailer lengths and 4 rear semitrailer lengths, so 11 x 2 x 4 x 4 = 352 configurations. Each was run at 3 speeds for two runs to determine the high-speed performance measures, and one speed for two runs to determine the low-speed performance measures, so there were 352 x (3 x 2 + 2) = 2,816 individual runs, plus a few more to address other factors.

3.2 Results

The bulk results for tridem-tandem B-trains are presented in Appendix 1, and for tandem-tridem B-trains in Appendix 2. Each Appendix contains three tables, for low-speed performance measures, static roll threshold, and high-speed performance measures. Each table includes results for all 11 tractor wheelbases described in Section 2.2, with each combination of B-train lead and rear semitrailer with a box length not over 20 m (65 ft 7 in), as shown in Table 5 for tridem-tandem B-trains, or Table 8 for tandem-tridem B-trains.

The results are presented and discussed in the next chapter.

4. DISCUSSION OF RESULTS

4.1 Low-speed Performance Measures

Table 11 presents the low-speed performance measures for all tractors with each B-train axle configuration with its shortest lead and rear semitrailers. Under the assumptions used in this work, this table shows that the low-speed offtracking increased with an increase in tractor wheelbase, rear outswing and friction demand were not materially affected by tractor wheelbase, and lateral friction utilization decreased with an increase in tractor wheelbase, for both B-train axle configurations. Rear outswing and lateral friction utilization were both well inside their respective performance standards, so neither would be a matter of concern for the tractors and B-trains considered here.

Table 11: Effect of Tractor Wheelbase on Low-speed Offtracking

Tractor WB	Tridem-tandem B-train				Tandem-tridem B-train			
	Low-speed OT (<5.6 m)	Rear OS (<0.2 m)	Friction Demand (<0.10)	Lateral Friction Utiliz'n (<0.80)	Low-speed OT (<5.6 m)	Rear OS (<0.2 m)	Friction Demand (<0.10)	Lateral Friction Utiliz'n (<0.80)
160 in	4.263	0.008	**0.149**	0.297	4.098	0.012	0.034	0.300
172 in	4.326	0.007	**0.151**	0.282	4.166	0.012	0.037	0.281
184 in	4.394	0.007	**0.153**	0.273	4.239	0.011	0.041	0.270
196 in	4.468	0.007	**0.153**	0.259	4.316	0.011	0.043	0.256
208 in	4.545	0.007	**0.154**	0.254	4.399	0.010	0.045	0.253
220 in	4.629	0.007	**0.154**	0.243	4.487	0.010	0.047	0.242
232 in	4.716	0.007	**0.154**	0.235	4.579	0.009	0.049	0.236
244 in	4.810	0.006	**0.154**	0.237	4.673	0.009	0.050	0.232
252 in	4.904	0.006	**0.154**	0.224	4.774	0.009	0.052	0.228
265 in	4.981	0.006	**0.153**	0.228	4.851	0.009	0.052	0.222
282 in	5.129	0.006	**0.153**	0.224	5.003	0.008	0.053	0.219

The level of friction demand shown for each B-train axle configuration was typical for that axle configuration. While the values exceeded the performance standard for the tridem-tandem B-train, so are highlighted in bold, recent tests have shown that this performance measure is not critically related to safety [3]. Friction demand therefore would not be a concern for the tractors and B-trains being considered here.

Table 12 presents the low-speed offtracking for all B-train combinations considered, and the five tractors with the longest wheelbase. The second column contains the lead semitrailer length for tridem/tandem and tandem-tridem B-trains, respectively. The empty cells were for box lengths that would exceed 20 m (65 ft 7 in). Cases where the

Table 12: Effect of Tractor Wheelbase and B-train Combination on Low-speed Offtracking

Tractor WB	Lead Length	Tridem-tandem B-train Rear Semitrailer Length				Tandem-tridem B-train Rear Semitrailer Length			
		28 ft	30 ft	32 ft	34 ft	34 ft	36 ft	38 ft	40 ft
232 in	**28/22 ft**	4.716	4.746	4.862	5.065	4.579	4.757	4.939	5.138
232 in	**30/24 ft**	4.982	5.011	5.127		4.787	4.964	5.146	
232 in	**32/26 ft**	5.256	5.284			5.026	5.202		
232 in	**34/28 ft**	5.539				5.275			
244 in	**28/22 ft**	4.810	4.839	4.955	5.155	4.673	4.849	5.030	5.228
244 in	**30/24 ft**	5.074	5.102	5.218		4.879	5.054	5.235	
244 in	**32/26 ft**	5.346	5.374			5.115	5.290		
244 in	**34/28 ft**	**5.626**				5.365			
256 in	**28/22 ft**	4.904	4.933	5.048	5.248	4.774	4.949	5.129	5.324
256 in	**30/24 ft**	5.169	5.197	5.311		4.979	5.153	5.332	
256 in	**32/26 ft**	5.439	5.468			5.213	5.387		
256 in	**34/28 ft**	**5.718**				5.459			
265 in	**28/22 ft**	4.981	5.010	5.124	5.322	4.851	5.026	5.205	5.400
265 in	**30/24 ft**	5.243	5.271	5.384		5.055	5.229	5.407	
265 in	**32/26 ft**	5.511	5.539			5.289	5.462		
265 in	**34/28 ft**	**5.788**				5.534			
282 in	**28/22 ft**	5.129	5.157	5.270	5.466	5.003	5.176	5.354	5.548
282 in	**30/24 ft**	5.387	5.415	5.528		5.205	5.377	5.554	
282 in	**32/26 ft**	**5.654**	**5.681**			5.436	5.608		
282 in	**34/28 ft**	**5.930**				**5.679**			

low-speed offtracking exceeded the performance standard of 5.60 m (220 in) are highlighted in bold. These were mostly for the longest lead semitrailer with the shortest rear semitrailer for a tridem-tandem B-train.

4.2 Static Roll Threshold

Table 13 presents the static roll threshold for all tractors with each B-train axle configuration with its shortest lead and rear semitrailers. Under the assumptions used in this work, this table shows that the static roll threshold was not affected by either tractor wheelbase, or vehicle speed, for either B-train axle configuration. The static roll threshold was lower for the tandem-tridem B-train than for the tridem-tandem B-train because payload must be kept away from the rear of the lead semitrailer and the front of the rear semitrailer to avoid overloading the centre tandem of the tandem-tridem B-train, which resulted in a higher payload centre of gravity. The static roll threshold for a specialized tandem-tridem B-train that could be loaded the entire length of each semitrailer would be essentially the same as for the tridem-tandem B-train. Neither B-train axle configuration met the performance standard of 0.40 g.

Table 14 presents the static roll threshold for each B-train axle configuration, for all B-train semitrailer combinations with a box length up 20 m (65 ft 7 in). The empty cells were for box lengths that would exceed 20 m (65 ft 7 in). Each entry in this table was an average for all eleven tractor wheelbases and all three speeds for each combination of tractor, lead and rear semitrailer. The static roll threshold increased as the length of either semitrailer increased, because a fixed payload weight of fixed density and fixed width was loaded in each semitrailer, so the payload centre of gravity height diminished as the semitrailer length increased.

Table 13: Effect of Tractor Wheelbase on Static Roll Threshold

Tractor Wheelbase	Tridem-tandem B-train			Tandem-tridem B-train		
	90 km/h	100 km/h	110 km/h	90 km/h	100 km/h	110 km/h
160 in	0.359	0.359	0.361	0.338	0.339	0.342
172 in	0.359	0.359	0.360	0.339	0.340	0.341
184 in	0.359	0.360	0.361	0.339	0.340	0.342
196 in	0.359	0.360	0.360	0.339	0.340	0.341
208 in	0.360	0.360	0.361	0.339	0.340	0.341
220 in	0.360	0.360	0.361	0.339	0.340	0.341
232 in	0.360	0.361	0.361	0.339	0.340	0.342
244 in	0.360	0.361	0.361	0.339	0.340	0.342
252 in	0.361	0.361	0.361	0.339	0.340	0.342
265 in	0.361	0.361	0.361	0.339	0.340	0.341
282 in	0.361	0.361	0.362	0.339	0.340	0.341

Table 14: Effect of B-train Combination on Static Roll Threshold

Lead Length	Tridem-tandem B-train Rear Semitrailer Length				Tandem-tridem B-train Rear Semitrailer Length			
	28 ft	30 ft	32 ft	34 ft	34 ft	36 ft	38 ft	40 ft
28/22 ft	0.360	0.376	0.385	0.390	0.340	0.349	0.357	0.364
30/24 ft	0.366	0.382	0.391		0.343	0.352	0.360	
32/26 ft	0.370	0.387			0.346	0.355		
34/28 ft	0.376				0.349			

The values shown in Table 14 are typical for a B-train loaded to 63,500 kg (139,992 kg) and loaded as described in Section 2.3.3. B-trains, and many other vehicles, that operate within the regulations of all provinces, and are loaded close to their allowable gross weight with a relatively high payload, operate at a static roll threshold between 0.35 and 0.40 g.

4.3 High-speed Offtracking

Table 15 presents the high-speed offtracking for all tractors with each B-train axle configuration with its shortest lead and rear semitrailers. Under the assumptions used in this work, this table shows that the high-speed offtracking increased with an increase in tractor wheelbase, and also increased with an increase in vehicle speed. All entries exceeded the performance standard of 0.46 m (18 in).

Table 16 presents the high-speed offtracking for all B-train semitrailer combinations with a box length up to 20 m (65 ft 7 in) for each B-train axle configuration, pulled by a tractor with 5.28 m (208 in) wheelbase. All entries exceeded the performance standard of 0.46 m (18 in). However, high-speed offtracking was not materially affected by the B-train combination semitrailer length, for all B-train combinations considered with a box length up to 20 m (65 ft 7 in), and for each B-train axle configuration.

Table 9 shows that it is possible to use a 6.20 m (244 in) wheelbase tractor within 25 m (65 ft 7 in) overall length if the B-train box length is suitably restricted, and

Table 16 showed that high-speed offtracking was not materially affected by the B-train combination semitrailer length. On that basis, from Table 15, B-trains within the provincial regulations may have high-speed offtracking from about 0.51 to 0.60 m (20 to 24 in) at 100 km/h (62.1 mi/h), which exceeds the performance of 0.46 m (18 in) by 0.05 to 0.14 m (2 to 6 in).

Table 15: Effect of Tractor Wheelbase on High-speed Offtracking

Tractor Wheelbase	Tridem-tandem B-train			Tandem-tridem B-train		
	90 km/h	100 km/h	110 km/h	90 km/h	100 km/h	110 km/h
160 in	0.473	0.511	0.539	0.495	0.530	0.557
172 in	0.482	0.521	0.550	0.504	0.540	0.568
184 in	0.493	0.532	0.561	0.514	0.551	0.579
196 in	0.501	0.542	0.572	0.523	0.561	0.589
208 in	0.511	0.552	0.583	0.532	0.571	0.600
220 in	0.519	0.561	0.593	0.540	0.580	0.610
232 in	0.528	0.571	0.604	0.549	0.590	0.621
244 in	0.536	0.580	0.613	0.556	0.599	0.630
252 in	0.544	0.589	0.623	0.564	0.608	0.640
265 in	0.549	0.595	0.630	0.569	0.614	0.647
282 in	0.560	0.608	0.644	0.580	0.626	0.661

Table 16: Effect of B-train Combination on High-speed Offtracking

Tridem-tandem B-train				Tandem-tridem B-train			
Trailer Lengths	90 km/h	100 km/h	110 km/h	Trailer Lengths	90 km/h	100 km/h	110 km/h
28/28 ft	0.511	0.552	0.583	22/34 ft	0.532	0.571	0.600
28/30 ft	0.503	0.545	0.576	22/36 ft	0.528	0.569	0.599
28/32 ft	0.501	0.544	0.575	22/38 ft	0.523	0.566	0.599
28/34 ft	0.501	0.547	0.580	22/40 ft	0.519	0.564	0.598
30/28 ft	0.508	0.552	0.586	24/34 ft	0.537	0.578	0.609
30/30 ft	0.500	0.545	0.578	24/36 ft	0.532	0.575	0.608
30/32 ft	0.498	0.544	0.578	24/38 ft	0.528	0.573	0.607
32/28 ft	0.505	0.553	0.588	26/34 ft	0.539	0.583	0.616
32/30 ft	0.497	0.545	0.581	26/36 ft	0.534	0.580	0.614
34/28 ft	0.501	0.552	0.591	28/34 ft	0.540	0.587	0.622

High-speed offtracking would appear to be a concern for the tractors and B-trains being considered here, but most of these vehicles are legal in all provinces. The actual amount of high-speed offtracking is not an issue on roads or freeway ramps with a speed limit up to 70 km/h (43.5 mi/h), or on a modern divided highway, which has a design speed that likely exceeds the highest truck operating speed [4]. The actual amount of high-speed offtracking may be an issue for winding two-lane highways with a speed limit from 80 to 100 km/h (49.7 to 62.1 mi/h) where the lanes are narrow, and shoulders are narrow or non-existent, and the operating speed of vehicles may exceed the design speed of the highway.

4.4 Load Transfer Ratio

Table 17 presents the load transfer ratio for all tractors with each B-train axle configuration with its shortest lead and rear semitrailers. Under the assumptions used in this work, this table shows that the load transfer ratio decreased with an increase in tractor wheelbase, and increased with an increase in vehicle speed. All entries met the performance standard of 0.60.

Table 18 presents the load transfer ratio for all B-train semitrailer combinations with a box length up 20 m (65 ft 7 in) for each B-train axle configuration, pulled by a tractor with 5.28 m (208 in) wheelbase. This shows that the load transfer ratio decreased with an increase in either semitrailer length, for each B-train axle configuration. All entries met the performance standard of 0.60.
In the evasive manoeuvre on which this performance measure is based, the semitrailers in a double trailer combination tend to roll out-of-phase with each other, so for example while the lead semitrailer rolls to the left, the rear semitrailer is rolling to the right. An A-train has no roll coupling between its trailers, and rearward amplification of lateral

acceleration can lead to rollover of the rear trailer if the manoeuvre is sufficiently aggressive. A B-train has roll coupling between its semitrailers, so when one semitrailer rolls to the left and the other is rolling to the right, each semitrailer tends to resist the tendency of the other to roll over. The two semitrailers may not be exactly out-of-phase, as the phasing depends on the vehicle speed, the steer period, the lengths of the semitrailers, and other details of the vehicle. So a situation may arise where one semitrailer is close to maximum roll to the left, but the other is moving to the right but is just past upright, when it is possible for the load transfer ratio to get quite high.

Table 17: Effect of Tractor Wheelbase on Load Transfer Ratio

Tractor Wheelbase	Tridem-tandem B-train			Tandem-tridem B-train		
	90 km/h	100 km/h	110 km/h	90 km/h	100 km/h	110 km/h
160 in	0.541	0.590	0.632	0.584	0.634	0.679
172 in	0.537	0.586	0.628	0.579	0.631	0.676
184 in	0.531	0.582	0.625	0.575	0.627	0.673
196 in	0.525	0.576	0.620	0.568	0.621	0.668
208 in	0.519	0.571	0.615	0.562	0.616	0.662
220 in	0.512	0.564	0.609	0.554	0.609	0.656
232 in	0.504	0.557	0.603	0.547	0.602	0.649
244 in	0.496	0.550	0.596	0.539	0.594	0.642
252 in	0.488	0.542	0.589	0.530	0.587	0.634
265 in	0.482	0.536	0.583	0.523	0.580	0.628
282 in	0.470	0.525	0.572	0.511	0.568	0.617

Table 18: Effect of B-train Combination on Load Transfer Ratio

Tridem-tandem B-train				Tandem-tridem B-train			
Trailer Lengths	90 km/h	100 km/h	110 km/h	Trailer Lengths	90 km/h	100 km/h	110 km/h
28/28 ft	0.519	0.571	0.615	**22/34 ft**	0.562	0.616	0.662
28/30 ft	0.496	0.547	0.591	**22/36 ft**	0.535	0.589	0.634
28/32 ft	0.479	0.530	0.573	**22/38 ft**	0.513	0.565	0.610
28/34 ft	0.464	0.514	0.557	**22/40 ft**	0.493	0.545	0.588
30/28 ft	0.492	0.544	0.589	**24/34 ft**	0.540	0.595	0.642
30/30 ft	0.470	0.521	0.566	**24/36 ft**	0.514	0.568	0.614
30/32 ft	0.454	0.504	0.548	**24/38 ft**	0.492	0.546	0.590
32/28 ft	0.468	0.520	0.566	**26/34 ft**	0.516	0.572	0.619
32/30 ft	0.447	0.498	0.543	**26/36 ft**	0.491	0.546	0.592
34/28 ft	0.447	0.498	0.543	**28/34 ft**	0.494	0.550	0.598

However, this is a momentary condition. The roll of the semitrailer rolling to the left is slowing, while the roll of the other semitrailer to the right is increasing fast, which quickly abates the magnitude of the load transfer ratio. An A-train and a B-train may both be quite lively in an evasive manoeuvre. However, while the rear trailer of the A-train may be rolled over quite readily, it is rather difficult to roll a B-train in this manoeuvre, and these results bear that out. It is considered very difficult for a driver to roll over a B-train in any evasive manoeuvre where the driver manages to keep the vehicle on the paved roadway and avoid a collision.

Load transfer ratio would not be a concern for the tractors and B-trains considered here.

4.5 Transient Offtracking

Table 19 presents the transient offtracking for all tractors with each B-train axle configuration with its shortest lead and rear semitrailers. Under the assumptions used in this work, this table shows that the transient offtracking was not materially affected by tractor wheelbase, and increased with vehicle speed. All entries met the performance standard of 0.80 m (32 in) at 90 km/h (55.8 mi/h, and exceeded it at 100 km/h (62.1 mi/h), marginally for the tridem-tandem axle configuration, less marginally for the tandem-tridem configuration.

Table 20 presents the transient offtracking for all B-train semitrailer combinations with a box length up 20 m (65 ft 7 in) for each B-train axle configuration, pulled by a tractor with 5.28 m (208 in) wheelbase. This shows that the transient offtracking decreased with an increase in either semitrailer length, for each B-train axle configuration.

Table 19: Effect of Tractor Wheelbase on Transient Offtracking

Tractor Wheelbase	Tridem-tandem B-train			Tandem-tridem B-train		
	90 km/h	100 km/h	110 km/h	90 km/h	100 km/h	110 km/h
160 in	0.671	**0.816**	**0.949**	0.719	**0.869**	**1.004**
172 in	0.675	**0.822**	**0.957**	0.724	**0.875**	**1.013**
184 in	0.681	**0.829**	**0.966**	0.729	**0.882**	**1.021**
196 in	0.682	**0.831**	**0.968**	0.729	**0.883**	**1.023**
208 in	0.683	**0.833**	**0.971**	0.730	**0.885**	**1.027**
220 in	0.680	**0.831**	**0.969**	0.726	**0.882**	**1.024**
232 in	0.678	**0.829**	**0.969**	0.724	**0.880**	**1.024**
244 in	0.673	**0.824**	**0.964**	0.717	**0.874**	**1.018**
252 in	0.669	**0.821**	**0.961**	0.713	**0.870**	**1.015**
265 in	0.664	**0.815**	**0.956**	0.707	**0.863**	**1.008**
282 in	0.656	**0.807**	**0.948**	0.698	**0.854**	**1.000**

Table 20: Effect of B-train Combination on Transient Offtracking

Tridem-tandem B-train				Tandem-tridem B-train			
Trailer Lengths	**90 km/h**	**100 km/h**	**110 km/h**	**Trailer Lengths**	**90 km/h**	**100 km/h**	**110 km/h**
28/28 ft	0.683	**0.833**	**0.971**	**22/34 ft**	0.730	**0.885**	**1.027**
28/30 ft	0.675	**0.824**	**0.962**	**22/36 ft**	0.708	**0.864**	**1.007**
28/32 ft	0.666	**0.817**	**0.957**	**22/38 ft**	0.688	**0.845**	**0.989**
28/34 ft	0.653	**0.807**	**0.949**	**22/40 ft**	0.668	**0.825**	**0.971**
30/28 ft	0.648	0.799	**0.938**	**24/34 ft**	0.708	**0.865**	**1.009**
30/30 ft	0.641	0.791	**0.930**	**24/36 ft**	0.687	**0.845**	**0.990**
30/32 ft	0.633	0.785	**0.925**	**24/38 ft**	0.668	**0.826**	**0.973**
32/28 ft	0.615	0.765	**0.904**	**26/34 ft**	0.680	**0.837**	**0.983**
32/30 ft	0.609	0.759	**0.897**	**26/36 ft**	0.660	**0.817**	**0.965**
34/28 ft	0.582	0.732	**0.871**	**28/34 ft**	0.651	**0.809**	**0.956**

4.6 Other Factors

The significant other factors identified in Section 2.7 were tractor drive axle spread, tandem axle allowable weight and allowable gross weight. These factors had no effect on the low-speed performance measures, so were run only for the high-speed performance measures. Inspection of Table 13 through Table 20 indicates that the poorest dynamic performance for both the tridem-tandem and tandem-tridem B-train is for any tractor with the shortest B-train, i.e. the shortest lead semitrailer with the shortest rear semitrailer. These were run with a 5.28 m (208 in) wheelbase tractor.

4.6.1 Tractor Drive Axle Spread

The effect on high-speed offtracking and transient offtracking of a tractor drive axle spread of 1.83 m (72 in), with an allowable tandem axle load of 19,100 kg (42,108 lb) in Ontario, is presented in Table 21 and
Table 22 respectively. The results are for a 5.28 m (208 in) wheelbase for each B-train axle configuration with its shortest lead and rear semitrailers. The effect was achieved by reducing the lead semitrailer payload length, which resulted in an increase in the payload centre of gravity height. The effect of this change in payload weight distribution, without any change in gross weight, was a small increase in the two performance measures.

Table 21: Effect of Tractor Drive Axle Spread on High-speed Offtracking

Drive Axle Spread	Tridem-tandem B-train			Tandem-tridem B-train		
	90 km/h	**100 km/h**	**110 km/h**	**90 km/h**	**100 km/h**	**110 km/h**
54 in	0.511	0.552	0.583	0.532	0.571	0.600
72 in	0.517	0.559	0.590	0.533	0.573	0.602

Table 22: Effect of Tractor Drive Axle Spread on Transient Offtracking

Drive Axle Spread	Tridem-tandem B-train			Tandem-tridem B-train		
	90 km/h	100 km/h	110 km/h	90 km/h	100 km/h	110 km/h
54 in	0.683	0.833	0.971	0.730	0.885	1.027
72 in	0.702	0.855	0.994	0.735	0.887	1.025

4.6.2 Tandem Axle Allowable Weight

The effect of a change from the baseline tandem axle load of 17,000 kg (37,478 lb) to 18,000 kg (39,682 lb) was considered for a 5.28 m (208 in) wheelbase tractor for each B-train axle configuration with its shortest lead and rear semitrailers.

Three cases were considered for the tridem-tandem B-train:

- 18000 kg on the drive axles only, achieved by reducing the lead semitrailer payload length from the rear so that the drive axle weight increased by about 1,000 kg (2,205 lb);
- 18,000 kg on the rear semitrailer axles, achieved by reducing the rear semitrailer payload length from the front so that the rear semitrailer weight increased by about 1,000 kg (2,205 lb); and
- 18,000 kg on both axle groups, achieved by reducing both payloads simultaneously.

One case was considered for the tandem-tridem B-train, transferring 1,996 kg (4,400 lb) of payload from the rear semitrailer to the front semitrailer, without change of payload length.

The effect on high-speed offtracking and transient offtracking is presented in Table 23 and Table 24 and Table 26, respectively. Each case resulted in a modest increase in each performance measure, because changing the payload length increased its centre of gravity height.

Table 23: Effect of 18,000 kg Tandem Axle Weight on High-speed Offtracking

18.000 kg Axle	Tridem-tandem B-train			Tandem-tridem B-train		
	90 km/h	100 km/h	110 km/h	90 km/h	100 km/h	110 km/h
None	0.511	0.552	0.583	0.532	0.571	0.600
Drive	0.513	0.555	0.586			
Rear	0.516	0.557	0.588			
Both	0.519	0.560	0.591	0.525	0.564	0.593

Table 24: Effect of 18,000 kg Tandem Axle Weight on Transient Offtracking

Tractor Wheelbase	Tridem-tandem B-train			Tandem-tridem B-train		
	90 km/h	100 km/h	110 km/h	90 km/h	100 km/h	110 km/h
None	0.683	0.833	0.971	0.730	0.885	1.027
Drive	0.689	0.841	0.979			
Rear	0.691	0.840	0.978			
Both	0.696	0.847	0.985	0.722	0.877	1.017

4.6.3 Allowable Gross Weight

The effect of an allowable gross weight of 62,500 kg (137,787 lb) on high-speed offtracking and transient offtracking is presented in Table 25 and Table 26 respectively. The results are for a 5.28 m (208 in) wheelbase tractor for each B-train axle configuration with its shortest lead and rear semitrailers. The effect was achieved by removing 499 kg (1,100 lb) of payload from each semitrailer, which resulted in a modest reduction the payload centre of gravity height. The effect of these reductions in payload weight and payload centre of gravity height is a small reduction in the two performance measures.

A B-train that operates in Quebec and the Atlantic provinces at a gross weight of 62,500 kg (137,787 lb) does so with very slightly better dynamic performance than one carrying 1,000 kg (2,205 lb) more payload in the rest of Canada.

Table 25: Effect of 62,500 kg Allowable Gross Weight on High-speed Offtracking

Gross Weight	Tridem-tandem B-train			Tandem-tridem B-train		
	90 km/h	100 km/h	110 km/h	90 km/h	100 km/h	110 km/h
63,500 kg	0.511	0.552	0.583	0.532	0.571	0.600
62,500 kg	0.501	0.542	0.573	0.522	0.561	0.590

Table 26: Effect of 62,500 kg Allowable Gross Weight on Transient Offtracking

Gross Weight	Tridem-tandem B-train			Tandem-tridem B-train		
	90 km/h	100 km/h	110 km/h	90 km/h	100 km/h	110 km/h
63,500 kg	0.683	0.833	0.971	0.730	0.885	1.027
62,500 kg	0.668	0.817	0.953	0.713	0.867	1.007

4.7 Front Outswing

Front outswing occurs when a power unit is partially through the turn, as seen in Figure 3. The single unit dump truck turned right out of an off-road facility, and crossed the centre-line of the road into the lane of an approaching vehicle. Figure 3 is a still from a video sequence taken from the approaching vehicle that illustrates approximately the maximum amount front outswing, estimated at 0.69 to 0.76 m (27 to 30 in), by scaling from the picture.

Figure 3: Front Outswing of a Power Unit in a Low-speed Right-hand Turn

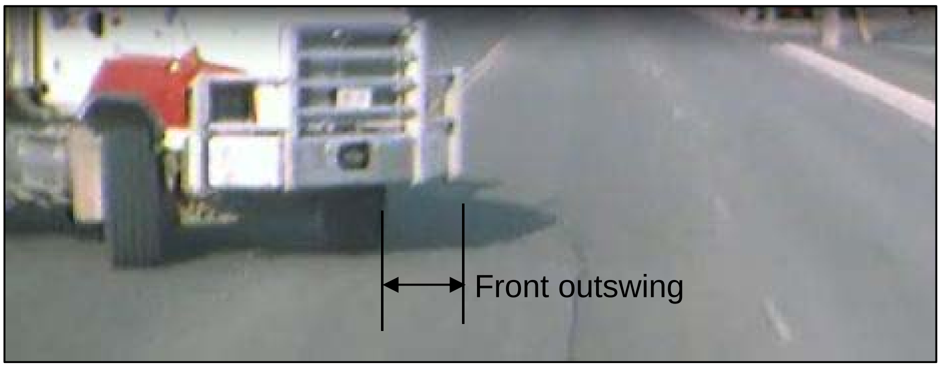


Table 27: Front Outswing of a Power Unit

Wheelbase	Front Axle Setback		
	0.76 m (30 in)	**1.22 m (48 in)**	**1.68 m (66 in)**
4.0 m (156 in)	0.22 m (9 in)	0.35 m (14 in)	0.48 m (19 in)
5.1 m (200 in)	0.28 m (11 in)	0.44 m (17 in)	0.61 m (24 in)
6.2 m (244 in)	0.34 m (13 in)	0.54 m (21 in)	0.74 m (29 in)

Table 27 shows the maximum front outswing of a power unit with specified wheelbase and front axle setback in a turn of 14 m (46 ft) radius. Front outswing increased as tractor wheelbase increased, and as front axle setback increased. The results in Table 27 assume that full offtracking had developed in the turn, and that the front corners of the vehicle were square. The values in Table 27 would be reduced for a vehicle with a radius or chamfer on its front corners. Significant front outswing is likely for a variety of body styles of straight truck, such as cement mixers or fire trucks that have an extended front bumper with equipment mounted on it, or any truck or tractor with a large front axle setback and a moose bumper, which might be similar to that seen on the truck in Figure 3.

Rear outswing of trailers clearly has safety implications. A driver making a right-hand turn at an intersection cannot see the left rear corner of the trailer during the turn for many trailer body styles. If the left rear corner of the trailer swings out into the lane to the left of the vehicle during the turn, a vehicle travelling in that lane may encounter the corner of the trailer without apparent warning, and any collision may have serious consequences if the other vehicle is travelling at the prevailing speed, such as when it is crossing directly across the road into which the truck is turning. Consequently, rear outswing is addressed by a formal performance standard, and is controlled in the M.o.U. and the regulations of all provinces, though it is not actually an issue for the B-trains considered here.

The issue of front outswing of a power unit is less clear. The front left corner of a turning power unit may potentially intrude into the space of other vehicles in the road into which the truck is turning, in the manner illustrated in Figure 3, and even if its wheels stay within its own space. The driver of the turning vehicle can see the front left corner of the power unit, can also see any vehicle approaching, and the driver of an approaching vehicle can see the truck making the turn. If any driver feels there will potentially be a conflict, the driver will give way momentarily, and conflict will be avoided. There is no formal performance standard for front outswing, it is not controlled in the M.o.U., or the regulations of any province

4.8 Comparison with Previous Work

The baseline 8-axle B-train considered in the CCMTA/RTAC Vehicle Weights and Dimensions Study was a tridem-tandem that was rather similar to those considered here, but used a 4.83 m (190 in) wheelbase tractor with two 8.23 m (27 ft) semitrailers, but was loaded to a gross weight of 56,500 kg (124,560 lb) [2]. The same combination was also evaluated at a gross weight of 64,500 kg (142,196 lb), with a front axle load of 6,500 kg (14,330 lb), tandem axle loads of 17,000 kg (37,478 lb), and a tridem axle load of 24,000 kg (52,910 lb), the only case from the Vehicle Weights and Dimensions Study that was close in dimensions and weights to the vehicles considered here.

Table 28 compares the static roll threshold and high-speed performance measures for this configuration with the tridem-tandem B-train considered with two 8.53 m (28 ft) semitrailers and a 4.98 m (196 in) wheelbase tractor for manoeuvres made at 100 km/h (62.1 mi/h). As far as can be determined, the payload weights and centre of gravity heights for the two vehicles were comparable, and the results are certainly reasonably

Table 28: Comparison of Dynamic Performance of B-trains

Performance Measure	VWD Study [2]	This Work
Static roll threshold	0.36 g	0.36 g
High-speed offtracking	0.49 m	0.54 m
Load transfer ratio	0.57	0.58
Transient offtracking	0.72 m	0.83 m

comparable, despite a number of differences in detail between the two vehicles. The results found here therefore do not seem significantly out of line with those used as the basis for configuration of B-trains in the M.o.U.

4.9 Summary

This discussion provides the following general conclusions for all combinations of tractor and tridem-tandem or tandem-tridem B-train:

- Static roll threshold was typical of any B-train carrying the payload considered here, depended on B-train box length and axle configuration, and was not affected by tractor wheelbase;
- High-speed offtracking increased with increased tractor wheelbase, and the performance standard was exceeded for all tractors with all B-trains;
- Load transfer ratio decreased with increased tractor wheelbase, and all tractors met the performance standard with all B-trains;
- Transient offtracking was not affected by tractor wheelbase, but was marginal at 100 km/h (62.1 mi/h), and exceeded the performance standard at 110 km/h (68.3 mi/h);
- Low-speed offtracking increased with increased tractor wheelbase and B-train box length, and tractors with a wheelbase over 6.20 m (244 in) with a tridem-tandem B-train with 20 m (65 ft 7 in) box length and the longest lead semitrailer just exceeded the performance standard;
- Friction demand was not affected by tractor wheelbase, and while all tractors exceeded the performance standard with all tridem-tandem B-trains, this performance measure is now considered not critically related to safety;
- Front outswing increased with increased front axle setback and the presence of a moose bumper, but other vehicles have comparable front overhang, and there is no formal performance standard;
- Rear outswing was not affected by tractor wheelbase, and all tractors met the performance standard with all B-trains;
- Minor changes in allowable axle loads do not significantly affect dynamic performance; and
- These results are typical for fully loaded M.o.U. B-trains.

The key performance measures for this work were therefore only:

- High-speed offtracking, for both B-train axle configurations; and
- Low-speed offtracking, for tridem-tandem B-trains only.

These are discussed in more detail below for each of the following four tractor and B-train options:

1. Tractors that can currently pull a 20 m (65 ft 7 in) box length B-train within the current overall length of 25 m (82 ft);
2. Tractors up to 6.20 m (244 in) wheelbase pulling a reduced box length B-train

within the current overall length of 25 m (82 ft);

3. Tractors up to 6.20 m (244 in) wheelbase pulling a 20 m (65 ft 7 in) box length B-train within an overall length of 27.5 m(90 ft 3 in); and
4. Tractors up to 7.16 m (282 in) wheelbase pulling a B-train up to 20 m (65 ft 7 in), box length within an overall length of 27.5 m (90 ft 3 in).

5. TRACTORS FOR A 20 M B-TRAIN WITHIN 25 M

5.1 Scope

This chapter addresses B-trains that currently operate within the M.o.U., and the regulations of all provinces. It presents the dynamic performance of tractors that can pull a B-train with a box length of 20 m (65 ft 7 in) within an overall length of 25 m (82 ft).

5.2 Results

Table 29, extracted from Table 9, shows that a tractor up to about 5.28 m (208 in) with 0.76 m (30 in) front axle setback can pull a 20 m (65 ft 7 in) box length tridem-tandem B-train. The wheelbase is reduced to 4.67 m (184 in) with 1.40 m (55 in) front axle setback, and further to 4.37 m (172 in) if a moose bumper is added. The tandem-tridem B-train had a 0.30 m (12 in) deeper lead semitrailer kingpin setback, so this axle configuration could be pulled by a tractor with 0.30 m (12 in) greater wheelbase.

Table 29: Effect of Front Axle Setback on Overall Length for 20 m Box Length

Tractor Wheelbase	Front Axle Setback		
	0.91 m (30 in)	**1.40 m (55 in)**	**1.75 m (69 in)**
160 in	23.72 m (934 in)	24.36 m (959 in)	24.71 m (973 in)
172 in	24.00 m (945 in)	24.64 m (970 in)	24.99 m (984 in)
184 in	24.31 m (957 in)	24.94 m (982 in)	
196 in	24.59 m (968 in)		
208 in	24.89 m (980 in)		

Low-speed offtracking was not an issue for tractors less than 6.20 m (244 in) wheelbase, as shown in Table 12, so was not considered here.

Table 30 presents the high-speed offtracking for B-trains with 20 m (65 ft 7 in) box length with tractors with a wheelbase up to 5.28 m (208 in) for the tridem-tandem B-train, or 5.59 m (220 in) for the tandem-tridem B-train, so that each combination was within 25 m (82 ft) overall length. High-speed offtracking was essentially unaffected by the B-train trailer combination, increased with an increase in tractor wheelbase, increased with an increase in speed, and exceeded the performance standard for all tractor and B-train combinations at all speeds.

Table 30: High-speed Offtracking for 20 m Box Length and 25 m Overall Length

Tractor WB		Tridem-tandem B-train			Tandem-tridem B-train			
	Trailer Lengths	90 km/h	100 km/h	110 km/h	Trailer Lengths	90 km/h	100 km/h	110 km/h
160 in	**28/34 ft**	**0.464**	**0.506**	**0.537**	**22/40 ft**	**0.482**	**0.524**	**0.555**
160 in	**30/32 ft**	**0.461**	**0.504**	**0.535**	**24/38 ft**	**0.491**	**0.533**	**0.564**
160 in	**32/30 ft**	**0.460**	**0.505**	**0.538**	**26/36 ft**	**0.497**	**0.540**	**0.572**
160 in	**34/28 ft**	**0.464**	**0.512**	**0.548**	**28/34 ft**	**0.503**	**0.547**	**0.579**
172 in	**28/34 ft**	**0.473**	**0.516**	**0.547**	**22/40 ft**	**0.491**	**0.534**	**0.566**
172 in	**30/32 ft**	**0.470**	**0.513**	**0.546**	**24/38 ft**	**0.500**	**0.543**	**0.575**
172 in	**32/30 ft**	**0.469**	**0.515**	**0.549**	**26/36 ft**	**0.507**	**0.550**	**0.582**
172 in	**34/28 ft**	**0.473**	**0.522**	**0.558**	**28/34 ft**	**0.513**	**0.557**	**0.589**
184 in	**28/34 ft**	**0.483**	**0.526**	**0.559**	**22/40 ft**	**0.501**	**0.545**	**0.577**
184 in	**30/32 ft**	**0.480**	**0.524**	**0.557**	**24/38 ft**	**0.510**	**0.554**	**0.586**
184 in	**32/30 ft**	**0.479**	**0.525**	**0.560**	**26/36 ft**	**0.516**	**0.561**	**0.593**
184 in	**34/28 ft**	**0.483**	**0.533**	**0.570**	**28/34 ft**	**0.522**	**0.567**	**0.601**
196 in	**28/34 ft**	**0.492**	**0.536**	**0.569**	**22/40 ft**	**0.510**	**0.554**	**0.587**
196 in	**30/32 ft**	**0.489**	**0.533**	**0.567**	**24/38 ft**	**0.518**	**0.563**	**0.596**
196 in	**32/30 ft**	**0.488**	**0.535**	**0.570**	**26/36 ft**	**0.525**	**0.570**	**0.604**
196 in	**34/28 ft**	**0.492**	**0.542**	**0.580**	**28/34 ft**	**0.531**	**0.577**	**0.611**
208 in	**28/34 ft**	**0.501**	**0.547**	**0.580**	**22/40 ft**	**0.519**	**0.564**	**0.598**
208 in	**30/32 ft**	**0.498**	**0.544**	**0.578**	**24/38 ft**	**0.528**	**0.573**	**0.607**
208 in	**32/30 ft**	**0.497**	**0.545**	**0.581**	**26/36 ft**	**0.534**	**0.580**	**0.614**
208 in	**34/28 ft**	**0.501**	**0.552**	**0.591**	**28/34 ft**	**0.540**	**0.587**	**0.622**
220 in					**22/40 ft**	**0.527**	**0.573**	**0.608**
220 in					**24/38 ft**	**0.536**	**0.582**	**0.617**
220 in					**26/36 ft**	**0.542**	**0.589**	**0.624**
220 in					**28/34 ft**	**0.548**	**0.596**	**0.632**

5.3 Summary

The results in Table 30 represent the high-speed offtracking performance of the existing fleet of B-trains that run with 20 m (65 ft 7 in) B-train box length within an overall length of 25 m (82 ft) in accordance with the M.o.U. and the regulations of all provinces. It ranges up to 0.55 m (22 in) for a tridem-tandem B-train, and 0.60 m (24 in) for a tandem-tridem B-train.

6. TRACTORS UP TO 6.2 M WHEELBASE FOR A B-TRAIN WITHIN 25 M

6.1 Scope

This chapter addresses vehicles that currently operate within the M.o.U., and the regulations of all provinces. It presents the dynamic performance of tractors with a wheelbase up to 6.20 m (244 in) that can pull a B-train with a box length up to 20 m (65 ft 7 in) within an overall length of 25 m (82 ft).

6.2 Results

Table 31, extracted from Table 9, shows the combinations of tractor with 0.76 m (30 in) front axle setback and B-train box length that fit within 25 m (82 ft) overall length. The overall length shown for a given box length would be increased by 0.64 m (25 in) with a 1.40 m (55 in) front axle setback, and a further 0.36 m (14 in) if a moose bumper would be added.

Table 31: Effect of Tractor Wheelbase on Overall Length

Tractor Wheelbase	B-train Box Length			
	18.16 m (715 in)	**18.77 m (739 in)**	**19.38 m (763 in)**	**20.00 m (787 in)**
160 in	21.89 m (862 in)	22.50 m (886 in)	23.11 m (910 in)	23.72 m (934 in)
172 in	22.17 m (873 in)	22.78 m (897 in)	23.39 m (921 in)	24.00 m (945 in)
184 in	22.48 m (885 in)	23.09 m (909 in)	23.70 m (933 in)	24.31 m (957 in)
196 in	22.76 m (896 in)	23.37 m (920 in)	23.98 m (944 in)	24.59 m (968 in)
208 in	23.06 m (908 in)	23.67 m (932 in)	24.28 m (956 in)	24.89 m (980 in)
220 in	23.34 m (919 in)	23.95 m (943 in)	24.56 m (967 in)	
232 in	23.65 m (931 in)	24.26 m (955 in)	24.87 m (979 in)	
244 in	23.93 m (942 in)	24.54 m (966 in)		

Low-speed offtracking was not an issue for tractors less than 6.20 m (244 in) wheelbase, as shown in Table 12, so was not considered here.

Table 16 showed that high-speed offtracking was not materially affected by B-train box length or semitrailer length, regardless of tractor wheelbase. Table 32 presents the average high-speed offtracking for all B-train combinations that are within 20 m (65 ft 7 in) box length and 25 m (82 ft) overall length for each tractor. The values are similar to those in Table 15 for the corresponding tractor wheelbases. High-speed offtracking increased with an increase in tractor wheelbase, increased with an increase in speed, and exceeded the performance standard for all tractor and B-train combinations at all speeds.

Table 32: Effect of Tractor Wheelbase on High-speed Offtracking

Tractor Wheelbase	Tridem-tandem B-train			Tandem-tridem B-train		
	90 km/h	100 km/h	110 km/h	90 km/h	100 km/h	110 km/h
160 in	0.465	0.507	0.538	0.494	0.534	0.564
172 in	0.474	0.517	0.549	0.503	0.544	0.575
184 in	0.485	0.528	0.560	0.513	0.555	0.586
196 in	0.493	0.538	0.571	0.522	0.565	0.596
208 in	0.503	0.548	0.582	0.531	0.575	0.607
220 in	0.513	0.558	0.591	0.540	0.583	0.615
232 in	0.522	0.568	0.602	0.549	0.593	0.626
244 in	0.532	0.577	0.611	0.556	0.600	0.633

6.3 Summary

The results in Table 32 represent the high-speed offtracking performance for the current fleet of B-trains that run with any tractor up to 6.20 m (244 in) wheelbase and any B-train with a box length within 20 m (65 ft 7 in), that together are within an overall length of 25 m (82 ft), in accordance with the M.o.U. and the regulations of all provinces. Table 32 includes all configurations addressed in the previous chapter. It ranges up to 0.58 m (23 in) for a tridem-tandem B-train, and 0.60 m (24 in) for a tandem-tridem B-train.

7. TRACTORS UP TO 6.2 M WHEELBASE WITH A 20 M B-TRAIN

7.1 Scope

This chapter addresses vehicles that currently are outside the M.o.U., and the regulations of all provinces. It presents the dynamic performance of tractors with a wheelbase up to 6.20 m (244 in) pulling a B-train with a box length up to 20 m (65 ft 7 in) within an overall length of 27.50 m (90 ft 3 in).

7.2 Results

Table 33, extracted from Table 9, shows the combinations of tractor with 0.76 m (30 in) front axle setback and B-train box length that fit within 25 m (82 ft) overall length. The overall length shown for a given box length would be increased by 0.64 m (25 in) with a 1.40 m (55 in) front axle setback, a further 0.36 m (14 in) if a moose bumper would be added, up to 0.61 m (24 in) with a shorter lead semitrailer kingpin setback, and up to 0.15 m (6 in) for a more forward tractor fifth wheel. This would bring the overall length for a 6.20 m (244 in) wheelbase tractor close to 27.50 m (90 ft 3 in), as discussed in section 2.6. This Chapter addresses only the cells shown, which are additional to those considered in the previous chapter, for tractor wheelbases from 5.59 to 6.20 m (220 to 244 in).

Table 33: Effect of Tractor Wheelbase on Overall Length

Tractor Wheelbase	B-train Box Length			
	18.16 m (715 in)	**18.77 m (739 in)**	**19.38 m (763 in)**	**20.00 m (787 in)**
220 in				25.17 m (991 in)
232 in				25.48 m (1003 in)
244 in			25.15 m (990 in)	25.76 m (1014 in)

Low-speed offtracking was not an issue for tractors less than 6.20 m (244 in) wheelbase, as shown in Table 12, so was not considered here.

Table 16 showed that high-speed offtracking was not materially affected by B-train box length or semitrailer length, regardless of tractor wheelbase. Table 34 presents the average high-speed offtracking for each tractor for all B-train combinations that are within 20 m (65 ft 7 in) box length and between 25 and 27.5 m (90 ft 3 in) overall length. The values are similar to those in Table 32 for the corresponding tractor wheelbases.

Table 34: Effect of Tractor Wheelbase on High-speed Offtracking

Tractor Wheelbase	Tridem-tandem B-train			Tandem-tridem B-train		
	90 km/h	100 km/h	110 km/h	90 km/h	100 km/h	110 km/h
220 in	0.511	0.557	0.591	0.539	0.584	0.617
232 in	0.520	0.567	0.602	0.548	0.594	0.628
244 in	0.527	0.575	0.611	0.555	0.602	0.637

7.3 Summary

A tractor up to 6.20 m (244 in) wheelbase that pulls a B-train with a box length up to 20 m (65 ft 7 in) and exceeds 25 m (82 ft) overall length would not have materially different dynamic performance than other tractor-B-train combinations that can currently operate freely within the regulations of the provinces.

8. TRACTORS UP TO 7.16 M WHEELBASE WITH A 20 M B-TRAIN

8.1 Scope

This chapter addresses vehicles that currently are outside the M.o.U., and the regulations of all provinces. It presents the dynamic performance of tractors with a wheelbase up to 7.16 m (282 in) that can pull a B-train with a box length up to 20 m (65 ft 7 in) within an overall length of 27.50 m (90 ft 3 in).

8.2 Results

Table 35, extracted from Table 9, shows the combinations of tractor with 0.76 m (30 in) front axle setback and tridem-tandem B-train box length that fit within 25 m (82 ft) overall length. The overall length shown for a given box length would be increased by 0.64 m (25 in) with a 1.40 m (55 in) front axle setback, a further 0.36 m (14 in) if a moose bumper would be added, up to 0.61 m (24 in) with a shorter lead semitrailer kingpin setback, and up to 0.15 m (6 in) for a more forward tractor fifth wheel. Some compromises within the internal dimensions of the tractor and B-train might be necessary to bring the overall length within 27.50 m (90 ft 3 in), as discussed in section 2.6. It would be reduced by 0.30 m (12 in) for a tandem-tridem B-train, as this has a lead semitrailer kingpin that much deeper.

Table 35: Effect of Tractor Wheelbase on Overall Length

Tractor Wheelbase	B-train Box Length			
	18.16 m (715 in)	**18.77 m (739 in)**	**19.38 m (763 in)**	**20.00 m (787 in)**
256 in	24.23 m (954 in)	24.84 m (978 in)	25.45 m (1002 in)	26.06 m (1026 in)
265 in	24.43 m (962 in)	25.04 m (986 in)	25.65 m (1010 in)	26.26 m (1034 in)
282 in	24.87 m (979 in)	25.48 m (1003 in)	26.09 m (1027 in)	26.70 m (1051 in)

Low-speed offtracking for these tractors is presented in Table 36, extracted from Table 12. The cells where the B-train box length would exceed 20 m (65 ft 7 in) have been left empty. Cases where the low-speed offtracking exceeded the performance standard of 5.60 m (220 in) are highlighted in bold.

Table 16 showed that high-speed offtracking was not materially affected by B-train box length or semitrailer length, regardless of tractor wheelbase. Table 37 presents the average high-speed offtracking for each tractor for all B-train combinations that are within 20 m (65 ft 7 in) box length and between 25 and 27.5 m (90 ft 3 in) overall length. The value for a 6.20 m (244 in) tractor wheelbase is also included for reference, pulling all B-train combinations it can within 25 m (82 ft) overall length, as the highest value for current legal vehicles from Table 32.

Table 36: Effect of Tractor Wheelbase and B-train Combination on Low-speed Offtracking

Tractor WB	Lead Length	Tridem-tandem B-train Rear Semitrailer Length				Tandem-tridem B-train Rear Semitrailer Length			
		28 ft	30 ft	32 ft	34 ft	34 ft	36 ft	38 ft	40 ft
256 in	**28/22 ft**	4.904	4.933	5.048	5.248	4.774	4.949	5.129	5.324
256 in	**30/24 ft**	5.169	5.197	5.311		4.979	5.153	5.332	
256 in	**32/26 ft**	5.439	5.468			5.213	5.387		
256 in	**34/28 ft**	**5.718**				5.459			
265 in	**28/22 ft**	4.981	5.010	5.124	5.322	4.851	5.026	5.205	5.400
265 in	**30/24 ft**	5.243	5.271	5.384		5.055	5.229	5.407	
265 in	**32/26 ft**	5.511	5.539			5.289	5.462		
265 in	**34/28 ft**	**5.788**				5.534			
282 in	**28/22 ft**	5.129	5.157	5.270	5.466	5.003	5.176	5.354	5.548
282 in	**30/24 ft**	5.387	5.415	5.528		5.205	5.377	5.554	
282 in	**32/26 ft**	**5.654**	**5.681**			5.436	5.608		
282 in	**34/28 ft**	**5.930**				**5.679**			

Table 37: Effect of Tractor Wheelbase on High-speed Offtracking

Tractor Wheelbase	Tridem-tandem B-train			Tandem-tridem B-train		
	90 km/h	100 km/h	110 km/h	90 km/h	100 km/h	110 km/h
244 in	**0.527**	**0.575**	**0.611**	**0.555**	**0.602**	**0.637**
252 in	**0.535**	**0.585**	**0.622**	**0.563**	**0.611**	**0.647**
265 in	**0.540**	**0.590**	**0.628**	**0.568**	**0.617**	**0.653**
282 in	**0.551**	**0.603**	**0.642**	**0.579**	**0.630**	**0.667**

8.3 Summary

A tractor over 6.20 m (244 in) wheelbase that pulled a tridem-tandem B-train and was over 25 m (82 ft) overall length exceeded the low-speed offtracking performance standard only for B-trains with a box length of 20 m (65 ft 7 in) and the longest lead semitrailer and shortest rear semitrailer. It met the performance standard when pulling any other B-train. Tandem-tridem B-trains slightly exceeded the performance standard for the longest wheelbase tractor with the longest lead semitrailer and shortest rear semitrailer.

A tractor from 6.20 to 7.16 m (244 to 282 in) wheelbase that pulled a B-train with a box length up to 20 m (65 ft 7 in) and exceeds 25 m (82 ft) overall length would exceed the high-speed offtracking of the current legal B-train with the highest high-speed offtracking by about 0.03 m (1 in). Otherwise, it would not have materially different dynamic performance than other tractor-B-train combinations that currently operate freely within the regulations of the provinces.

9. CONCLUSIONS

This work has evaluated the dynamic performance of tridem-tandem and tandem-tridem B-trains with a box length from about 18 to 20 m (59 to 65 ft 7 in), pulled by tractors with a wheelbase from 4.06 to 7.16 m (160 to 282 in). This work was commissioned to assess the effect on dynamic performance of B-trains up to 20 m (65 ft 7 in) box length when pulled by tractors with wheelbase:

- Up to 6.20 m (244 in); and
- From 6.20 to 7.16 m (244 to 282 in)

27.5 m (90 ft 3 in) is a realistic maximum overall length for a 6.20 m (244 in) tractor to pull a B-train with box length up to 20 m (65 ft 7 in) and with virtually no restrictions on either tractor or B-train internal dimensions. Tractors with a wheelbase longer than 6.20 m (244 in) can be configured pull any B-train up to 20 m (65 ft 7 in) box length with minor restrictions on internal tractor and B-train dimensions.

The static roll threshold depended on B-train box length. It was not affected by tractor wheelbase, and was typical of any B-train carrying the payload considered here.

High-speed offtracking increased with increased tractor wheelbase, and exceeded the performance standard for all tractors with all B-trains. B-trains within the provincial regulations may have high-speed offtracking from about 0.51 to 0.60 m (20 to 24 in) at 100 km/h (62.1 mi/h), which exceeds the performance standard of 0.46 m (18 in) by 0.05 to 0.14 m (2 to 6 in).

Load transfer ratio decreased with increased tractor wheelbase, and met the performance standard for all tractors with all B-trains.

Transient offtracking was not affected by tractor wheelbase, was close to the performance standard at 100 km/h (62.1 mi/h), and exceeded it at 110 km/h (68.3 mi/h).

Low-speed offtracking increased with increased tractor wheelbase and B-train box length, and the performance standard was only exceeded by a small amount, only by tractors with a wheelbase over 6.20 m (244 in) when pulling a tridem-tandem B-train with 20 m (65 ft 7 in) box length with the longest possible lead semitrailer. All other configurations met the performance standard.

Friction demand was not affected by tractor wheelbase, and while all tractors exceeded the performance standard with all B-trains, this performance measure is now considered not critically related to safety.

Front outswing increased with increased front axle setback and the presence of a moose bumper. There is no formal performance standard, and the potential front overhang of the B-trains considered here was comparable to that of other existing vehicles.

Rear outswing was not affected by tractor wheelbase, and all tractors met the performance standard with all B-trains.

Minor changes in payload distribution, such as for 17,000 vs 18,000 kg (37,478 vs 39,682 lb) allowable tandem axle load, a 1.83 m (72 in) drive tandem axle spread for 19,100 vs 17,000 kg (42,108 vs 37,478 lb) allowable tandem axle load in Ontario, or 62,500 vs 63,500 kg (137,787 vs 139,992 lb) allowable gross weight, had negligible effect on dynamic performance.

A tractor up to 6.20 m (244 in) wheelbase that pulls B-trains with a box length up to 20 m (65 ft 7 in) and exceeds 25 m (82 ft) overall length would not have materially different dynamic performance than other tractor-B-train combinations that can currently operate freely within the regulations of the provinces within 25 m (82 ft) overall length.

A tractor from 6.20 to 7.16 m (244 to 282 in) wheelbase that pulls B-trains with a box length up to 20 m (65 ft 7 in) and exceeds 25 m (82 ft) overall length would exceed the low-speed offtracking performance standard for tridem-tandem B-trains with the longest lead semitrailer and shortest rear semitrailer, but otherwise would meet the performance standard, and would exceed the high-speed offtracking of the current legal B-train with the highest high-speed offtracking by about 0.03 m (1 in). Otherwise, there would be no materially different dynamic performance than other tractor-B-train combinations that currently operate freely within the regulations of the provinces within 25 m (82 ft) overall length.

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APPENDIX 1 – RESULTS FOR TRIDEM-TANDEM B-TRAINS

LOW-SPEED PERFORMANCE MEASURES

Tr WB (in)	Lead Len (ft)	Rear Len (ft)	Low-speed Offtracking (< 5.60 m)	Rear Outswing (<0.20 m)	Friction Demand (<0.10)	Lateral Friction Utilization (<0.80)
160	28	28	4.263	0.008	0.149	0.297
172	28	28	4.326	0.007	0.151	0.282
184	28	28	4.394	0.007	0.153	0.273
196	28	28	4.468	0.007	0.153	0.259
208	28	28	4.545	0.007	0.154	0.254
220	28	28	4.629	0.007	0.154	0.243
232	28	28	4.716	0.007	0.154	0.235
244	28	28	4.810	0.006	0.154	0.237
256	28	28	4.904	0.006	0.154	0.224
265	28	28	4.981	0.006	0.153	0.228
282	28	28	5.129	0.006	0.153	0.224
160	28	30	4.293	0.013	0.150	0.297
172	28	30	4.356	0.012	0.151	0.282
184	28	30	4.424	0.012	0.153	0.273
196	28	30	4.497	0.011	0.154	0.259
208	28	30	4.575	0.011	0.154	0.254
220	28	30	4.659	0.010	0.154	0.243
232	28	30	4.746	0.010	0.155	0.235
244	28	30	4.839	0.009	0.154	0.237
256	28	30	4.933	0.009	0.154	0.224
265	28	30	5.010	0.009	0.153	0.228
282	28	30	5.157	0.008	0.153	0.224
160	28	32	4.416	0.020	0.150	0.297
172	28	32	4.478	0.020	0.151	0.282
184	28	32	4.545	0.019	0.153	0.273
196	28	32	4.617	0.018	0.154	0.259
208	28	32	4.694	0.017	0.155	0.254
220	28	32	4.777	0.016	0.154	0.243
232	28	32	4.862	0.016	0.155	0.235
244	28	32	4.955	0.015	0.154	0.237
256	28	32	5.048	0.014	0.154	0.224
265	28	32	5.124	0.014	0.154	0.228
282	28	32	5.270	0.013	0.153	0.224

160	28	34	4.628	0.023	0.150	0.297
172	28	34	4.689	0.022	0.152	0.282
184	28	34	4.753	0.021	0.154	0.273
196	28	34	4.825	0.020	0.154	0.259
208	28	34	4.899	0.019	0.155	0.254
220	28	34	4.980	0.019	0.155	0.243
232	28	34	5.065	0.018	0.155	0.235
244	28	34	5.155	0.017	0.154	0.237
256	28	34	5.248	0.016	0.154	0.224
265	28	34	5.322	0.016	0.154	0.228
282	28	34	5.466	0.015	0.153	0.224
160	30	28	4.539	0.007	0.142	0.297
172	30	28	4.601	0.007	0.144	0.280
184	30	28	4.666	0.007	0.146	0.271
196	30	28	4.739	0.007	0.146	0.263
208	30	28	4.814	0.007	0.147	0.250
220	30	28	4.897	0.007	0.147	0.248
232	30	28	4.982	0.006	0.147	0.242
244	30	28	5.074	0.006	0.147	0.233
256	30	28	5.169	0.006	0.146	0.232
265	30	28	5.243	0.006	0.146	0.228
282	30	28	5.387	0.006	0.145	0.219
160	30	30	4.569	0.013	0.143	0.297
172	30	30	4.631	0.012	0.144	0.280
184	30	30	4.696	0.011	0.146	0.271
196	30	30	4.768	0.011	0.146	0.263
208	30	30	4.844	0.010	0.147	0.250
220	30	30	4.926	0.010	0.147	0.248
232	30	30	5.011	0.009	0.147	0.242
244	30	30	5.102	0.009	0.147	0.233
256	30	30	5.197	0.009	0.147	0.232
265	30	30	5.271	0.009	0.146	0.228
282	30	30	5.415	0.008	0.145	0.220
160	30	32	4.691	0.020	0.143	0.297
172	30	32	4.752	0.019	0.144	0.280
184	30	32	4.816	0.018	0.146	0.271
196	30	32	4.887	0.017	0.147	0.263
208	30	32	4.961	0.016	0.147	0.250
220	30	32	5.042	0.016	0.147	0.248
232	30	32	5.127	0.015	0.148	0.242

244	30	32	5.218	0.015	0.147	0.233
256	30	32	5.311	0.014	0.147	0.232
265	30	32	5.384	0.013	0.146	0.228
282	30	32	5.528	0.013	0.146	0.219
160	32	28	4.824	0.007	0.137	0.299
172	32	28	4.884	0.007	0.138	0.285
184	32	28	4.947	0.007	0.140	0.270
196	32	28	5.019	0.007	0.140	0.260
208	32	28	5.092	0.007	0.141	0.254
220	32	28	5.172	0.006	0.141	0.245
232	32	28	5.256	0.006	0.141	0.240
244	32	28	5.346	0.006	0.141	0.230
256	32	28	5.439	0.006	0.140	0.229
265	32	28	5.511	0.006	0.140	0.224
282	32	28	5.654	0.006	0.139	0.213
160	32	30	4.853	0.012	0.137	0.299
172	32	30	4.913	0.012	0.138	0.285
184	32	30	4.976	0.011	0.140	0.270
196	32	30	5.048	0.011	0.141	0.259
208	32	30	5.121	0.010	0.141	0.254
220	32	30	5.201	0.010	0.141	0.245
232	32	30	5.284	0.009	0.141	0.240
244	32	30	5.374	0.009	0.141	0.230
256	32	30	5.468	0.009	0.141	0.229
265	32	30	5.539	0.008	0.140	0.224
282	32	30	5.681	0.008	0.139	0.214
160	34	28	5.117	0.007	0.132	0.298
172	34	28	5.176	0.007	0.133	0.284
184	34	28	5.237	0.007	0.135	0.273
196	34	28	5.307	0.007	0.135	0.257
208	34	28	5.378	0.006	0.136	0.254
220	34	28	5.457	0.006	0.136	0.243
232	34	28	5.539	0.006	0.136	0.237
244	34	28	5.626	0.006	0.135	0.230
256	34	28	5.718	0.006	0.135	0.228
265	34	28	5.788	0.006	0.134	0.219
282	34	28	5.930	0.006	0.134	0.212

STATIC ROLL THRESHOLD

Tr WB (in)	Lead Len (ft)	Rear Len (ft)	Static Roll Threshold		
			90 km/h	100 km/h	110 km/h
160	28	28	0.359	0.359	0.361
172	28	28	0.359	0.359	0.360
184	28	28	0.359	0.360	0.361
196	28	28	0.359	0.360	0.360
208	28	28	0.360	0.360	0.361
220	28	28	0.360	0.360	0.361
232	28	28	0.360	0.361	0.361
244	28	28	0.360	0.361	0.361
256	28	28	0.361	0.361	0.361
265	28	28	0.361	0.361	0.361
282	28	28	0.361	0.361	0.362
160	28	30	0.374	0.374	0.375
172	28	30	0.374	0.375	0.376
184	28	30	0.375	0.375	0.376
196	28	30	0.375	0.375	0.376
208	28	30	0.375	0.375	0.376
220	28	30	0.375	0.376	0.376
232	28	30	0.375	0.376	0.376
244	28	30	0.375	0.376	0.376
256	28	30	0.376	0.376	0.376
265	28	30	0.376	0.376	0.376
282	28	30	0.376	0.376	0.377
160	28	32	0.383	0.383	0.384
172	28	32	0.383	0.383	0.384
184	28	32	0.384	0.384	0.384
196	28	32	0.384	0.384	0.384
208	28	32	0.385	0.385	0.385
220	28	32	0.385	0.385	0.385
232	28	32	0.385	0.385	0.386
244	28	32	0.385	0.385	0.386
256	28	32	0.385	0.386	0.386
265	28	32	0.385	0.386	0.386
282	28	32	0.385	0.386	0.386

160	28	34	0.388	0.389	0.388
172	28	34	0.388	0.389	0.388
184	28	34	0.389	0.389	0.390
196	28	34	0.390	0.389	0.389
208	28	34	0.390	0.390	0.390
220	28	34	0.390	0.390	0.390
232	28	34	0.390	0.391	0.390
244	28	34	0.390	0.390	0.391
256	28	34	0.390	0.391	0.391
265	28	34	0.390	0.391	0.391
282	28	34	0.390	0.391	0.391
160	30	28	0.364	0.365	0.366
172	30	28	0.364	0.365	0.366
184	30	28	0.365	0.365	0.366
196	30	28	0.365	0.365	0.366
208	30	28	0.365	0.366	0.366
220	30	28	0.366	0.366	0.366
232	30	28	0.366	0.366	0.367
244	30	28	0.366	0.366	0.367
256	30	28	0.366	0.367	0.367
265	30	28	0.366	0.367	0.367
282	30	28	0.367	0.367	0.368
160	30	30	0.380	0.381	0.381
172	30	30	0.381	0.381	0.381
184	30	30	0.381	0.381	0.381
196	30	30	0.381	0.382	0.382
208	30	30	0.382	0.382	0.382
220	30	30	0.381	0.382	0.382
232	30	30	0.382	0.382	0.382
244	30	30	0.382	0.382	0.383
256	30	30	0.382	0.383	0.383
265	30	30	0.382	0.383	0.383
282	30	30	0.383	0.384	0.383
160	30	32	0.389	0.389	0.389
172	30	32	0.390	0.389	0.390
184	30	32	0.390	0.390	0.391
196	30	32	0.391	0.390	0.391
208	30	32	0.391	0.391	0.391
220	30	32	0.391	0.391	0.391
232	30	32	0.392	0.391	0.391

244	30	32	0.391	0.392	0.392
256	30	32	0.392	0.392	0.392
265	30	32	0.392	0.392	0.392
282	30	32	0.392	0.392	0.392
160	32	28	0.369	0.369	0.370
172	32	28	0.369	0.369	0.370
184	32	28	0.369	0.370	0.370
196	32	28	0.369	0.370	0.370
208	32	28	0.370	0.370	0.371
220	32	28	0.370	0.370	0.371
232	32	28	0.370	0.371	0.371
244	32	28	0.370	0.371	0.371
256	32	28	0.371	0.371	0.372
265	32	28	0.371	0.371	0.372
282	32	28	0.372	0.372	0.372
160	32	30	0.385	0.385	0.385
172	32	30	0.386	0.385	0.386
184	32	30	0.386	0.386	0.386
196	32	30	0.386	0.386	0.386
208	32	30	0.387	0.387	0.387
220	32	30	0.387	0.387	0.387
232	32	30	0.388	0.388	0.387
244	32	30	0.387	0.388	0.388
256	32	30	0.388	0.388	0.388
265	32	30	0.388	0.388	0.388
282	32	30	0.388	0.389	0.388
160	34	28	0.372	0.373	0.374
172	34	28	0.373	0.373	0.374
184	34	28	0.374	0.373	0.374
196	34	28	0.373	0.374	0.374
208	34	28	0.374	0.374	0.375
220	34	28	0.374	0.374	0.375
232	34	28	0.374	0.375	0.375
244	34	28	0.375	0.375	0.375
256	34	28	0.375	0.376	0.376
265	34	28	0.375	0.376	0.376
282	34	28	0.376	0.376	0.376

HIGH-SPEED PERFORMANCE MEASURES

Tr WB (in)	Lead Len (ft)	Rear Len (ft)	High-speed Offtracking (<0.46 m)			Load Transfer Ratio (<0.60)			Transient Offtracking (<0.80 m)		
			90 km/h	100 km/h	110 km/h	90 km/h	100 km/h	110 km/h	90 km/h	100 km/h	110 km/h
160	28	28	0.473	0.511	0.539	0.541	0.590	0.632	0.671	0.816	0.949
172	28	28	0.482	0.521	0.550	0.537	0.586	0.628	0.675	0.822	0.957
184	28	28	0.493	0.532	0.561	0.531	0.582	0.625	0.681	0.829	0.966
196	28	28	0.501	0.542	0.572	0.525	0.576	0.620	0.682	0.831	0.968
208	28	28	0.511	0.552	0.583	0.519	0.571	0.615	0.683	0.833	0.971
220	28	28	0.519	0.561	0.593	0.512	0.564	0.609	0.680	0.831	0.969
232	28	28	0.528	0.571	0.604	0.504	0.557	0.603	0.678	0.829	0.969
244	28	28	0.536	0.580	0.613	0.496	0.550	0.596	0.673	0.824	0.964
256	28	28	0.544	0.589	0.623	0.488	0.542	0.589	0.669	0.821	0.961
265	28	28	0.549	0.595	0.630	0.482	0.536	0.583	0.664	0.815	0.956
282	28	28	0.560	0.608	0.644	0.470	0.525	0.572	0.656	0.807	0.948
160	28	30	0.465	0.504	0.532	0.517	0.565	0.606	0.661	0.806	0.940
172	28	30	0.475	0.514	0.543	0.513	0.561	0.603	0.667	0.813	0.948
184	28	30	0.485	0.525	0.554	0.508	0.558	0.600	0.672	0.820	0.956
196	28	30	0.494	0.534	0.564	0.502	0.552	0.595	0.673	0.821	0.959
208	28	30	0.503	0.545	0.576	0.496	0.547	0.591	0.675	0.824	0.962
220	28	30	0.511	0.554	0.586	0.489	0.541	0.585	0.672	0.821	0.960
232	28	30	0.520	0.564	0.596	0.482	0.534	0.579	0.670	0.821	0.960
244	28	30	0.528	0.572	0.606	0.474	0.527	0.572	0.665	0.816	0.955
256	28	30	0.536	0.582	0.616	0.467	0.520	0.566	0.661	0.812	0.952
265	28	30	0.541	0.588	0.622	0.461	0.514	0.560	0.656	0.807	0.946
282	28	30	0.552	0.600	0.636	0.449	0.503	0.549	0.649	0.799	0.939
160	28	32	0.463	0.503	0.532	0.499	0.547	0.587	0.651	0.798	0.933
172	28	32	0.472	0.513	0.543	0.495	0.543	0.585	0.657	0.805	0.942
184	28	32	0.483	0.524	0.554	0.490	0.540	0.582	0.663	0.812	0.951
196	28	32	0.491	0.533	0.564	0.485	0.535	0.577	0.664	0.814	0.953
208	28	32	0.501	0.544	0.575	0.479	0.530	0.573	0.666	0.817	0.957
220	28	32	0.509	0.553	0.586	0.472	0.524	0.567	0.664	0.815	0.955
232	28	32	0.518	0.563	0.596	0.466	0.518	0.561	0.662	0.814	0.955
244	28	32	0.525	0.571	0.605	0.458	0.510	0.555	0.658	0.810	0.950
256	28	32	0.533	0.581	0.616	0.451	0.504	0.549	0.654	0.806	0.947
265	28	32	0.538	0.586	0.622	0.445	0.498	0.543	0.649	0.801	0.942

282	28	32	0.549	0.599	0.636	0.434	0.488	0.533	0.643	0.794	0.935
160	28	34	0.464	0.506	0.537	0.482	0.530	0.570	0.636	0.785	0.923
172	28	34	0.473	0.516	0.547	0.479	0.526	0.567	0.642	0.793	0.932
184	28	34	0.483	0.526	0.559	0.475	0.524	0.565	0.649	0.801	0.942
196	28	34	0.492	0.536	0.569	0.470	0.519	0.561	0.650	0.803	0.945
208	28	34	0.501	0.547	0.580	0.464	0.514	0.557	0.653	0.807	0.949
220	28	34	0.509	0.555	0.589	0.458	0.508	0.551	0.651	0.805	0.948
232	28	34	0.518	0.565	0.600	0.451	0.502	0.546	0.650	0.804	0.948
244	28	34	0.525	0.574	0.610	0.444	0.495	0.540	0.646	0.800	0.944
256	28	34	0.534	0.583	0.620	0.437	0.489	0.534	0.644	0.798	0.942
265	28	34	0.539	0.589	0.626	0.432	0.484	0.529	0.639	0.792	0.937
282	28	34	0.550	0.601	0.640	0.421	0.474	0.519	0.633	0.786	0.930
160	30	28	0.470	0.511	0.542	0.511	0.561	0.603	0.632	0.777	0.910
172	30	28	0.480	0.522	0.553	0.508	0.558	0.601	0.638	0.785	0.920
184	30	28	0.490	0.532	0.564	0.503	0.554	0.598	0.644	0.792	0.929
196	30	28	0.498	0.542	0.575	0.498	0.549	0.594	0.646	0.795	0.933
208	30	28	0.508	0.552	0.586	0.492	0.544	0.589	0.648	0.799	0.938
220	30	28	0.516	0.561	0.595	0.485	0.538	0.583	0.646	0.797	0.937
232	30	28	0.525	0.571	0.606	0.479	0.532	0.578	0.646	0.797	0.937
244	30	28	0.532	0.580	0.615	0.471	0.525	0.571	0.642	0.793	0.934
256	30	28	0.541	0.589	0.625	0.464	0.518	0.565	0.639	0.790	0.931
265	30	28	0.546	0.595	0.632	0.458	0.512	0.559	0.634	0.785	0.927
282	30	28	0.557	0.608	0.646	0.448	0.502	0.549	0.628	0.779	0.920
160	30	30	0.463	0.504	0.535	0.488	0.536	0.579	0.624	0.769	0.903
172	30	30	0.472	0.514	0.546	0.485	0.534	0.576	0.630	0.777	0.912
184	30	30	0.482	0.525	0.557	0.481	0.530	0.574	0.637	0.785	0.922
196	30	30	0.491	0.535	0.567	0.476	0.526	0.570	0.639	0.787	0.925
208	30	30	0.500	0.545	0.578	0.470	0.521	0.566	0.641	0.791	0.930
220	30	30	0.508	0.554	0.588	0.464	0.515	0.560	0.639	0.790	0.929
232	30	30	0.517	0.564	0.599	0.457	0.510	0.555	0.639	0.790	0.930
244	30	30	0.525	0.572	0.608	0.450	0.503	0.548	0.635	0.786	0.926
256	30	30	0.533	0.582	0.618	0.443	0.496	0.542	0.632	0.783	0.924
265	30	30	0.538	0.587	0.624	0.438	0.491	0.537	0.628	0.778	0.919
282	30	30	0.548	0.600	0.638	0.428	0.481	0.527	0.622	0.772	0.913
160	30	32	0.461	0.504	0.535	0.471	0.519	0.560	0.615	0.761	0.897
172	30	32	0.470	0.513	0.546	0.468	0.516	0.558	0.621	0.769	0.906
184	30	32	0.480	0.524	0.557	0.464	0.513	0.556	0.629	0.778	0.917
196	30	32	0.489	0.533	0.567	0.459	0.508	0.552	0.631	0.781	0.920
208	30	32	0.498	0.544	0.578	0.454	0.504	0.548	0.633	0.785	0.925
220	30	32	0.506	0.553	0.588	0.448	0.499	0.543	0.632	0.784	0.924

232	30	32	0.515	0.563	0.598	0.442	0.493	0.538	0.632	0.784	0.926
244	30	32	0.522	0.571	0.607	0.435	0.487	0.532	0.628	0.780	0.922
256	30	32	0.530	0.580	0.618	0.428	0.480	0.526	0.626	0.778	0.920
265	30	32	0.535	0.586	0.624	0.423	0.475	0.521	0.622	0.773	0.916
282	30	32	0.546	0.599	0.638	0.413	0.466	0.512	0.616	0.767	0.910
160	32	28	0.468	0.512	0.545	0.486	0.534	0.577	0.595	0.739	0.873
172	32	28	0.477	0.522	0.556	0.482	0.532	0.575	0.602	0.748	0.883
184	32	28	0.487	0.533	0.567	0.479	0.529	0.573	0.609	0.757	0.894
196	32	28	0.496	0.543	0.577	0.473	0.525	0.569	0.612	0.760	0.899
208	32	28	0.505	0.553	0.588	0.468	0.520	0.566	0.615	0.765	0.904
220	32	28	0.513	0.562	0.598	0.462	0.514	0.560	0.614	0.765	0.905
232	32	28	0.522	0.572	0.609	0.456	0.509	0.555	0.614	0.765	0.906
244	32	28	0.529	0.580	0.618	0.449	0.502	0.549	0.611	0.762	0.903
256	32	28	0.538	0.589	0.628	0.443	0.496	0.543	0.609	0.760	0.902
265	32	28	0.542	0.595	0.634	0.437	0.491	0.538	0.605	0.756	0.898
282	32	28	0.553	0.608	0.648	0.427	0.481	0.528	0.600	0.751	0.893
160	32	30	0.460	0.505	0.538	0.464	0.511	0.553	0.588	0.733	0.867
172	32	30	0.469	0.515	0.549	0.461	0.509	0.552	0.596	0.742	0.877
184	32	30	0.479	0.525	0.560	0.457	0.506	0.550	0.603	0.751	0.888
196	32	30	0.488	0.535	0.570	0.452	0.502	0.546	0.605	0.754	0.892
208	32	30	0.497	0.545	0.581	0.447	0.498	0.543	0.609	0.759	0.897
220	32	30	0.505	0.554	0.591	0.441	0.492	0.538	0.608	0.758	0.898
232	32	30	0.514	0.564	0.601	0.436	0.487	0.533	0.608	0.759	0.900
244	32	30	0.521	0.572	0.611	0.429	0.481	0.527	0.605	0.756	0.897
256	32	30	0.529	0.582	0.621	0.423	0.475	0.521	0.604	0.754	0.896
265	32	30	0.534	0.587	0.627	0.418	0.470	0.516	0.600	0.750	0.891
282	32	30	0.545	0.600	0.640	0.408	0.460	0.507	0.595	0.745	0.886
160	34	28	0.464	0.512	0.548	0.462	0.510	0.553	0.560	0.703	0.837
172	34	28	0.473	0.522	0.558	0.459	0.508	0.552	0.568	0.713	0.848
184	34	28	0.483	0.533	0.570	0.456	0.506	0.550	0.575	0.723	0.860
196	34	28	0.492	0.542	0.580	0.451	0.502	0.546	0.579	0.727	0.865
208	34	28	0.501	0.552	0.591	0.447	0.498	0.543	0.582	0.732	0.871
220	34	28	0.509	0.561	0.600	0.441	0.493	0.538	0.582	0.733	0.873
232	34	28	0.518	0.571	0.611	0.435	0.487	0.534	0.583	0.734	0.875
244	34	28	0.525	0.580	0.620	0.429	0.482	0.528	0.581	0.732	0.873
256	34	28	0.533	0.589	0.630	0.423	0.476	0.523	0.580	0.731	0.873
265	34	28	0.538	0.595	0.636	0.418	0.471	0.518	0.577	0.727	0.869
282	34	28	0.549	0.607	0.650	0.409	0.461	0.509	0.573	0.722	0.865

APPENDIX 2 – RESULTS FOR TANDEM-TRIDEM B-TRAINS

LOW-SPEED PERFORMANCE MEASURES

Tr WB (in)	Lead Len (ft)	Rear Len (ft)	Low-speed Offtracking (< 5.60 m)	Rear Outswing (<0.20 m)	Friction Demand (<0.10)	Lateral Friction Utilization (<0.80)
160	22	34	4.098	0.012	0.034	0.300
172	22	34	4.166	0.012	0.037	0.281
184	22	34	4.239	0.011	0.041	0.270
196	22	34	4.316	0.011	0.043	0.256
208	22	34	4.399	0.010	0.045	0.253
220	22	34	4.487	0.010	0.047	0.242
232	22	34	4.579	0.009	0.049	0.236
244	22	34	4.673	0.009	0.050	0.232
256	22	34	4.774	0.009	0.052	0.228
265	22	34	4.851	0.009	0.052	0.222
282	22	34	5.003	0.008	0.053	0.219
160	22	36	4.285	0.017	0.034	0.300
172	22	36	4.351	0.016	0.038	0.281
184	22	36	4.422	0.016	0.041	0.271
196	22	36	4.499	0.015	0.044	0.256
208	22	36	4.580	0.014	0.046	0.253
220	22	36	4.666	0.014	0.047	0.242
232	22	36	4.757	0.013	0.049	0.236
244	22	36	4.849	0.013	0.050	0.232
256	22	36	4.949	0.012	0.052	0.228
265	22	36	5.026	0.012	0.052	0.222
282	22	36	5.176	0.012	0.054	0.219
160	22	38	4.476	0.023	0.035	0.300
172	22	38	4.540	0.022	0.038	0.281
184	22	38	4.610	0.021	0.041	0.271
196	22	38	4.685	0.020	0.044	0.261
208	22	38	4.766	0.019	0.046	0.253
220	22	38	4.850	0.019	0.048	0.242
232	22	38	4.939	0.018	0.049	0.236
244	22	38	5.030	0.017	0.050	0.232
256	22	38	5.129	0.017	0.052	0.228
265	22	38	5.205	0.016	0.053	0.223
282	22	38	5.354	0.016	0.054	0.219

160	22	40	4.684	0.030	0.035	0.300
172	22	40	4.747	0.028	0.039	0.281
184	22	40	4.816	0.027	0.042	0.271
196	22	40	4.889	0.026	0.044	0.261
208	22	40	4.967	0.025	0.046	0.253
220	22	40	5.051	0.024	0.048	0.242
232	22	40	5.138	0.023	0.049	0.236
244	22	40	5.228	0.022	0.051	0.232
256	22	40	5.324	0.021	0.053	0.228
265	22	40	5.400	0.021	0.053	0.222
282	22	40	5.548	0.020	0.054	0.219
160	24	34	4.317	0.012	0.031	0.300
172	24	34	4.383	0.012	0.035	0.284
184	24	34	4.454	0.011	0.038	0.270
196	24	34	4.530	0.011	0.040	0.260
208	24	34	4.611	0.010	0.043	0.253
220	24	34	4.697	0.010	0.044	0.242
232	24	34	4.787	0.009	0.046	0.236
244	24	34	4.879	0.009	0.047	0.229
256	24	34	4.979	0.009	0.049	0.228
265	24	34	5.055	0.009	0.049	0.223
282	24	34	5.205	0.008	0.051	0.219
160	24	36	4.503	0.017	0.031	0.300
172	24	36	4.567	0.016	0.035	0.284
184	24	36	4.637	0.015	0.038	0.270
196	24	36	4.711	0.015	0.041	0.261
208	24	36	4.791	0.014	0.043	0.253
220	24	36	4.875	0.013	0.045	0.242
232	24	36	4.964	0.013	0.046	0.236
244	24	36	5.054	0.012	0.047	0.229
256	24	36	5.153	0.012	0.049	0.228
265	24	36	5.229	0.012	0.050	0.223
282	24	36	5.377	0.011	0.051	0.219
160	24	38	4.693	0.023	0.032	0.300
172	24	38	4.755	0.022	0.035	0.284
184	24	38	4.824	0.021	0.038	0.271
196	24	38	4.897	0.020	0.041	0.261
208	24	38	4.976	0.019	0.043	0.253
220	24	38	5.058	0.018	0.045	0.242
232	24	38	5.146	0.017	0.047	0.236

244	24	38	5.235	0.017	0.048	0.229
256	24	38	5.332	0.016	0.049	0.228
265	24	38	5.407	0.016	0.050	0.222
282	24	38	5.554	0.015	0.051	0.219
160	26	34	4.567	0.012	0.029	0.300
172	26	34	4.631	0.011	0.033	0.282
184	26	34	4.700	0.011	0.036	0.270
196	26	34	4.774	0.010	0.038	0.261
208	26	34	4.854	0.010	0.041	0.253
220	26	34	4.937	0.009	0.043	0.238
232	26	34	5.026	0.009	0.044	0.232
244	26	34	5.115	0.009	0.045	0.229
256	26	34	5.213	0.008	0.047	0.229
265	26	34	5.289	0.008	0.048	0.217
282	26	34	5.436	0.008	0.049	0.212
160	26	36	4.752	0.016	0.030	0.300
172	26	36	4.814	0.015	0.033	0.282
184	26	36	4.882	0.015	0.036	0.270
196	26	36	4.955	0.014	0.039	0.261
208	26	36	5.033	0.013	0.041	0.251
220	26	36	5.114	0.013	0.043	0.238
232	26	36	5.202	0.012	0.044	0.232
244	26	36	5.290	0.012	0.045	0.229
256	26	36	5.387	0.011	0.047	0.228
265	26	36	5.462	0.011	0.048	0.217
282	26	36	5.608	0.011	0.049	0.212
160	28	34	4.829	0.011	0.028	0.297
172	28	34	4.891	0.011	0.031	0.282
184	28	34	4.958	0.010	0.034	0.274
196	28	34	5.030	0.010	0.037	0.261
208	28	34	5.107	0.009	0.039	0.251
220	28	34	5.188	0.009	0.041	0.240
232	28	34	5.275	0.009	0.042	0.232
244	28	34	5.365	0.008	0.043	0.225
256	28	34	5.459	0.008	0.045	0.222
265	28	34	5.534	0.008	0.046	0.215
282	28	34	5.679	0.007	0.047	0.212

STATIC ROLL THRESHOLD

Tr WB (in)	Lead Len (ft)	Rear Len (ft)	Static Roll Threshold		
			90 km/h	100 km/h	110 km/h
160	22	34	0.338	0.339	0.342
172	22	34	0.339	0.340	0.341
184	22	34	0.339	0.340	0.342
196	22	34	0.339	0.340	0.341
208	22	34	0.339	0.340	0.341
220	22	34	0.339	0.340	0.341
232	22	34	0.339	0.340	0.342
244	22	34	0.339	0.340	0.342
256	22	34	0.339	0.340	0.342
265	22	34	0.339	0.340	0.341
282	22	34	0.339	0.340	0.341
160	22	36	0.347	0.348	0.350
172	22	36	0.347	0.348	0.350
184	22	36	0.347	0.348	0.350
196	22	36	0.348	0.348	0.350
208	22	36	0.348	0.349	0.350
220	22	36	0.348	0.349	0.350
232	22	36	0.349	0.349	0.350
244	22	36	0.349	0.349	0.350
256	22	36	0.349	0.350	0.350
265	22	36	0.349	0.350	0.350
282	22	36	0.349	0.350	0.351
160	22	38	0.355	0.356	0.358
172	22	38	0.355	0.356	0.358
184	22	38	0.355	0.356	0.357
196	22	38	0.356	0.356	0.357
208	22	38	0.356	0.357	0.357
220	22	38	0.356	0.357	0.357
232	22	38	0.357	0.357	0.358
244	22	38	0.357	0.357	0.358
256	22	38	0.357	0.357	0.358
265	22	38	0.358	0.357	0.358
282	22	38	0.358	0.358	0.358

160	22	40	0.363	0.363	0.365
172	22	40	0.363	0.363	0.364
184	22	40	0.363	0.363	0.364
196	22	40	0.363	0.363	0.364
208	22	40	0.364	0.364	0.364
220	22	40	0.364	0.364	0.364
232	22	40	0.365	0.364	0.365
244	22	40	0.365	0.364	0.365
256	22	40	0.365	0.365	0.365
265	22	40	0.365	0.365	0.365
282	22	40	0.366	0.365	0.365
160	24	34	0.341	0.342	0.344
172	24	34	0.341	0.342	0.343
184	24	34	0.341	0.342	0.344
196	24	34	0.341	0.343	0.344
208	24	34	0.342	0.343	0.344
220	24	34	0.342	0.343	0.344
232	24	34	0.342	0.343	0.344
244	24	34	0.342	0.343	0.344
256	24	34	0.342	0.343	0.344
265	24	34	0.342	0.343	0.344
282	24	34	0.342	0.343	0.344
160	24	36	0.349	0.350	0.353
172	24	36	0.349	0.350	0.352
184	24	36	0.350	0.351	0.352
196	24	36	0.350	0.351	0.352
208	24	36	0.351	0.351	0.352
220	24	36	0.351	0.352	0.352
232	24	36	0.351	0.352	0.352
244	24	36	0.352	0.352	0.353
256	24	36	0.352	0.352	0.353
265	24	36	0.352	0.352	0.353
282	24	36	0.353	0.353	0.353
160	24	38	0.357	0.358	0.360
172	24	38	0.358	0.358	0.359
184	24	38	0.358	0.358	0.360
196	24	38	0.359	0.359	0.359
208	24	38	0.359	0.359	0.360
220	24	38	0.359	0.359	0.360
232	24	38	0.360	0.360	0.360

244	24	38	0.361	0.360	0.360
256	24	38	0.361	0.360	0.360
265	24	38	0.361	0.360	0.360
282	24	38	0.362	0.361	0.361
160	26	34	0.343	0.344	0.346
172	26	34	0.344	0.345	0.346
184	26	34	0.344	0.345	0.346
196	26	34	0.344	0.345	0.346
208	26	34	0.345	0.346	0.347
220	26	34	0.345	0.346	0.347
232	26	34	0.345	0.346	0.347
244	26	34	0.345	0.346	0.347
256	26	34	0.346	0.346	0.347
265	26	34	0.345	0.346	0.347
282	26	34	0.346	0.347	0.348
160	26	36	0.352	0.353	0.355
172	26	36	0.352	0.353	0.354
184	26	36	0.353	0.353	0.355
196	26	36	0.354	0.354	0.355
208	26	36	0.354	0.354	0.355
220	26	36	0.354	0.354	0.355
232	26	36	0.355	0.355	0.355
244	26	36	0.355	0.355	0.356
256	26	36	0.356	0.355	0.356
265	26	36	0.356	0.356	0.356
282	26	36	0.356	0.356	0.356
160	28	34	0.346	0.347	0.348
172	28	34	0.346	0.347	0.348
184	28	34	0.347	0.347	0.349
196	28	34	0.347	0.348	0.349
208	28	34	0.347	0.348	0.349
220	28	34	0.348	0.349	0.349
232	28	34	0.348	0.349	0.350
244	28	34	0.348	0.349	0.350
256	28	34	0.349	0.349	0.350
265	28	34	0.349	0.349	0.350
282	28	34	0.349	0.349	0.350

HIGH-SPEED PERFORMANCE MEASURES

Tr WB (in)	Lead Len (ft)	Rear Len (ft)	High-speed Offtracking (<0.46 m)			Load Transfer Ratio (<0.60)			Transient Offtracking (<0.80 m)		
			90 km/h	100 km/h	110 km/h	90 km/h	100 km/h	110 km/h	90 km/h	100 km/h	110 km/h
160	22	34	0.495	0.530	0.557	0.584	0.634	0.679	0.719	0.869	1.004
172	22	34	0.504	0.540	0.568	0.579	0.631	0.676	0.724	0.875	1.013
184	22	34	0.514	0.551	0.579	0.575	0.627	0.673	0.729	0.882	1.021
196	22	34	0.523	0.561	0.589	0.568	0.621	0.668	0.729	0.883	1.023
208	22	34	0.532	0.571	0.600	0.562	0.616	0.662	0.730	0.885	1.027
220	22	34	0.540	0.580	0.610	0.554	0.609	0.656	0.726	0.882	1.024
232	22	34	0.549	0.590	0.621	0.547	0.602	0.649	0.724	0.880	1.024
244	22	34	0.556	0.599	0.630	0.539	0.594	0.642	0.717	0.874	1.018
256	22	34	0.564	0.608	0.640	0.530	0.587	0.634	0.713	0.870	1.015
265	22	34	0.569	0.614	0.647	0.523	0.580	0.628	0.707	0.863	1.008
282	22	34	0.580	0.626	0.661	0.511	0.568	0.617	0.698	0.854	1.000
160	22	36	0.490	0.528	0.556	0.556	0.606	0.649	0.695	0.846	0.983
172	22	36	0.500	0.538	0.566	0.552	0.603	0.647	0.700	0.853	0.992
184	22	36	0.510	0.549	0.578	0.547	0.599	0.644	0.706	0.860	1.001
196	22	36	0.518	0.558	0.588	0.541	0.594	0.639	0.707	0.862	1.004
208	22	36	0.528	0.569	0.599	0.535	0.589	0.634	0.708	0.864	1.007
220	22	36	0.536	0.578	0.609	0.528	0.582	0.628	0.705	0.861	1.006
232	22	36	0.544	0.588	0.620	0.521	0.576	0.622	0.703	0.860	1.006
244	22	36	0.552	0.596	0.629	0.513	0.569	0.615	0.698	0.855	1.001
256	22	36	0.560	0.605	0.639	0.505	0.561	0.608	0.694	0.851	0.997
265	22	36	0.565	0.611	0.646	0.499	0.555	0.602	0.688	0.845	0.991
282	22	36	0.575	0.624	0.660	0.488	0.544	0.592	0.680	0.837	0.983
160	22	38	0.486	0.526	0.555	0.532	0.582	0.624	0.672	0.823	0.963
172	22	38	0.495	0.536	0.566	0.528	0.579	0.622	0.678	0.831	0.972
184	22	38	0.505	0.547	0.577	0.524	0.575	0.619	0.685	0.839	0.982
196	22	38	0.514	0.556	0.587	0.518	0.570	0.615	0.686	0.842	0.985
208	22	38	0.523	0.566	0.599	0.513	0.565	0.610	0.688	0.845	0.989
220	22	38	0.531	0.575	0.608	0.506	0.559	0.604	0.686	0.842	0.988
232	22	38	0.540	0.585	0.619	0.499	0.553	0.598	0.685	0.842	0.988
244	22	38	0.547	0.594	0.628	0.492	0.546	0.592	0.680	0.837	0.984
256	22	38	0.555	0.603	0.638	0.484	0.539	0.585	0.677	0.834	0.981
265	22	38	0.560	0.609	0.645	0.478	0.534	0.580	0.671	0.828	0.975

282	22	38	0.571	0.621	0.659	0.467	0.523	0.570	0.664	0.821	0.968
160	22	40	0.482	0.524	0.555	0.510	0.560	0.601	0.649	0.801	0.942
172	22	40	0.491	0.534	0.566	0.507	0.557	0.599	0.656	0.810	0.952
184	22	40	0.501	0.545	0.577	0.503	0.554	0.596	0.663	0.818	0.963
196	22	40	0.510	0.554	0.587	0.498	0.549	0.593	0.665	0.821	0.966
208	22	40	0.519	0.564	0.598	0.493	0.545	0.588	0.668	0.825	0.971
220	22	40	0.527	0.573	0.608	0.486	0.539	0.583	0.666	0.824	0.970
232	22	40	0.536	0.583	0.618	0.480	0.533	0.578	0.666	0.823	0.971
244	22	40	0.543	0.592	0.628	0.472	0.527	0.571	0.662	0.819	0.967
256	22	40	0.551	0.601	0.638	0.466	0.520	0.565	0.659	0.816	0.965
265	22	40	0.556	0.607	0.644	0.460	0.514	0.560	0.655	0.811	0.960
282	22	40	0.567	0.619	0.658	0.449	0.504	0.550	0.648	0.805	0.953
160	24	34	0.500	0.538	0.566	0.559	0.611	0.656	0.694	0.845	0.983
172	24	34	0.509	0.547	0.576	0.555	0.608	0.654	0.700	0.853	0.992
184	24	34	0.519	0.558	0.588	0.551	0.605	0.651	0.706	0.860	1.002
196	24	34	0.528	0.568	0.598	0.545	0.600	0.647	0.706	0.862	1.005
208	24	34	0.537	0.578	0.609	0.540	0.595	0.642	0.708	0.865	1.009
220	24	34	0.545	0.587	0.619	0.533	0.588	0.636	0.705	0.863	1.008
232	24	34	0.554	0.597	0.629	0.526	0.582	0.630	0.704	0.862	1.008
244	24	34	0.561	0.606	0.639	0.518	0.575	0.623	0.699	0.857	1.004
256	24	34	0.569	0.615	0.649	0.510	0.568	0.616	0.695	0.853	1.001
265	24	34	0.574	0.621	0.655	0.504	0.562	0.611	0.689	0.847	0.995
282	24	34	0.585	0.633	0.669	0.493	0.551	0.600	0.681	0.839	0.987
160	24	36	0.495	0.535	0.564	0.532	0.584	0.627	0.670	0.822	0.962
172	24	36	0.504	0.545	0.575	0.529	0.581	0.625	0.677	0.830	0.972
184	24	36	0.514	0.556	0.587	0.525	0.578	0.622	0.683	0.839	0.982
196	24	36	0.523	0.565	0.597	0.519	0.573	0.619	0.685	0.842	0.986
208	24	36	0.532	0.575	0.608	0.514	0.568	0.614	0.687	0.845	0.990
220	24	36	0.540	0.585	0.618	0.507	0.562	0.609	0.685	0.843	0.990
232	24	36	0.549	0.594	0.628	0.501	0.556	0.603	0.684	0.843	0.990
244	24	36	0.556	0.603	0.637	0.493	0.550	0.597	0.680	0.838	0.986
256	24	36	0.564	0.612	0.648	0.486	0.543	0.590	0.677	0.835	0.984
265	24	36	0.569	0.618	0.654	0.480	0.537	0.585	0.672	0.830	0.978
282	24	36	0.580	0.630	0.668	0.470	0.527	0.575	0.665	0.822	0.971
160	24	38	0.491	0.533	0.564	0.508	0.560	0.602	0.648	0.801	0.942
172	24	38	0.500	0.543	0.575	0.505	0.557	0.600	0.655	0.810	0.952
184	24	38	0.510	0.554	0.586	0.502	0.555	0.598	0.663	0.819	0.963
196	24	38	0.518	0.563	0.596	0.497	0.550	0.594	0.665	0.822	0.967
208	24	38	0.528	0.573	0.607	0.492	0.546	0.590	0.668	0.826	0.973
220	24	38	0.536	0.582	0.617	0.485	0.540	0.585	0.667	0.825	0.972

232	24	38	0.544	0.592	0.627	0.479	0.534	0.580	0.666	0.825	0.974
244	24	38	0.552	0.600	0.636	0.472	0.528	0.574	0.663	0.821	0.970
256	24	38	0.560	0.610	0.646	0.466	0.521	0.568	0.660	0.818	0.968
265	24	38	0.564	0.615	0.653	0.460	0.516	0.563	0.655	0.813	0.963
282	24	38	0.575	0.628	0.667	0.450	0.506	0.553	0.649	0.807	0.956
160	26	34	0.502	0.543	0.572	0.533	0.586	0.631	0.661	0.814	0.953
172	26	34	0.511	0.552	0.583	0.530	0.583	0.629	0.668	0.822	0.963
184	26	34	0.521	0.563	0.595	0.526	0.581	0.627	0.675	0.831	0.974
196	26	34	0.530	0.573	0.605	0.521	0.576	0.623	0.677	0.833	0.978
208	26	34	0.539	0.583	0.616	0.516	0.572	0.619	0.680	0.837	0.983
220	26	34	0.547	0.592	0.625	0.510	0.566	0.614	0.678	0.836	0.983
232	26	34	0.556	0.602	0.636	0.503	0.560	0.608	0.677	0.836	0.984
244	26	34	0.563	0.610	0.645	0.496	0.553	0.602	0.673	0.832	0.980
256	26	34	0.572	0.620	0.655	0.489	0.547	0.596	0.670	0.829	0.978
265	26	34	0.576	0.625	0.662	0.483	0.541	0.591	0.665	0.824	0.973
282	26	34	0.587	0.638	0.675	0.473	0.531	0.580	0.659	0.817	0.966
160	26	36	0.497	0.540	0.572	0.507	0.559	0.603	0.639	0.792	0.933
172	26	36	0.507	0.550	0.582	0.504	0.556	0.601	0.646	0.801	0.943
184	26	36	0.516	0.561	0.593	0.500	0.554	0.599	0.654	0.810	0.954
196	26	36	0.525	0.570	0.604	0.496	0.550	0.596	0.657	0.814	0.959
208	26	36	0.534	0.580	0.614	0.491	0.546	0.592	0.660	0.817	0.965
220	26	36	0.542	0.589	0.624	0.485	0.540	0.587	0.659	0.817	0.965
232	26	36	0.551	0.599	0.635	0.479	0.535	0.582	0.659	0.817	0.967
244	26	36	0.558	0.607	0.644	0.472	0.529	0.576	0.655	0.814	0.963
256	26	36	0.566	0.617	0.654	0.466	0.523	0.570	0.653	0.811	0.961
265	26	36	0.571	0.622	0.660	0.460	0.517	0.566	0.649	0.807	0.957
282	26	36	0.582	0.635	0.674	0.451	0.508	0.556	0.643	0.801	0.951
160	28	34	0.503	0.547	0.579	0.509	0.562	0.607	0.630	0.782	0.922
172	28	34	0.513	0.557	0.589	0.506	0.560	0.606	0.637	0.791	0.933
184	28	34	0.522	0.567	0.601	0.503	0.558	0.604	0.645	0.800	0.945
196	28	34	0.531	0.577	0.611	0.498	0.554	0.601	0.648	0.804	0.950
208	28	34	0.540	0.587	0.622	0.494	0.550	0.598	0.651	0.809	0.956
220	28	34	0.548	0.596	0.632	0.488	0.544	0.593	0.650	0.809	0.957
232	28	34	0.557	0.606	0.642	0.482	0.539	0.588	0.651	0.809	0.958
244	28	34	0.564	0.614	0.651	0.476	0.533	0.582	0.647	0.806	0.956
256	28	34	0.572	0.623	0.661	0.469	0.527	0.576	0.645	0.804	0.954
265	28	34	0.577	0.629	0.668	0.464	0.522	0.572	0.641	0.799	0.949
282	28	34	0.588	0.641	0.681	0.454	0.512	0.562	0.636	0.793	0.944

APPENDIX 3 – EVALUATION OF DYNAMIC PERFORMANCE OF HEAVY TRUCKS

Evaluation of the Dynamic Performance of Heavy Trucks

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1. INTRODUCTION

The Trans-Canada Highway was completed in the early 1960's, and made nation-wide inter-provincial trucking possible. However, the provinces took widely different approaches to their truck weight and dimension regulations after 1970, which limited the development of inter-provincial trucking. The Canadian Council of Motor Transport Administrators (CCMTA) and the Roads and Transportation Association of Canada (RTAC) recognized this issue, and began a process to harmonize truck weight and dimension regulations between the provinces in 1975. A round of bridge studies showed this was feasible, and in 1983 the CCMTA/RTAC Vehicle Weights and Dimensions Study was undertaken at a cost of $2.5 million, then the largest single transportation research project ever conducted in Canada. This study examined the dynamic performance of various candidate heavy truck configurations, and the impact of various axle groups on pavements.

The methodology for assessment of dynamic performance of heavy trucks was developed during the CCMTA/RTAC Vehicle Weights and Dimensions Study [1], [2]. Consideration of these findings [3], [4], the pavement findings, and the prior bridge studies, led to the national Memorandum of Understanding on Vehicle Weights and Dimensions ("the M.o.U.") [5], which set standards for the most common tractor-semitrailer and double trailer combinations used in inter-provincial trucking. These standards were adopted by all provinces from 1989 through 1994 as the basis for their regulation of these configurations. The same approach was used subsequently when straight trucks and truck-trailer combinations were added to the national M.o.U. [5] in 1991.

This report describes the process used for assessment of the dynamic performance of heavy truck configurations. This process is generally used by most provinces, when considering a new configuration for addition to their own vehicle weight and dimension regulations, or for operation under a special permit.

2. APPROACH AND METHODOLOGY

2.1 Introduction

The methodology for assessment of dynamic performance of heavy trucks was developed during the CCMTA/RTAC Vehicle Weights and Dimensions Study [1], [2]. Consideration of the findings [3], [4], led to the national Memorandum of Understanding on Vehicle Weights and Dimensions ("the M.o.U.") [5], which set standards for the most common tractor-semitrailer and double trailer combinations used in inter-provincial trucking. These standards have been adopted by all provinces as the basis for their regulation of these configurations. The same approach was used subsequently when straight trucks and truck-trailer combinations were added to the national M.o.U. [5]. This approach has also been used by most provinces, when adding vehicle configurations outside the M.o.U. to their own vehicle weight and dimension regulations, such as for 5- and 6-axle semitrailers in Ontario [7], and when considering configurations proposed for a special permit.

2.2 Assessment of Vehicle Dynamic Performance

Vehicle dynamic performance is assessed by computer simulation, in three steps:

1. Subject a vehicle to a standardized input;
2. Evaluate the performance measures; then
3. Compare the performance measures to their performance standards.

An input is a specific manoeuvre conducted by a vehicle at a specific speed. Inputs are standardized so that different vehicles can be compared.

A performance measure is a parameter that describes the behaviour of some aspect of vehicle dynamic performance. Each performance measure is derived from specific responses of a vehicle to a specific standardized input. The following eleven performance measures may be considered:

- Static roll threshold;
- High-speed offtracking;
- Load transfer ratio;
- Transient offtracking;
- Low-speed offtracking;
- Friction demand;
- Braking efficiency
- Lateral friction utilization;
- Maximum self-steer angle;
- Rear outswing; and
- Front outswing.

The first seven are the so-called "RTAC" performance measures, developed during the

CCMTA/RTAC Vehicle Weights and Dimensions Study [1], [2], [3], [4]. This Study addressed trailers, so the performance measures were developed to characterize the performance of the trailer within the whole vehicle. The other four were developed subsequently, to address particular aspects of vehicle dynamic performance that were not significant in the configurations considered during the CCMTA/RTAC Vehicle Weights and Dimensions Study:

A performance standard is the criterion or boundary between satisfactory and unsatisfactory performance. Performance standards have been set so that, in both normal and moderately aggressive manoeuvres:

- The driver maintains control of the vehicle; and
- The vehicle does not roll over; and
- The vehicle does not intrude into the space of other vehicles.

2.3 Computer Simulation

This work was conducted using the Yaw/roll model [8]. This is the same model that was used during the CCMTA/RTAC Vehicle Weights and Dimensions Study [2]. Other simulation models are available that might be used for the same, and other, purposes.

The Yaw/roll model is a dynamic simulation of moderate complexity that represents the combined lateral, yaw and roll response of heavy articulated vehicles steering inputs. The model uses relatively simple input data. The model can represent a vehicle combination with up to six vehicle units, up to eight axles on any vehicle unit, up to eleven axles in total, with up to five of the axles (excluding the front axle) self-steering or forced steering. The model includes fifth wheel, turntable, pintle hook, C-dolly and other couplings, so A-, B- and C-train combinations, and others, can be represented. The non-linear characteristics of self-steering axles and couplings are represented directly within the model, while lookup tables represent the non-linear characteristics of tires and suspensions. The model does not represent longitudinal tire forces needed for drive and brake torque, so is restricted to travel at constant longitudinal velocity on a smooth, level road surface with uniform frictional characteristics.

The model operates either in closed loop mode or open loop mode. In closed loop mode, the steer input is defined, either at the steering wheel or the steering axle. The vehicle does not follow any specific path on the ground, it goes where its dynamic characteristics take it. Two different vehicles subject to the same closed loop input may follow quite different paths on the ground, depending on the dynamic characteristics of each vehicle. In open loop mode, a path is specified on the ground, and a driver model is used to cause the vehicle to follow that path. Parameters supplied to the driver model determine how closely the specified path is actually followed.

The Yaw/roll simulation program had been used extensively in previous simulation studies, for example, [1], [6], [7]. It has been shown to provide reasonable agreement with test results for a large number of vehicle configurations [8], [9].

The absolute accuracy of a vehicle simulation depends critically both on how well the model represents the vehicle system, and how accurately data are known for its components. Previous work has addressed the accuracy of the model [8], [9]. The relative accuracy, for purposes of comparison of similar vehicles, is less dependent upon the accuracy of component data. The simulation can be expected to provide a proper ranking of vehicles in a comparison as long as the data are reasonably representative.

The performance measures relevant to a particular configuration are obtained from a standard manoeuvre, which is designed to provide the necessary responses.

2.4 Standard Manoeuvres

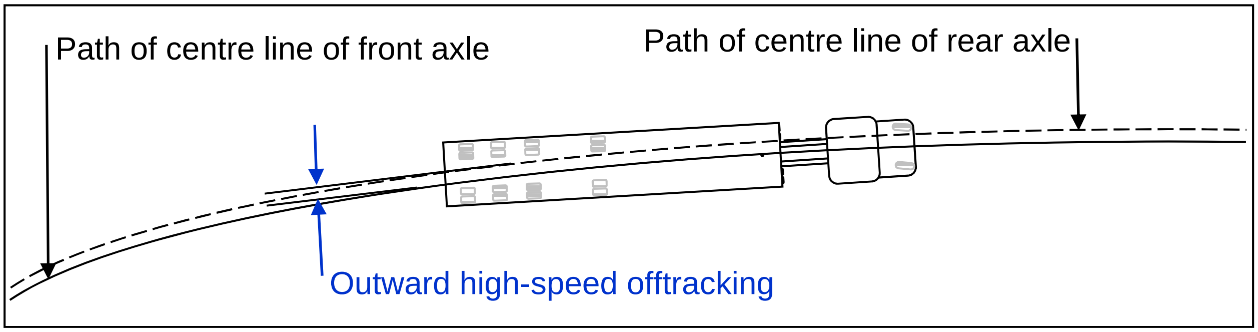
Each performance measure is derived from one of five standard manoeuvres. The RTAC high-speed performance measures were established at 100 km/h (62.1 mi/h), but other speeds may be used, depending on the prevailing speed limits where the vehicle will be operated.

2.4.1 High-speed Turn

A high-speed turn, made on a high-friction surface, is used to evaluate the static rollover threshold and high-speed offtracking performance measures. The turn consists of:

- A short tangent (straight) segment; followed by
- A spiral entry, of 2-5 s duration; to
- A curve whose radius corresponds to a lateral acceleration of 0.20 g at the specified speed, followed for 10-15 s to allow steady state high-speed offtracking to be achieved, as shown in Figure 1; then
- Steering wheel angle is increased at 2 deg/s, until the vehicle rolls over or becomes unstable in yaw.

Figure 1: High-speed Turn



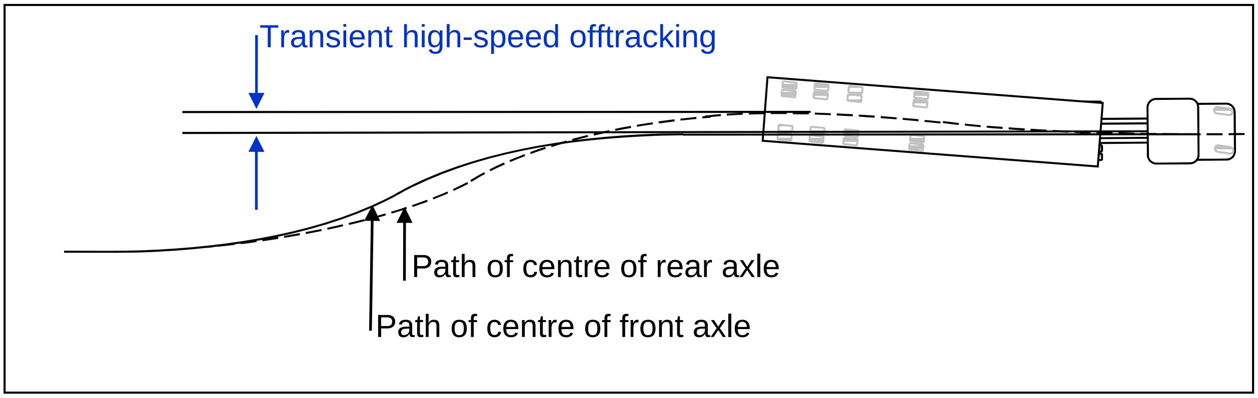
The speed is chosen depending on the prevailing speed limits where the vehicle will be operated. The duration of the spiral is chosen to avoid significant perturbation of the vehicle as it enters the curve. The duration of the steady curve is chosen to allow any perturbations of the vehicle to be damped out, so that a steady high-speed offtracking condition is achieved. These should be longer for vehicles with low damping, like A-train double and triple trailer combinations.

2.4.2 High-speed Lane Change

A high-speed lane change made on a high-friction surface is used to evaluate the load transfer ratio and transient high-speed offtracking performance measures. This manoeuvre is shown in Figure 2. The path consists of:

- A short tangent (straight) approach; followed by
- A side-step which corresponds to a single sinusoidal cycle of lateral acceleration of 0.15 g at the front axle of the power unit, with a period of 3.0 s; followed by
- A long tangent exit, parallel to the approach.

Figure 2: High-speed Lane Change



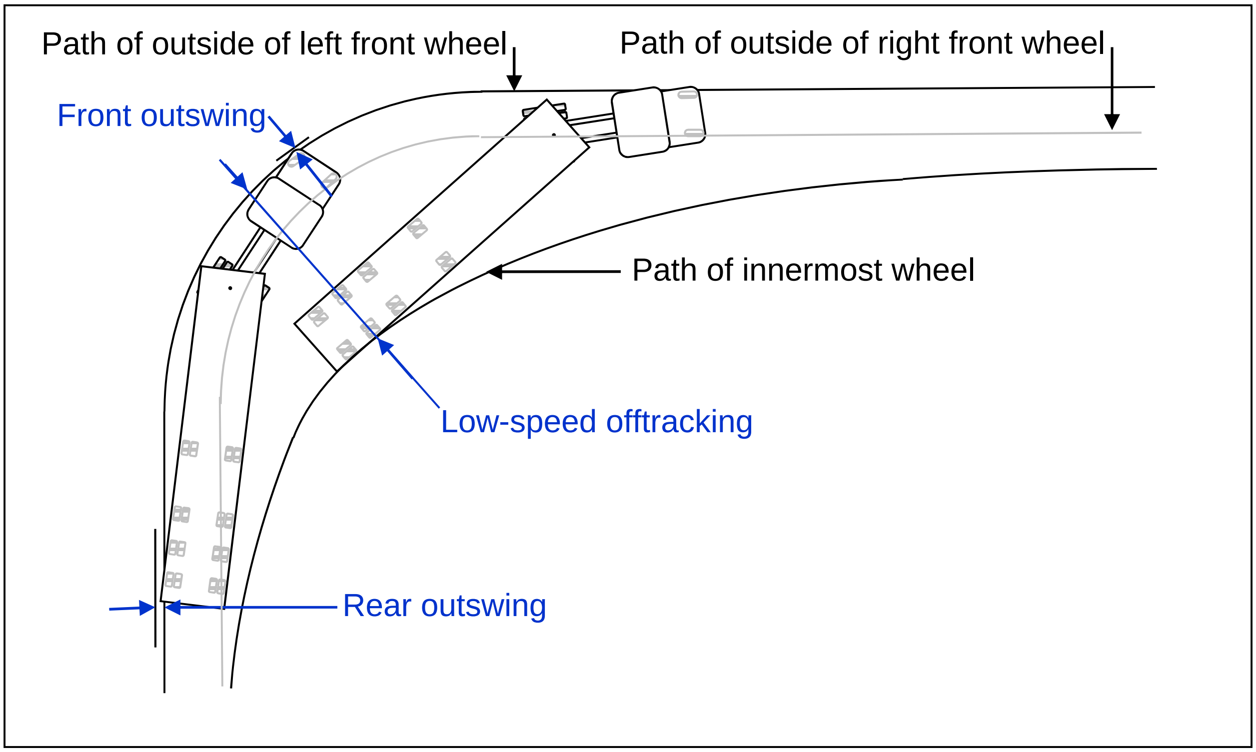
This represents a manoeuvre to avoid an obstacle in the path of the vehicle [2]. The speed is chosen depending on the prevailing speed limits where the vehicle will be operated. The amount of side-step depends on the period and vehicle speed.

This manoeuvre is sufficiently moderate that it does not cause the rearmost trailer of a double or triple trailer combination to roll over. The period corresponds to that at which the greatest response occurred for most trucks in the simulations for the CCMTA/RTAC Vehicle Weights and Dimensions Study [2], but was not necessarily the period at which greatest response would actually occur for any particular vehicle. The two performance measures do not depend strongly on steer period for tractor-semitrailers, whereas they may for double and triple trailer combinations, and truck-trailer combinations.

2.4.3 Low-speed Right-hand Turn on a High-friction Surface

A 90 degree right-hand turn made at a speed of 8.8 km/h (5.5 mi/h) on a high-friction surface is used to evaluate the low-speed offtracking, friction demand and both outswing performance measures. It represents a turn that might be made at a typical intersection. The manoeuvre is shown in Figure 3. The coefficient of friction is usually 0.80.

Figure 3: Low-speed Right-hand Turn



The CCMTA/RTAC Vehicle Weights and Dimensions Study used a turn radius of 10.97 m (36 ft) at the outside of the left front wheel of the power unit [2]. However, not all power units can make a turn of this radius. A 14.00 m (46 ft) radius at the outside of the left front wheel of the power unit was used to establish the geometry of the curb line for design of the open throat intersection to be used where significant numbers of turns are made by large trucks. This radius is appropriate for most long-wheelbase power units, and was also recommended for assessment of vehicle configurations to be agreed under provisions of the North American Free Trade Agreement (NAFTA) [11]. However, some power units of extreme wheelbase cannot make a 14.00 m (46 ft) radius turn, and a larger radius is necessary for these.

2.4.4 Low-speed Right-hand Turn on a Low-friction Surface

A 90 degree right-hand turn made at a speed of 8.8 km/h (5.5 mi/h) on a low-friction surface is used to evaluate the lateral friction utilization performance measure. This is the same manoeuvre as shown in Figure 3, but performed on a low-friction surface, usually with a coefficient of friction of 0.20.

2.4.5 Tight Low-speed Right-hand Turn on a High-friction Surface

A 90 degree right-hand turn made at a speed of 8.8 km/h (5.5 mi/h) on a high-friction surface is used to evaluate the maximum self-steer angle performance measure. This is the same manoeuvre as shown in Figure 3, but using a tight turn radius close to the minimum possible for the class of power unit considered, typically 12 m (39 ft 4 in).

2.5 Performance Measures and Performance Standards

2.5.1 Static Roll Threshold

The static roll threshold performance measure is the lateral acceleration, in g, at which a vehicle just rolls over in a steady turn. This measure is known to correlate well with the incidence of single truck rollover crashes [1], [18].

The static roll threshold is a particularly significant performance measure for any vehicle loaded close to its allowable gross weight with a high payload centre of gravity. The static roll threshold diminishes as payload weight increases, and payload centre of gravity height above the ground increases. It does not depend directly on speed

The CCMTA/RTAC Vehicle Weights and Dimensions Study set a target static roll threshold of 0.40 g [4]. This value was not used when vehicles were configured for the national M.o.U. [5], because it was recognized that certain commodities inherently have a high centre of gravity at the axle and gross weights allowed in Canada. So, vehicles that meet the M.o.U. may have a static roll threshold less than 0.40 g. However, provinces that use an assessment of dynamic performance as part of the review of a special permit application may impose the 0.40 g static roll threshold.

Studies in the U.S. considered static roll thresholds of 0.35 and 0.38 g, and concluded that any roll threshold higher than 0.35 g would restrict commerce, and would require a considerable number of exemptions. The static roll threshold is not considered in U.S. Federal regulations, nor is it known to be a factor in any state law, regulation or permit.

New Zealand has narrow winding roads. Its regulations resulted in short, high vehicles. The outcome was a much higher rollover rate than common in North America. New Zealand therefore established a minimum operational static roll threshold of 0.35 g, for both new and existing vehicles [12]. Carriers were required to reduce payload, or modify or replace an existing vehicle to meet this roll threshold.

Australia adopted a static roll threshold of 0.35 g for its new performance-based approach to regulation, which allows a vehicle carrying general freight to be configured simply to performance standards [13].
Tank trucks are now being treated more cautiously. The Australian performance-based standards set the minimum static roll threshold at 0.40 g for tank trucks [13]. European countries set the minimum static roll threshold for tank trucks at 0.40 g based on a tilt test, or 0.42 g based on a specified calculation procedure [14]. New Zealand set the minimum static roll threshold at 0.45 g for tank trucks, but its allowable axle weights and gross weight are modest by Canadian standards, so tank trucks have a low centre of gravity and meet this without difficulty.

This work uses 0.40 g as the static roll threshold performance standard, simply for presentation. It should not preclude setting a different limit when warranted for any configuration.

2.5.2 High-speed Offtracking

The high-speed offtracking performance measure is the lateral offset between the path of the steer axle of a tractor and the path of the last axle of the vehicle in a steady turn of 0.20 g lateral acceleration, as shown in Figure 1. Since the driver guides the tractor along a desired path, there is a clear safety hazard if the rearmost axle follows a more outboard path than the tractor front axle that might intersect a curb or other roadside obstacle, or intrude into an adjacent lane of traffic. This is particularly critical, because many trailer body styles block the driver’s view of the left rear corner of the vehicle.

High-speed offtracking should not exceed 0.46 m (18 in) outboard of the path of the tractor. This allows the rearmost wheel of a vehicle with a 2.59 m (102 in) wide trailer whose power unit is centred in a 3.66 m (12 ft) wide lane within 0.08 m (3 in) of the edge of its lane.

High-speed offtracking is particularly significant for a long semitrailer with more than three axles, especially if it has self-steering axles, and double and triple trailer combinations. High-speed offtracking increases with vehicle overall length, as trailer effective wheelbase diminishes, as payload weight increases, payload centre of gravity height above the ground increases, and as vehicle speed increases.

High-speed offtracking is not a concern for operation on urban roads and freeway ramps, where speed and lateral acceleration are modest, or on freeways and other high-speed roads where the operating speed is not greater than the design speed [17]. So, while long combination vehicles typically fail the high-speed offtracking performance standard, their actual high-speed offtracking will not be an issue because they are generally restricted to freeways and local approved access routes. High-speed offtracking may be a concern for operation on other roads, which may have a design speed less than the actual traffic speed, and especially if traffic lanes are less than 3.66 m (12 ft) in width, or there is a curb, or no shoulder [17].

2.5.3 Load Transfer Ratio

The load transfer ratio performance measure is the fractional change in load between left- and right-hand side tires on a vehicle in an obstacle avoidance manoeuvre. It indicates how close all of the tires on one side of the rearmost roll-coupled unit came to lifting off, which is generally immediately precedes rollover.

The load transfer ratio should not exceed 0.60, which is equivalent to an 80%-20% left-right division of wheel loads. When the load transfer ratio reaches 1.00, all the load of the vehicle is on the wheels on one side, and the vehicle is on the verge of rollover.

Load transfer ratio is a particularly significant performance measure for any vehicle with a high payload centre of gravity, A-train double and triple trailer combinations, and truck-trailer combinations. Load transfer ratio increases as trailer wheelbase diminishes, hitch offset increases, payload weight increases, payload centre of gravity height above the ground increases, and vehicle speed increases.

2.5.4 Transient High-speed Offtracking

The transient high-speed offtracking performance measure is the peak overshoot in the lateral position of the rearmost trailer axle from the path of the tractor front axle in an obstacle avoidance manoeuvre, as shown in Figure 2. It is an indication of potential for side-swipe of a vehicle in an adjacent lane, or for impact-induced rollover due to a curb strike. This measure quantifies the "tail-wagging" response of a vehicle to a rapid steer input.

Transient high-speed offtracking should not exceed 0.80 m (31.5 in).

Transient high-speed offtracking does not exist for a single unit vehicle. It is a particularly significant performance measure for double and triple trailer combinations, and truck-trailer combinations. Transient high-speed offtracking increases as trailer wheelbase diminishes, payload weight increases, payload centre of gravity height above the ground increases, and vehicle speed increases.

2.5.5 Low-speed Offtracking

The low-speed offtracking performance measure is the extent of inboard offtracking of the rearmost trailer from the front axle of the power unit in a 90 degree right-hand turn at a typical intersection, as shown in Figure 3. This property is of concern to the "fit" of the vehicle on the road system, and has implications for safety as well as abuse of roadside appurtenances.

The M.o.U. configuration with the greatest offtracking is a tractor with 6.20 m (244 in) wheelbase and its fifth wheel over its turn centre, towing a semitrailer with 12.50 m (41 ft) wheelbase. This vehicle has low-speed offtracking of 5.60 m (18 ft 4 in) in a 90 deg right-hand turn with a radius of 14.00 m (46 ft) at the left front wheel of the tractor. If another vehicle can turn more tightly than 14.00 m (46 ft), or cannot make a turn of this radius, it may be compared to the offtracking of this vehicle in a turn that both can make.

Low-speed offtracking is a particularly significant performance measure for long semitrailers, and long double and triple trailer combination vehicles. It increases with wheelbase of each vehicle unit.

2.5.6 Friction Demand

The friction demand performance measure is a measure of the resistance of a vehicle with multiple widely-spaced axles to turning, such as at an intersection. It results in a "demand" for tire side force at the tractor's drive axles. The performance measure was developed from the hypothesis that the tractor of a tractor-semitrailer whose friction demand exceeds that which is available from drive tire-road friction could jackknife [2]. The friction demand measure describes the minimum tire-pavement friction necessary for the vehicle to negotiate an intersection turn without suffering such loss of control.

Friction demand should not exceed 0.10.

Friction demand is a particularly significant performance measure for tractor-semitrailer combinations, where the semitrailer has three or more widely spaced axles that are not self-steering.

Tests conducted during the CCMTA/RTAC Vehicle Weights and Dimensions Study were unable to produce a jackknife with a tri-axle semitrailer [2]. A recent series of full-scale tests with five-axle semitrailers with two self-steering axles did produce a jackknife, and also showed that a tractor could plough out of the turn [8]. A tractor ploughs out of a turn when the front axle has insufficient side-force capability, and the vehicle departs from the turn heading straight along a tangent to the turn. This is a manifestation of excessive lateral friction utilization, as described in Section 2.5.8 below. While jackknife and plough-out did occur in these tests, they occurred at a speed well above that at which any driver would make such a turn in such a vehicle. It was shown that a reduction in the resistance to turning, an increase in turn radius, or a reduction in speed, all reduced friction demand. It was suggested that drivers would control turn radius and speed to keep friction demand at a level that allowed turns to be made for a satisfactory level of effort. It was therefore concluded that friction demand was an operational consideration, and the safety warrants for the performance measure no longer pertain [8].

2.5.7 Braking Efficiency

The braking efficiency performance measure assesses how effectively the braking system of a combination vehicle uses the available tire-road friction to stop the vehicle [2]. Braking efficiency is particularly problematic for vehicles with a significant difference in actual axle weight in proportion to the braking capability of the axle.

An antilock brake system (ABS) has been required since 2000 on power units and trailers sold in Canada. An ABS should ensure the braking efficiency performance standard is met over a much wider range of road and load conditions than the original RTAC performance measure. This performance measure is therefore no longer relevant, and is no longer evaluated.

2.5.8 Lateral Friction Utilization

The lateral friction utilization performance measure reflects the effort required by the steer axle to turn a vehicle. It results in a "demand" for tire side force at the steer axle, and this must be comfortably within the friction available from the tire-pavement interface for the vehicle to be able to turn [11].

Lateral friction utilization should be less than 0.80 m. If the lateral friction utilization reaches 1.0, the limit of control has been reached and the tractor will tend to plough out of the turn.

The lateral friction utilization performance measure is particularly significant for a power unit with a tridem drive, a self-steering axle with a high centring force, or a rigid liftable axle.

2.5.9 Maximum Self-steer Angle

The maximum self-steer angle performance measure is the maximum self-steer angle of any self-steer axle in a tight right-hand turn. A self-steer axle needs enough self-steer that it does not bottom in turns that a vehicle is likely to make on a highway [7].

Maximum self-steer angle should be less than the wheel cut available on the axle.

Maximum self-steer angle is only applicable to a vehicle that has a self-steer axle.

2.5.10 Rear Outswing

The rear outswing performance measure is the extent of intrusion of any left-hand side corner of a vehicle into the lane to the left of that occupied by the vehicle as it makes a right-hand turn, as shown in Figure 3. A left rear corner, either of the power unit or a trailer, is potentially an obstacle to another vehicle traveling in the lane to the left of the vehicle. It offers the possibility of a serious collision if the other vehicle is traveling at a higher speed than the turning truck.

Rear outswing should be less than 0.20 m (8 in).

Rear outswing is a particularly significant performance measure for a truck, tractor-semitrailer or truck-pony trailer where the power unit and/or trailer has a long effective rear overhang. It is generally not significant for combinations with three or more vehicle units.

2.5.11 Front Outswing

The front outswing performance measure is the extent of intrusion of any left-hand side corner of a vehicle outside the path of the left front wheel as the vehicle makes a right-hand turn, as shown in Figure 3. A left front corner, either of the power unit or a trailer, is potentially an obstacle to another vehicle traveling in the lane to the left of the vehicle. It offers the possibility of a serious collision if the other vehicle is traveling at a higher speed than the turning truck.

Front outswing should be less than 0.20 m (8 in).

Front outswing may be a significant performance measure for a power unit with a large front axle setback, or a semitrailer with a large kingpin setback, which is most commonly (but not necessarily) the lead semitrailer of a B-train.

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