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A DISCUSSION OF THE HIGH-SPEED OFFTRACKING PERFORMANCE STANDARD

A degree in mathematics led to the aerospace industry, then to head of heavy truck research with Ontario Ministry of Transportation. Now an independent consultant, he also works part–time with the National Research Council of Canada.

Mechanical Engineering degree from Queen's University in 1991. 16 years experience in the transportation sector. Currently a vehicle test engineer at Can-ada's National Research Coun-cil.

John BILLING **Jeff PATTEN**

Centre for Surface Transportation Technology, National Research Council of Canada
Agincourt, Canada

Abstract

Performance measures developed during the CCMTA/RTAC Vehicle Weights and Dimensions Study conducted in Canada from 1984 through 1986, and corresponding performance standards, allow the dynamic performance of heavy vehicles to be assessed in an objective manner that relates directly to highway safety. High-speed offtracking is the lateral offset between the steer axle and the rearmost axle of a vehicle in a steady high-speed turn, and there is a clear safety hazard if the rearmost axle tracks outward so that it might strike a curb or intrude into an adjacent lane. The dynamic performance of many new and proposed configurations, such as long semitrailers, especially those equipped with self-steering axles, and double trailer combinations, tends to be on or beyond the performance standard. This paper examines the applicability of the performance standard to the operation of various configurations.

Keywords: High-speed offtracking, Dynamic performance, Heavy vehicles, Performance measures, Performance standards.

Résumé

Les mesures de performance réalisées dans l'étude CCMTA/RTAC sur les poids et dimensions des véhicules, menée au Canada de 1984 à 1986, conformes aux normes performancielles, permettent d'évaluer les performances dynamiques des poids lourds d'une manière objective en relation directe avec la sécurité routière. Le balayage à vitesse élevée est le décalage latéral entre l'essieu directeur (avant) et le dernier essieu arrière d'un véhicule dans un virage à courbure constante pris à vitesse élevée, et il y a un réel danger pour la sécurité si l'essieu arrière passe en dehors de la trace normale de sorte qu'il pourrait couper le virage ou mordre sur une voie adjacente. Les performance dynamiques de beaucoup nouvelles configurations proposées, comme les longues semi-remorques, surtout celles équipées d'essieux auto-directeurs, et les combinaisons à double remorques, ont tendance à être à la limite ou en deçà des performances normées. Cet article examine la validité de l'application de la norme performancielle à l'exploitation de diverses configurations de poids lourds.

Mots-clés: Balayage à vitesse élevée, performance dynamique, poids lourds, mesures de performance, normes performancielles.

1. Introduction

The CCMTA/RTAC Vehicle Weights and Dimensions Study conducted in Canada from 1984 through 1986 developed a number of performance measures, and corresponding performance standards, that allow the dynamic performance of heavy vehicles to be assessed in an objective manner that relates directly to highway safety (CCMTA/RTAC Vehicle Weights and Dimensions Study Implementation Planning Committee, 1987). These performance measures became the basis for vehicle configurations in Canada's national Memorandum of Understanding on Vehicle Weights and Dimensions, which are allowed by regulation in all provinces (Council of Ministers Responsible for Transportation and Highway Safety, 1997). The performance measures are also used by all provinces to assess new configurations, and particularly configurations for which a carrier requests a special permit.

Vehicle configurations have evolved since the Vehicle Weights and Dimensions Study, and some provinces have increased allowable axle and gross weights for M.o.U. configurations. Consequently, the dynamic performance of many new and proposed configurations, such as long semitrailers, especially those equipped with self-steering axles, and double trailer combinations, has been on or beyond the high-speed offtracking performance standard. This paper summarizes some assessments of the applicability of the performance measure that have arisen from a number of recent studies.

2. The High-speed Offtracking Performance Measure

A high-speed turn was used to evaluate the high-speed offtracking performance measure, as shown in Figure 1. The turn started with a short tangent segment, and was followed by a spiral entry of 4 s duration to a curve whose radius corresponded to a lateral acceleration of 0.20 g at the travel speed. The curve was followed for 20 s, to reach steady state high-speed offtracking, and high-speed offtracking was computed as the lateral offset of the path of the centre of the rearmost axle of the vehicle from the path of the centre of steer axle of the power unit, as shown in Figure 1 (Ervin and Guy, 1986). 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 that might intersect a curb or other roadside obstacle, or intrude into an adjacent lane of traffic. Instances were cited where a vehicle rolled over after the rearmost axle struck a curb, and the view was expressed that "high-speed offtracking is patently undesirable, and should be minimized" (Ervin and Guy, 1986). This performance measure is particularly significant for a long semitrailer equipped with self-steering axles, and double trailer combinations.

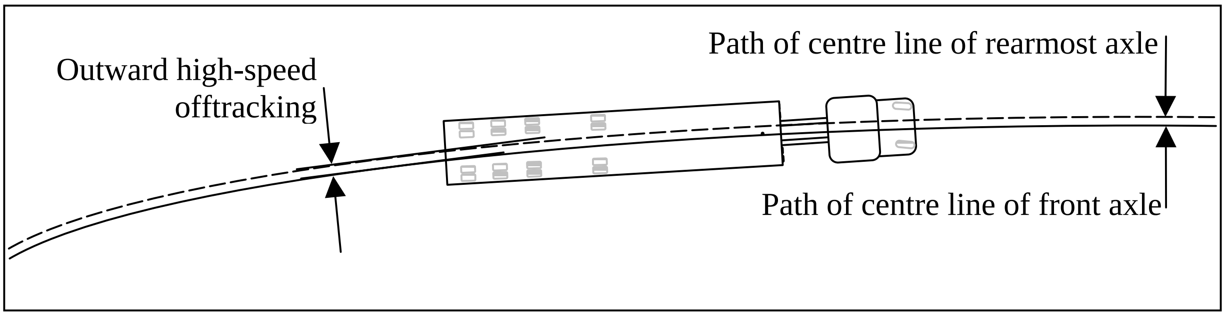

Figure 1 – High-speed Offtracking in a High-speed Turn

Figure 2 – Vehicle in a High-speed Turn

High-speed offtracking should not exceed 0.46 m outboard of the path of the tractor. This allows the rearmost wheel of a vehicle with a 2.59 m wide trailer whose tractor is centred in a 3.66 m wide lane within 0.08 m of the edge of its lane (Ervin and Guy, 1986).

Tests of two 5-axle semitrailers, each with two self-steering axles, showed that high-speed offtracking does occur, and was of the magnitude predicted by computer simulations for the particular vehicles (Billing and Patten, 2004). Figure 2 illustrates high-speed offtracking during this test program, but not during a test. The picture was taken from the passenger seat of a chase vehicle while the truck was traveling at about 85 km/h on a curve with an inside radius of 192 m and 7.5 deg of banking, which resulted in an unbalanced lateral acceleration of about 0.16 g. The lane was 3.66 m wide, the tractor right front wheel was close to the right-hand lane stripe, and the rearmost left tire was on the left-hand lane stripe. It is likely that the vehicle was exhibiting outward high-speed offtracking in the range 0.53-0.83 m, depending on the exact location of the front axle, and the accuracy of the lane stripes. It was certainly evident from the chase vehicle that there was little articulation between the tractor and semitrailer, so it was almost straight.

3. High-speed Offtracking of Various Vehicle Configurations

The high-speed offtracking performance measure was evaluated by computer simulation using the Yaw/Roll model (Gillespie and MacAdam, 1982). The vehicle was driven at a constant speed and a driver model was used to enter and follow a curve of specified radius at that speed which results in a lateral acceleration of 0.20 g. The performance measure was usually evaluated at 100 km/h in a curve of 393.3 m radius. However, vehicles may operate on a variety of roads with a variety of speed limits. High-speed offtracking was therefore evaluated for various curve radii and speeds.

Table 1 presents the high-speed offtracking of various configurations in common use in Canada, from various recent studies completed by the authors. This work considered tractor-semitrailers with a tandem, tridem, self-steer tri-axle, or self-steer quad semitrailer, or a 5-axle semitrailer with two self-steering axles, 7- and 8-axle B-trains, and a 9-axle A-train Turnpike Double. These configurations are shown in Figure 3 through Figure 10 respectively, except for the 7-axle B-train. Length refers to semitrailer length for a tractor-semitrailer, or box length for a B-train. Each entry is for a vehicle with a van body loaded within 445 kg of its allowable gross weight, with a payload height 2.44 m above the deck of the trailer. A high payload weight and a high payload centre of gravity results in greatest high-speed offtracking. Results were available for some vehicles for speeds of 90, 100 and 110 km/h, while others were only available for 100 km/h. High-speed offtracking was evaluated in whatever curve radius resulted in a lateral acceleration of 0.20 g at the given speed. Any performance measure in Table 1 that exceeds the performance standard of 0.46 m is highlighted in bold.

The results in Table 1 show that high-speed offtracking increased with vehicle speed, semitrailer wheelbase, use of a self-steering axle, gross vehicle weight and overall length.

Table 1 – High-speed Offtracking of Various Configurations

Vehicle			**High-speed Offtracking (m)**		
Configuration	**Length**	**Wheelbase**	**90 km/h**	**100 km/h**	**110 km/h**
Tandem semitrailer	16.20 m	Long	0.330	0.384	0.423
Tandem semitrailer	16.20 m	Medium	0.334	0.383	0.420
Tandem semitrailer	16.20 m	Short	0.338	0.380	0.415
Tandem semitrailer	14.65 m	Long	0.330	0.384	0.423
Tandem semitrailer	14.65 m	Medium	0.338	0.380	0.415
Tandem semitrailer	14.65 m	Short	0.339	0.377	0.402
Tridem semitrailer	16.20 m	Long	0.359	0.411	0.449
Tridem semitrailer	16.20 m	Medium	0.363	0.411	0.444
Tridem semitrailer	16.20 m	Short	0.365	0.410	0.442
Tridem semitrailer	14.65 m	Long	0.365	0.410	0.442
Tridem semitrailer	14.65 m	Medium	0.368	0.407	0.438
Tridem semitrailer	14.65 m	Short	0.370	0.404	0.436
SS Tri-axle	16.20 m			**0.521**	
SS Tri-axle	14.65 m			**0.525**	
SS Quad	16.20 m			**0.511**	
SS Quad	14.65 m			**0.507**	
SS Quad	16.20 m		0.449	**0.508**	**0.552**
SS Quad	14.65 m		0.457	**0.504**	**0.544**
5-axle 113 Semitrailer	14.65 m			**0.545**	
5-axle 131 Semitrailer	14.65 m			**0.593**	
7-axle B-train	18.5 m			**0.547**	
7-axle B-train	20.0 m			**0.561**	
8-axle B-train	18.5 m			**0.527**	
8-axle B-train	20.0 m			**0.542**	
8-axle B-train	18.5 m		**0.495**	**0.536**	**0.564**
Turnpike Double	16.20 m	Long	**0.552**	**0.608**	**0.654**
Turnpike Double	16.20 m	Medium	**0.593**	**0.641**	**0.683**
Turnpike Double	16.20 m	Short	**0.631**	**0.672**	**0.710**
Turnpike Double	14.65 m	Long	**0.489**	**0.544**	**0.590**
Turnpike Double	14.65 m	Medium	**0.555**	**0.602**	**0.639**
Turnpike Double	14.65 m	Short	**0.617**	**0.651**	**0.680**

Figure 3 – Tandem Semitrailer

Figure 4 – Tridem Semitrailer

Figure 5 – Self-steer Triaxle Semitrailer

Figure 6 – Self-steer Quad Semitrailer

Figure 7 – 5-axle 113 Semitrailer

Figure 8 – 5-axle 131 Semitrailer

Figure 9 – 8-axle B-train

Figure 10 – Turnpike Double

Tandem and tridem semitrailers met the performance standard of 0.46 m for 14.65 and 16.20 m semitrailers of any wheelbase at a speed up to 110 km/h. All other vehicle configurations failed the performance standard at 100 km/h. This was a concern, because other than the Turnpike Doubles, they were all legal vehicles in some provinces, and generally amount to 20-25% of the heavy truck fleet in most provinces.

4. Discussion

4.1 Standard Lanes

The applicability of the high-speed offtracking performance standard was first discussed as a consequence of the test program mentioned above (Billing and Patten, 2004), and was also briefly discussed in this forum (Billing, Patten and Madill, 2006). Since then, assessments have been conducted of a number of configurations that also did not meet the performance standard. It was not apparent that high-speed offtracking was a significant factor in collisions, so it appeared appropriate to consider the performance measure in more depth, and particularly as it relates to vehicles actually on the highway system. The discussion in this section relates to lanes with a standard width of 3.66 m.

The starting point is the horizontal alignment of highways, which in North America is based on a design speed and a so-called side-friction factor, which is equivalent to the unbalanced lateral acceleration of a vehicle driving in a curve (American Association of State Highway and Transportation Officials, 2001).

The design speed is the speed selected to determine the geometric design features of the roadway (American Association of State Highway and Transportation Officials, 2001). The design speed is influenced principally by the type of the highway, whether the area is rural or urban, the character of terrain, environmental factors, type and anticipated volume of traffic, and economic considerations. A higher design speed can be used in level or rolling terrain than in mountainous terrain. A design speed should be consistent with the speeds expected, as drivers adjust their speed based on their perception of the physical limitations of the highway and its traffic. Where there is an evident reason for limiting speed, drivers are more willing to accept a lower design speed than where there is no apparent reason for it.

The side friction factor was set at a lateral acceleration which caused feelings of discomfort to drivers, as determined from experiments with a ball-bank indicator conducted in the 1930's and 1940's. The side friction factor is a decreasing function of the design speed, changing linearly from 0.16 at 50 km/h to 0.14 at 80 km/h, then linearly again to 0.103 at 110 km/h and 0.091 at 120 km/h.

A particular design speed is associated with a side friction factor, and these result in a design radius for any turn on a highway. Table 2 shows the design speed, side friction factor, the design radius arising from the design speed and side friction factor, and also the radius which would result in a 0.2 g lateral acceleration as used for evaluation of the high-speed offtracking performance measure. The side friction factor values shown are typical, as the actual values vary slightly by jurisdiction. All these curves are assumed without superelevation. A real highway would use superelevation, so the curves would have a smaller radius than the curves considered here, but the unbalanced lateral acceleration would remain the same, so the results for high-speed offtracking should be similar. It is immediately obvious from Table 2 that the minimum radius likely on any highway is significantly larger than that used to evaluate high-speed offtracking in a turn at 0.2 g.

Figure 11 shows the high-speed offtracking for tandem, tridem and self-steer quad semitrailers, an 8-axle B-train, and a Turnpike Double, each loaded close to its allowable gross weight with a high payload. The solid lines are for a turn at that radius shown in

Table 2 – Minimum Curve Radii

Design Speed (km/h)	Side Friction Factor	Design Radius (m)	Radius at 0.2 g (m)
50	0.160	122.9	98.3
60	0.153	185.1	141.6
70	0.147	262.2	192.7
80	0.140	359.6	251.7
90	0.128	497.8	318.6
100	0.116	678.1	393.3
110	0.103	924.1	475.9
120	0.091	1,244.6	566.3

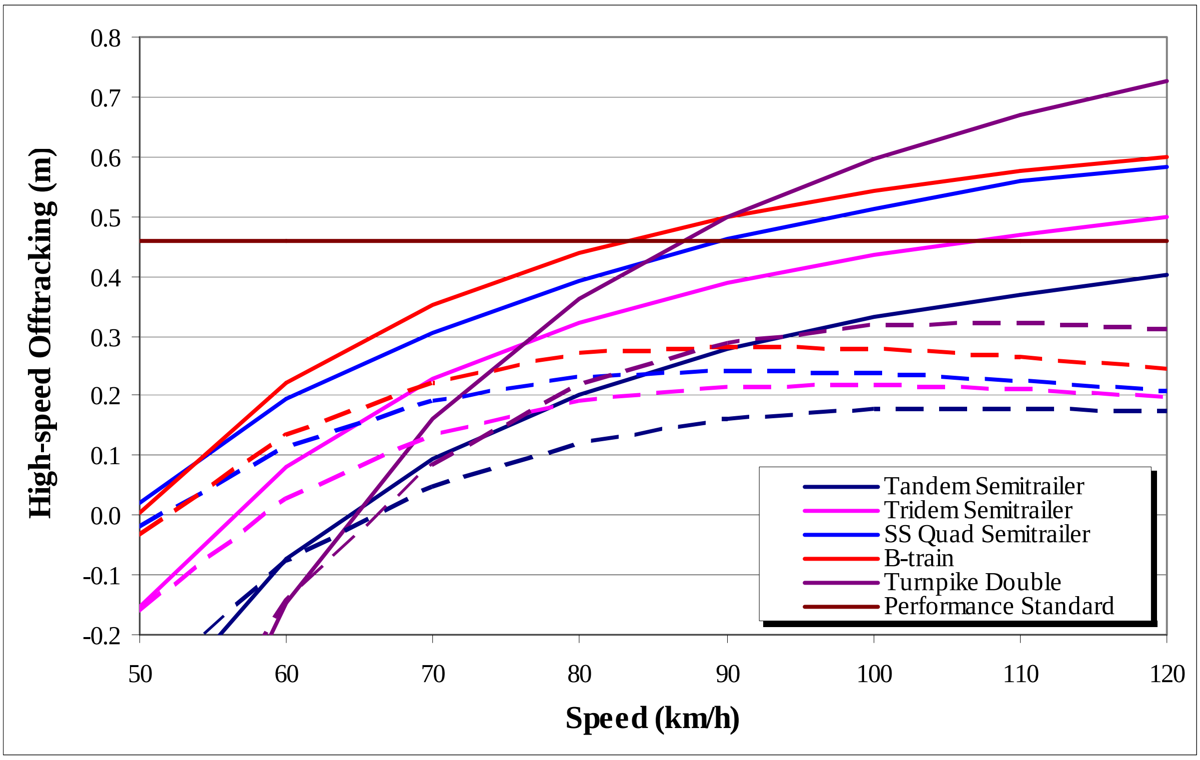

Figure 11 – High-speed Offtracking for Various Configurations

Table 2 that gives a lateral acceleration of 0.2 g, with the results at 120 km/h from bottom to top in the order of configuration given above. The dotted lines are for turns at the design radius, in the same order as above. Figure 11 provides a number of useful insights.

The transition from low-speed to high-speed offtracking, defined as zero high-speed offtracking in Figure 11, takes place between about 50 and 65 km/h, depending on the configuration. It generally takes place at a lower speed for a longer or heavier legal vehicle, but at a higher speed for a Turnpike Double, which is two 16.20 m semitrailers.

It is evident that no configuration approaches the performance standard of 0.46 m up to at least 70 km/h. Since this includes most urban roads and most freeway ramps, high-speed offtracking should not be an issue on any road where the design speed, or the operating speed, is no more than 70 km/h. Many freeway ramps in North America have an advisory speed posted on a yellow sign. The posting is conservative, as it is generally in increments of 10 km/h, so results in an unbalanced lateral acceleration between about 0.05 and 0.17 g. Truck drivers, especially those with a high payload centre of gravity, tend to pay scrupulous attention to such advisory speed signs.

The design speed on freeways is typically 110 to 130 km/h, and the speed limits in Canada are 100 or 110 km/h, depending on the province. Few trucks appear to exceed 115 km/h. Figure 11 shows, as an example, that any of these vehicles traveling at the design speed of 110 km/h and the design radius will be well inside the performance standard. Most freeways should have a design speed somewhat higher than the fastest trucks, so the actual levels of high-speed offtracking will be even less than those shown in Figure 11 for the design radii. High-speed offtracking therefore should not be an issue on freeways.

There are a variety of urban and rural roads with a design speed between 70 and 110 km/h. Figure 11 also shows that high-speed offtracking should not be an issue for trucks that travel on such roads at the design speed. The Turnpike Double operates only by special permit on freeways and on other roads where there is adequate access to a freeway. The permit usually has strict requirements for the carrier to monitor and report speed. To the limited extent that Turnpike Doubles operate on roads with a design speed between 70 and 110 km/h, it is considered unlikely that they would exceed the design speed, so high-speed offtracking would not be an issue for this configuration. High-speed offtracking is also not an issue for other configurations on such roads, to the extent that they do not exceed the design speed. The B-train and self-steer quad exceed the performance standard between 80 and 90 km/h when traveling on such a radius that their lateral acceleration reaches 0.20 g. It takes 15.6 and 22.5 km/h over the design speed of 80 and 90 km/h respectively to reach 0.20 g on a curve of design radius. If it is assumed that the legal speed limit is the same as the design speed, these appear somewhat unlikely excess speeds for trucks of those configurations on most roads of the type considered here. Reaching 0.20 g on a curve of design radius would be even less likely where the legal speed limit is set below the design speed. Beyond this, a driver exceeding the speed limit would tend to cut to the inside of a curve in a manner that effectively and significantly increases the turn radius, and also moves the vehicle inward from the centre of the lane. Increasing the radius reduces the lateral acceleration, which reduces high-speed offtracking, and moving inward allows additional space for high-speed offtracking. So, while the conclusion for urban and rural roads with a design speed between 70 and 110 km/h may be less clear than for urban roads, freeway ramps and freeways, there do not appear to be a significant range of situations where a vehicle might exceed the performance standard and intrude into the space of another vehicle.

On balance, therefore, on roads with 3.66 m wide lanes, there seems little likelihood that many vehicles will reach or exceed the high-speed offtracking performance standard. The most likely situation would be for a B-train loaded to its allowable gross weight with a high payload centre of gravity on an urban or rural road with a design speed between about 80 and 100 km/h.

The originators of the performance measure were primarily concerned that high-speed offtracking might result in the rearmost axle of a vehicle striking a curb (Ervin and Guy, 1986). Curbs are usually found on urban roads, some freeway ramps, locally on high-speed roads to channel water for drainage, and on bridges. It is unlikely that a heavy vehicle would be driven at such a speed as to achieve 0.20 g lateral acceleration on an urban road, and

Figure 11 shows that these vehicles do not develop significant outward offtracking for radii compatible with typical urban speed limits of 50 to 70 km/h. Freeway ramps often have a curb. The tightest common ramp radius is 30.5 m, used in the inner loop of a clover leaf interchange. Tight ramps are usually widened substantially, to allow for low-speed offtracking of a tractor-semitrailer traveling at creep speed during heavy traffic, so the lane is effectively considerably wider than 3.66 m, and outward high-speed offtracking should not be an issue. While it is fairly common for the rearmost axles of a large truck to run over a curb while making a low-speed turn in an urban area, the type of curb strike that would provoke a rollover does not seem very likely either on an urban roadway or a tight freeway ramp. High-speed roads, and roads in rural areas, generally provide a shoulder to allow vehicles to pull off the road, so do not have a curb along most of their length, though a curb may be used locally to channel water for drainage, and on bridges. They may also have additional pavement width beyond the stripe marking the edge of the road, though this is not always the case. Where a curb is used, there is usually about 0.3 m of concrete gutter between the edge of pavement and the rise of the curb, which allows additional space for high-speed offtracking that is not included in the performance standard.

So, while the original intent of the performance measure remains sound, its application appears unduly limiting for many classes of vehicle. There is no doubt, though, that the performance measure remains a useful means to screen out vehicles that actually do have large high-speed offtracking, such as long semitrailers with a rear-mounted self-steering axle.

4.2 Narrow Lanes

There are urban and rural roads in many jurisdictions with traffic lanes narrower than the standard of 3.66 m. Trucks may be found on roads with 3.35 m lanes, or even where there are 3.05 m lanes. Many states in the U.S. have restrictions on semitrailer or vehicle length, or vehicle width, for operation on roads with such narrow lanes.

High-speed offtracking should not exceed 0.46 m outboard of the path of a tractor centred in a 3.66 m wide lane, which allows the rearmost wheel of a vehicle with a 2.59 m wide trailer within 0.08 m of the edge of its lane (Ervin and Guy, 1986). If a similar approach is applied to a 3.35 m wide lane, the performance standard should be 0.30 m.

Highways with 3.35 m lanes typically would have a design speed no more than 100 km/h. The dashed lines in Figure 11 show that high-speed offtracking should not be an issue for any of the configurations considered, provided they do not exceed the design speed. Turnpike Doubles would not be expected to operate on this class of road. There may be issues for B-trains, self-steer quad and tridem semitrailers, to the extent that their operating speed exceeds the design speed of the road. This would be exacerbated for a road with narrow, or no, shoulders.

5. Conclusions

The warrant for the high-speed offtracking performance measure, and the current well-established value of 0.46 m for the performance standard for 3.66 m wide lanes, are not in doubt. Tests conducted previously showed that high-speed offtracking does occur, and in amounts consistent with the predictions of computer simulations. The performance measure remains a powerful means to screen out vehicles with poor high-speed turning characteristics.

However, a number of configurations legal in various provinces in Canada, or allowed to operate under special permit, may exceed the high-speed offtracking performance standard. Closer examination of how these vehicles perform on roads with various design speeds suggests that these vehicles should not actually exceed the performance standard on urban roads, freeway ramps, or freeways. The critical case would appear to be B-trains on urban and rural highways with a design speed between 70 and 110 km/h.

It would be appropriate to use a high-speed offtracking performance standard of 0.30 m on highways with 3.35 m lanes, which typically would have a design speed no more than 100 km/h. High-speed offtracking should not be an issue for any of the configurations considered, provided they do not exceed the design speed. There may be issues for B-trains, self-steer quad and tridem semitrailers, to the extent that their operating speed exceeds the design speed of the road. This might be exacerbated for roads with narrow, or no, shoulders.

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