REPORT

Safety Analysis of a Double & Triple B-train Carrying Loaded Containers

Prepared for Saskatchewan Highways and Transportation

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1. Introduction

This study examines the dynamic performance of a double and triple trailer B-train hauling loaded containers. For each configuration, the axle width of the last trailer is varied. The triple B-train hauls three 20' long (6.10 m) loaded containers and the double B-train hauls a 20' (6.10 m) container on the lead trailer and a 48' (14.6m) container on the second trailer. The analysis was done using the UMTRI Yaw/Roll Model configured with the TAC methodology for heavy vehicle performance assessment. A description of the performance measures follow.

2. Performance Measures

Eight performance measures were calculated for the vehicles that were simulated. The performance measures used were as follows:

1. Static Rollover Threshold (SRT)
2. Rearward Amplification (RA)
3. Load Transfer Ratio (LTR)
4. High Speed Transient Offtracking (HSTO)
5. High Speed Friction Utilization (HSFU)
6. Low Speed Offtracking (LSO)
7. High Speed Offtracking (HSO)
8. Low Speed Friction Utilization (LSFU).

2.1 Steady-State Roll Stability

Steady-state roll stability is an expression of the magnitude of lateral acceleration required to produce vehicle rollover. It is given as a proportion of gravitational acceleration (g). Total rollover occurs when the wheels on one side of the vehicle lift off the road surface, as illustrated in Figure 1.

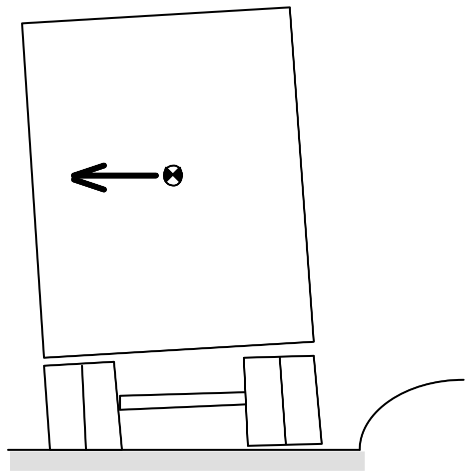


Figure 1. Illustration of rollover initiation.

Rollover occurs when the lateral acceleration equals or exceeds the vehicle's rollover limit (which may be assisted by roadway crossfall or camber). Lateral acceleration on a curve is highly sensitive to speed, and the speed required to produce rollover reduces as the curve radius reduces.

Roll stability is influenced by the center of gravity (COG) height, the effective track width provided by the axles and tires, and the suspension roll characteristics. The COG height is affected by the chassis height, load space height, load space length and average freight density. The significance of roll stability depends on the commodity, body type and operation involved.

This performance measure is evaluated in terms of the steady-state lateral acceleration at which all wheels on the inside of the turn have lifted off the road surface. This is accomplished by increasing the steer angle of a vehicle unit until all axles on one side of a given vehicle unit lift off.

2.2 Rearward Amplification

When articulated vehicles undergo rapid steering, the steering effect at the trailer is magnified, and this results in increased side force, or lateral acceleration, acting on the rear trailer. This in turn, increases the likelihood of the trailer rolling over under some circumstances. As an example, a truck faced with the need to change lanes quickly on a freeway to avoid an accident can do so at less risk if it has favourable rearward amplification characteristics.

Similarly, steering from side to side produces more lateral movement at the rear unit than at the hauling unit. Rearward amplification (RA) is defined as the ratio of the lateral acceleration at the COG of the rearmost unit to that at the hauling unit in a dynamic manoeuvre of a particular frequency. Rearward amplification expresses the tendency of the vehicle combination to develop higher lateral accelerations in the rear unit when undergoing avoidance manoeuvres; it is therefore an important consideration, additional to roll stability of the rear unit, in evaluating total dynamic stability. Rearward amplification also relates to the amount of additional road space used by the vehicle combination in an avoidance manoeuvre.

The number of articulation points and the overall length generally influences rearward amplification. Other important factors are the cornering stiffnesses of the trailer tires and their relationship with the axle weights of the trailer. While rearward amplification is an important performance attribute for multi-articulated vehicles, it is generally of lesser significance for tractor-trailers.

This performance measure was evaluated in terms of the SAE standard scenario for measuring rearward amplification [1]. This SAE standard defines a single lane-change manoeuvre to be negotiated at a constant speed of 88 km/h (55 mph), and the test is illustrated in Figure 2. As the SAE standard does not include analytical procedures for the results of computer simulations, the methods developed for the RTAC Study [2], and subsequently refined by the National Research Council of Canada [3] are adopted. Rearward amplification is determined as the ratio of peak trailer lateral acceleration to peak tractor lateral acceleration.

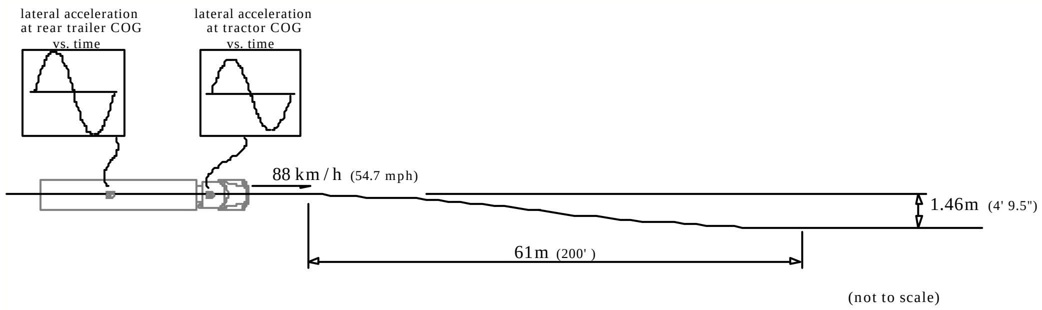


Figure 2. Rearward Amplification of Lateral Acceleration

2.3 Load Transfer Ratio

Load Transfer Ratio (LTR) is defined as the proportion of load on one side of a vehicle unit transferred to the other side of the vehicle in a transient manoeuvre. Where vehicle units are roll-coupled - as in tractor-trailers and B- trains - the load transfer ratio is computed for all axles on the vehicle. When the load transfer ratio reaches a value of 1, rollover is about to occur. The LTR is a vital measure of rollover stability and is particularly relevant to high-speed operations in dense traffic.

This performance measure is evaluated in terms of the SAE standard scenario for measuring rearward amplification [1]. This SAE standard defines a single lane-change manoeuvre to be negotiated at a constant speed of 88 km/h (55 mph), and the test is illustrated in Figue2 . Note that the SAE manoeuvre actually represents a partial lane change. As the SAE standard does not include analytical procedures for the results of computer simulations, the methods developed for the RTAC Study [2], and subsequently refined by the National Research Council (NRC) of Canada [3] were adopted. LTR was determined as the peak value of the proportion of load transferred from one side of the tractor-trailer to the other, during the standard lane-change manoeuvre.

2.4 Friction Utilization

Friction Utilization is the non-tractive friction required between the tires and the road surface at any axle of a vehicle combination. It is a measure of the lateral shear force between the tires and the road that results from the vehicle negotiating a curve in the road or carrying out a transient manoeuvre. The NRC (3) has recommended the use of lateral friction utilization measures for both low-speed and high-speed situations. The friction utilization measure is considered to encompass the friction demand measure, which was used in the RTAC Study [2] in that the friction demand measure only applied to the drive axles, whereas friction utilization applies to all axles of the vehicle.

(i) Low-Speed Friction Utilization

In low-speed turns, such as intersections, the tires on certain axles may be required to generate sufficiently high lateral forces that loss of adhesion could occur on slippery surfaces. Although relatively high lateral force coefficients are generated on individual tires in the drive axle group and trailer axle group, the force vectors applying to the axles in either of these axle groups act in opposite directions during slow speed manoeuvres. In doing so the force vectors balance each other off in a “stable” manner as tire saturation approaches. Under these conditions there is no threat to directional control.

The friction utilization of the steer axle tires is considered to be the most critical parameter under slow speed conditions. If saturation occurs, the vehicle may plough straight ahead failing to negotiate the turn. This is particularly important on low friction surfaces, such as when roads are covered in snow and ice.

This performance measure was evaluated for a standard 90 degree turn of radius 12.8 meters (measured at the center of the steering axle) negotiated at a speed of 18 km/h [2]. This manoeuvre is illustrated in Figure 3. However, the speed of 18km/h is used because this corresponds to a lateral acceleration of 0.2g; on a surface such as ice, which has a low peak friction coefficient ($?_{peak}$=0.2), this manoeuvre shows whether the vehicle will be able to negotiate the turn without ploughing out. The low-speed friction utilization at each axle is determined as the peak value of the ratio of the lateral force to the vertical force on a surface with a friction coefficient of 0.8.

(ii) High-Speed Friction Utilization

In a high-speed manoeuvre, such as a lane-change, the lateral force demands placed on the tires of certain axles could also lead to instability of the vehicle combination.

This performance measure is evaluated in terms of the SAE standard scenario for measuring rearward amplification [1]. This SAE standard defines a single lane-change manoeuvre to be negotiated at a constant speed of 88 km/h (55 mph), and the test is illustrated in Figure 3. The high-speed friction utilization at each axle is determined as the peak value of the ratio of the lateral force to the vertical force.

2.5 Low-Speed Offtracking

Low-speed offtracking represents a measure of the swept path of the vehicle and its lateral road space requirement when turning at intersections or when turning into loading areas.

This performance measure is evaluated for a standard 90 degree right-hand turn of radius 12.8 meters (measured at the center of the steering axle) negotiated at a speed of 5 km/h [3]. This manoeuvre is illustrated in Figure 3. The low-speed offtracking is determined as the maximum radial distance between the path of the midpoint of the steer axle and the path of the midpoint of the rearmost trailer axle.

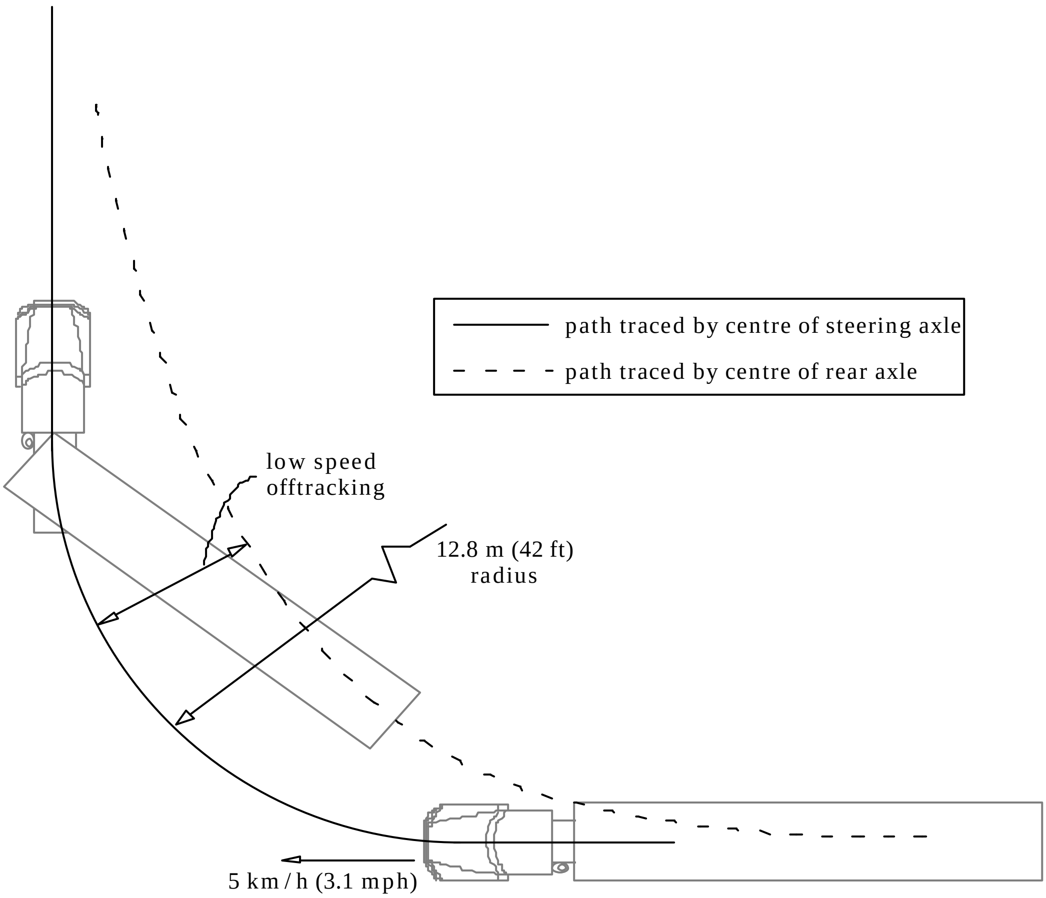


Figure 3. Low Speed Offtracking

In addition, the swept width of the vehicle's path is determined. This is the maximum radial distance between the outer and inner extremities of the swept path of the vehicle and may be approximated by the offtracking plus the width of the vehicle.

3.1.6 High-Speed Offtracking

High-speed offtracking is defined as the extent to which the rearmost tires of the vehicle track outboard of the tires of the hauling unit in a steady-turn at highway speed. High-speed offtracking relates closely to road width requirements for the travel of combination vehicles. This manoeuvre is illustrated in Figure 4.

This performance measure is evaluated for a constant-radius curve of radius 393 meters (1290 ft), with a planar surface, negotiated at a speed of 100 km/h (62 mph); this manoeuvre produces a constant lateral acceleration of 0.2 g and is used in the RTAC Study [2]. High-speed offtracking was determined as the radial distance between the path of the center of the steer axle and the path of the center of the rearmost trailer axle.

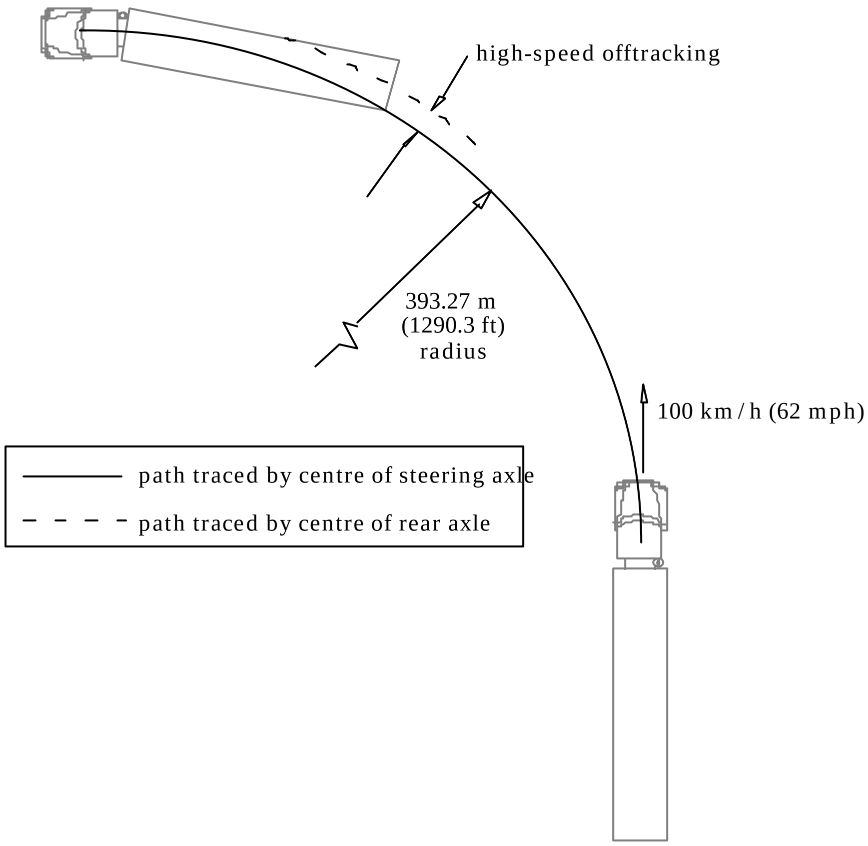


Figure 4. High Speed Offtracking

3.1.7 Transient High-Speed Offtracking

Transient high-speed offtracking is a measure of the lateral excursion of the rear of the vehicle with reference to the path taken by the front of the vehicle during a dynamic manoeuvre as shown in Figure 5. This expresses the amount of additional road space used by the vehicle combination in an avoidance manoeuvre.

This performance measure is evaluated in terms of the SAE standard scenario for measuring rearward amplification and transient high-speed offtracking [1]. This SAE standard defines a single lane-change manoeuvre to be negotiated at a constant speed of 88 km/h (55 mph), and the test is illustrated in Figure 2. Transient high-speed offtracking is determined as the peak lateral offset between the path of the center steer axle and the center of the rearmost trailer axle.

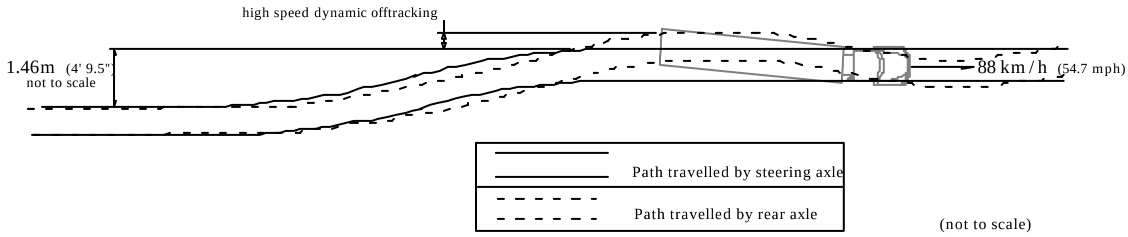


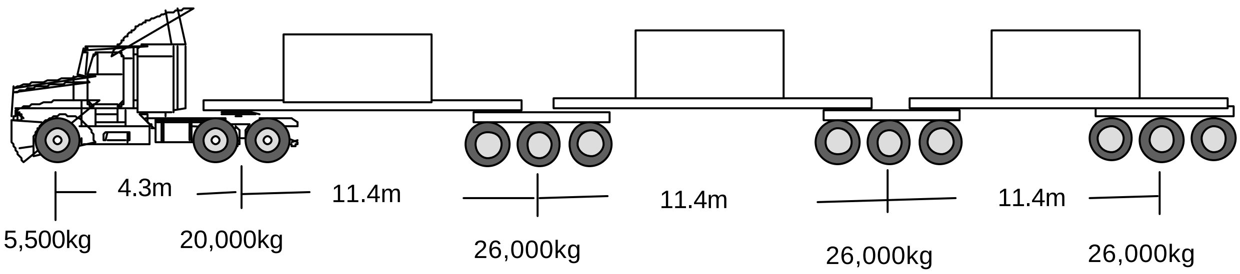
Figure 5. Transient High-Speed Offtracking

3. Vehicles Examined in this Study

This study examined a double and a triple B-train carrying loaded 6.1m (20 ft) containers. The triple unit "Configuration A" is illustrated in Figure 6.

<u>Configuration A</u>

Option 1 – Loaded containers; first and second trailer and axle width is 9'6" (2.90 m); third trailer and axle width is 8'6" (2.59 m)



The first and second trailer and axle width is 9’6” (2.90 m) wide; the tare weight of each trailer is 5,900 kg; the deck height of each trailer is 1.5 m from ground. The tridem axle spread of the first and second trailer is 3.1 m. The containers are 20’ long (6.10 m) and their tare weight is 2,500 kg. The containers are 8 ft wide and 8 ft high (2.44m) with an assumed empty C of G to be at 4 ft (1.22m) relative to the base of the container.

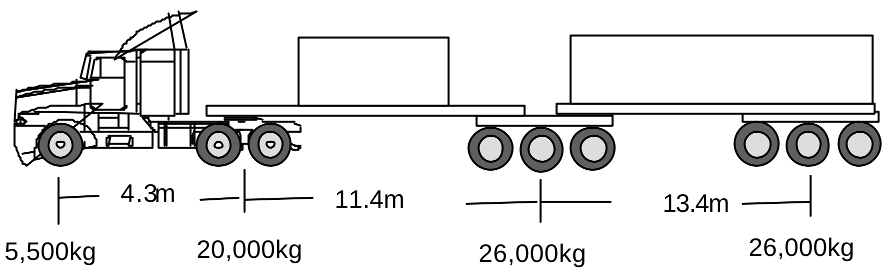
Third trailer and axle width is 8’6” (2.59 m) and a trailer tare weight of 6,000 kg. The deck height of the third trailer is 1.2 m. The container is 20’ long (6.10 m) and its tare weight is 2,500 kg.

Each 20 ft container has a payload of 22,700 kg and the height of load in the container is 1.8 m above the base of the container. The C of G of the payload was taken as 0.9 meters above the floor of the container. The fifth wheel kingpin locations on the two trailers were coincident with the center axle of the trailer tridems.

Option 2 – Same conditions as Option 1 except the third trailer axle width is increased to 9’6” (2.90 m)

Configuration “B” Double

Option 1 – Loaded containers; first and second trailer and axle width is 9’6” (2.90 m); third trailer and axle width is 8’6” (2.59 m)



Lead trailer axle width is 9’6” (2.90 m) with an empty trailer tare weight of 5,900kg and deck height of 1.5 m above ground. The 20’ container has a tare weight of 2,500 kg and carries a payload of 22,700 kg. The load height inside the container is 1.8m above the floor of the container.

Second trailer axle width is 8’6” (2.59 m) with a deck height of 1.2m and tare weight of 6,000kg. It carries a 48’ container with a tare weight of 4,200 kg and a payload of 27,200 kg and a load height of 0.9 m above the floor of the container.

Option 2 – Same conditions as Option 1 except the second trailer axle width is increased to 9’6” (2.90 m)

Results

Performance Measure	TAC Target Value	A1	A2	B1	B2
Static roll threshold (ideal)	0.40g (ideal)	0.45g	0.47g	0.44g	0.47g
Load transfer ratio	0.60 (max)	0.17	0.16	0.22	0.20
Rearward amplification	2.00 (max)	0.83	0.83	0.86	0.84
High speed dynamic offtracking	0.80 m (max)	0.22m	0.21m	0.17m	0.16m
High speed offtracking	0.46 m (max)	0.79m	0.77m	0.59m	0.57m
Low speed offtracking	6.00 m (max)	12.5m	12.5m	9.59m	9.59m
High speed friction utilization					
Tractor axle 1		15%	15%	16%	16%
Low speed friction utilization					
Tractor axle 1		29%	29%	29%	29%

All of the vehicles examined possess good vehicle dynamic characteristics. The performance of the double and triple B-trains are very similar. The vehicles do exceed the recommended high speed offtracking and low off tracking performance characteristics which are not considered as dynamic manoeuvres. This means that the vehicles are not subject to instability however the amount of roadway width required is greater than most heavy vehicles however these geometric issues can be considered when selecting acceptable routes for the vehicles.

4. References

Fancher, P. S.; Ervin, R. D.; Winkler, C. B.; Gillespie, T. D. 1986. A factbook of the mechanical properties of the components for single-unit and articulated heavy trucks. Phase I. Final report. Michigan University, Ann Arbor, Transportation Research Institute. 190 p. Sponsor: National Highway Traffic Safety Administration, Washington, D.C. Report No. UMTRI-86-12/ DOT/HS 807 125. UMTRI-74246

R. D. Ervin and Y. Guy (1986). Volume 2 - “The Influence of Weights and Dimensions on the Stability and Control of Heavy Trucks in Canada - Part 2”. Roads and Transportation Association of Canada, 1765 St. Laurent Blvd. Ottawa, Canada K1G 3V4.