DEVELOPMENT OF CONFIGURATIONS FOR INFRASTRUCTURE–FRIENDLY FIVE- AND SIX-AXLE SEMITRAILERS

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ABSTRACT

Ontario has not regulated heavy vehicle axle configurations, so diverse configurations have developed with widely spaced rigid liftable axles to maximize gross weight. Ontario Ministry of Transportation (MTO) recognized that heavy trucks that raise liftable axles when loaded cause significant road wear, and increase the risk of bridge failure. Consequently, MTO reduced the allowable gross weight of semitrailers with a single rigid liftable axle, and introduced the alternative self-steer triaxle and self-steer quad axle groups, with a single self-steering axle ahead of a fixed tandem or tridem axle group. The self-steering axle must carry the same load as each fixed axle, and the driver must not be able to lift it from the cab.

This paper addresses semitrailers with five or more axles. The dynamic performance of ten existing configurations that haul heavy loads within Ontario and to Michigan was assessed by computer simulation against customary standards. The dynamic performance of seven candidate infrastructure-friendly configurations that could replace them was also assessed, including the effect of variations in axle spacings and self-steer axle parameters. Two semitrailers were built, one with two self-steering axles ahead of a fixed tridem, and the other with one self-steering axle ahead and another behind a fixed tridem, and a full-scale test program was conducted to validate the simulations and to address issues related to performance measures that had arisen from the simulation study. A computer simulation was run for comparison with responses measured during every test run.

MTO has now introduced these new configurations into regulation as a consequence of this work.

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1 INTRODUCTION

Ontario has allowed a gross weight up to 63,500 kg (140,000 lb) since 1970, without regulating axle configuration, so diverse configurations now exist with widely spaced rigid liftable axles. Ontario Ministry of Transportation (MTO) found un-controlled use of liftable axles cost highway owners C$300 million more each year than if these axles were always down with weight equally distributed to all axles. Semitrailer length increases have also incidentally increased actual gross weight, and significantly increased the risk of failure of certain types of bridge. MTO therefore developed a four-phase program to constrain use of rigid liftable axles.

Phase 1 reduced the allowable gross weight of a tri-axle semitrailer with a rigid liftable axle from 2006, and introduced self-steer tri-axle and self-steer quad semitrailers as replacements, with a single self-steering axle ahead of a fixed tandem or tridem axle group. A self-steering axle must carry the same load as each fixed axle, and must not be liftable from the cab. These became founding principles for “safe, productive and infrastructure-friendly” (SPIF) vehicles. Phase 2 required dump semi-trailers built after 2002 to meet these standards. Phase 3 addressed other multi-axle semitrailers. MTO engaged the Centre for Surface Transportation Technology of the National Research Council of Canada (NRC/CSTT) first to assess the dynamic performance of existing semitrailers, and candidate SPIF configurations to replace them (Billing and Patten, 2003), then to conduct a full-scale test of two specific configurations (Billing and Patten, 2004).

2 ASSESSMENT OF MULTI-AXLE SEMITRAILERS

2.1 Computer Simulation Model

The Yaw/roll computer simulation model was used to evaluate dynamic performance (Gillespie and MacAdam, 1982). This simulation represents the non-linear lateral, yaw and roll response of a combination vehicle to a steering input with relatively simple input data, and has been shown to match test results (Lam and Billing, 1986).

This work used generic tandem drive tractors with a 6.20 m (244 in) wheelbase, with a fifth wheel placed to balance the axle weights, and generic 14.65 m (48 ft) long flatbed semitrailers, with a kingpin setback of 0.46 m (18 in) for a 3-axle tractor, or 0.91 m (36 in) for a 4-axle tractor, and the rearmost axle 0.71 m (28 in) from the rear of the semitrailer. The weight of payload was the difference between the allowable gross weight and the tare weight of a vehicle, rounded down to the nearest thousand pounds. Payload was a solid block with a density of

545 kg/cu m (34 lb/cu ft) over the full width and the maximum possible length so that all axle loads were within allowable limits. The payload centre of gravity was about 2.28-2.41 m (90-95 in) above the ground.

2.2 Performance Measures

Dynamic performance was assessed by customary performance measures (CCMTA/RTAC, 1987), supplemented by others to address particular aspects of the vehicles that were the subject of this work. Each performance measure was computed by an algorithm that scanned the time history of the simulation variables.

High-speed offtracking (HSOT) and static rollover (SRT) performance measures were evaluated from a turn at 100 km/h (62.1 mi/h) on a high-friction surface. Load transfer ratio (LTR) and transient high-speed offtracking (TOT) were evaluated from a lane change at 100 km/h (62.1 mi/h) on a high-friction surface. Low-speed offtracking (LSOT), rear outswing (RO) and friction demand (FD) were evaluated from a 90 degree right-hand turn of 14 m (46 ft) radius at the outside of the left front wheel of the tractor at 8.8 km/h (5.5 mi/h) on a high-friction surface. Lateral friction utilization (LFU) was evaluated in a similar turn on a low-friction surface. Maximum steer of a self-steering axle (MSSA) was evaluated in a 12 m (39.4 ft) radius turn. The performance standards for these performance measures are designed to keep a vehicle upright and within its customary space envelope on the highway.

2.3 Dynamic Performance of Existing Configurations

Tractor-semitrailers with eight or more axles haul dense or bulk commodities like metals, logs, lumber, waste, liquids and aggregates within Ontario, or between Ontario and Michigan, and operate at an allowable gross weight in the range 59,875 to 62,300 kg (132,000 to 137,346 lb). There are about 5,550 of these out of an estimated 277,000 semitrailers operating in Ontario, but each has multiple rigid liftable axles, so they contribute to pavement wear and bridge risk out of proportion to their small number in the fleet. Vehicles are described by a configuration code, which consists of the number of axles in each axle group from front to rear, with a code for the hitch by which one vehicle unit tows another in its proper sequence between axle groups. For example, the vehicle configuration code **12S131** describes a tractor with a single front axle **1** and a tandem drive axle **2** with a fifth wheel **S** that tows a semitrailer with a single axle **1**, a tridem **3** and another single axle **1**. Ten configurations accounted for almost 96% of 31 tractor-semitrailer configurations with eight or more axles in the 1999 Commercial Vehicle Survey. Configuration 12S131 (about 48% of vehicles) and Configurations 12S113 and 12S23 (26%) are configured to Ontario rules for use in Ontario. Configuration 12S141 (12%), Configuration 12S114 (5%), and the recent new Configuration 12S1112, are configured to Ontario rules for use between Ontario and Michigan. Configurations 12S14, 12S15, 12S6, 12S7, and 12S8 (5% together) are configured to Michigan rules primarily for use in Michigan.

Table **1** summarizes the performance measures for the four most common existing configurations with liftable axles both down and up. A performance measure that fails its performance standard is in bold face. High-speed dynamic performance of these configurations with liftable axles down is marginal at best. All must raise liftable axles to turn, which degrades dynamic performance further and overloads other axles. These configurations have poor dynamic performance, and cannot be considered “infrastructure-friendly”.

Table 1: Dynamic Performance of Existing Vehicle Configurations

Configuration	Lift	Performance Measure						
		SRT (g)	**HSOT (m)**	**LTR**	**TOT (m)**	**LSOT (m)**	**RO (m)**	**FD**
		>0.400	**<0.460**	**<0.600**	**<0.800**	**<5.600**	**<0.200**	**<0.100**
12S113	Down	**0.392**	**0.529**	**0.601**	**0.813**	4.005	0.102	**0.675**
12S113	Up	**0.355**	**0.638**	0.570	0.757	5.165	0.033	**0.143**
12S131	Down	**0.398**	**0.557**	0.580	0.793	4.003	0.091	**0.611**
12S131	Up	**0.335**	**0.607**	**0.705**	**0.910**	4.177	**0.254**	**0.112**
12S114	Down	0.427	**0.480**	0.594	0.785			
12S114	Up	**0.378**	**0.571**	0.539	0.690	4.977	0.059	0.070
12S141	Down	0.429	**0.511**	**0.612**	**0.859**			
12S141	Up	**0.366**	**0.549**	**0.666**	**0.856**	4.059	**0.235**	0.099

Table 2: Dynamic Performance of Candidate Vehicle Configurations

Configuration	Performance Measure								
	SRT (g)	**HSOT (m)**	**LTR**	**TOT (m)**	**LSOT (m)**	**RO (m)**	**FD**	**LFU**	**MSSA (deg)**
	>0.400	**<0.460**	**<0.600**	**<0.800**	**<5.600**	**<0.200**	**<0.100**	**<0.800**	**<20.0**
12S113	0.433	**0.545**	0.536	0.721	5.068	0.037	**0.225**	0.580	19.63
12S131	0.427	**0.533**	0.569	0.746	3.979	0.173	**0.215**	0.539	17.66
12S114	0.435	**0.471**	0.536	0.680	5.024	0.039	**0.243**	0.536	**22.52**
12S141	0.420	**0.486**	0.590	0.766	3.444	**0.308**	**0.295**	0.529	19.84
13S13	0.408	**0.491**	0.521	0.640	5.154	0.037	**0.116**	0.798	17.11

2.4 Dynamic Performance of Candidate SPIF Configurations

MTO identified configurations 12S113, 12S131, 12S114, 12S141 and 13S13 as the primary candidate SPIF configurations. Each of the first four candidates was derived from an existing configuration by replacing a rigid liftable axle with a self-steering axle, equalizing the axle weights, and adjusting the axle spacings within bridge load constraints to achieve a comparable allowable gross weight. Simulations were conducted with the self-steering axles free to steer at one of three levels of centring force, or locked. Table 2 summarizes the performance measures for the candidate configurations for the most practical axle configurations from parametric variations on axle spacing and self-steering axle properties. All candidate configurations fail the high-speed offtracking performance standard by 0.03-0.08 m (1-3 in), which is comparable to a self-steer quad, and also fail the friction demand performance standard. Configuration 12S141 fails the rear outswing performance standard.

Configurations 12S113 and 12S114 perform best when the two self-steering axles are as close to each other and the fixed axle group as bridge loading will allow, and have a low centring force. The self-steering axles need at least 25 deg of steer, and do not appear to need to be locked at highway speed. Configurations 12S131 and 12S141 perform best if the fixed axle group is set to the rear of centre between the two self-steering axles, to reduce the effective rear overhang. The self-steering axles also need a low centring force, and should preferably have at least 25 deg of steer. The rearmost self-steering axle should be locked at highway speed, and the lock should engage and disengage automatically with vehicle speed.

3 FULL-SCALE TEST OF CANDIDATE VEHICLES

3.1 Test Program

A number of issues arose from the simulation study of the candidate vehicles, relating to the warrants for the friction demand performance measure, the self-steer capability needed for successful operation, the actual level of high-speed offtracking, the need for self-steering axles to be locked at highway speed, whether self-steering axles introduce potential hazards that do not occur in existing vehicles, and the relationship between computer simulation and test results. MTO arranged for two suitable semitrailers of configurations 12S113 and 12S131 to be built, in collaboration with industry, and these issues were addressed by full-scale tests.

A conventional tractor with a 6.05 m (238 in) wheelbase was used to pull the 113 semitrailer shown in Figure 1, which has an open-top live-bottom dump body with a gross weight of 61,653 kg (135,920 b), and the 131 flatbed semitrailer shown in Figure 2, with a gross weight of 61,494 kg (135,570 b). Each self-steering axle had an air-operated lock, and an air-operated centring device set by a regulator. The self-steering axles on the 113 semitrailer had 28 deg of steer and single tires, with 20 deg of steer and dual tires on the 131 semitrailer. Both semitrailers were 14.65 m (48 ft) long, and were loaded very close to all target weights.

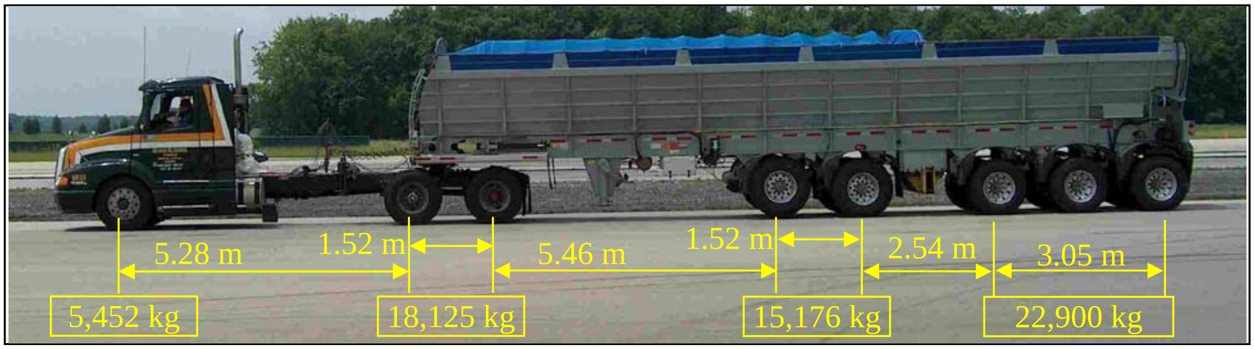

Figure 1: View of Configuration 12S113

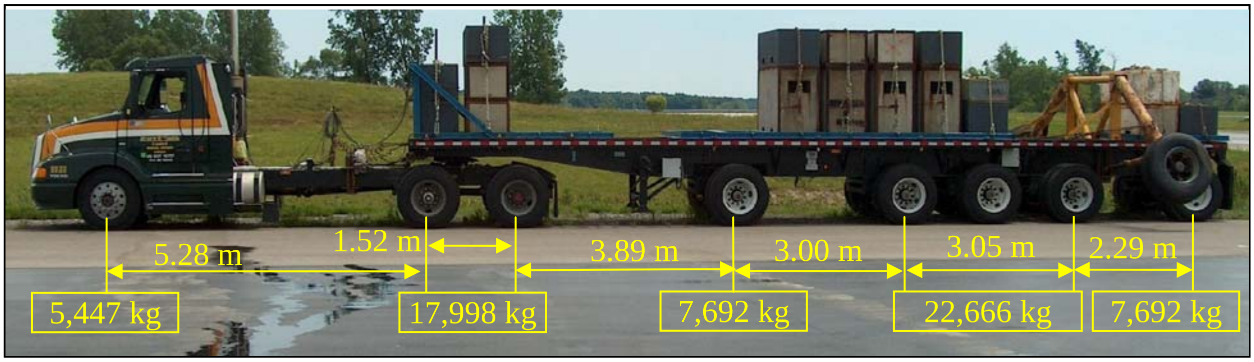

Figure 2: View of Configuration 12S131

3.2 Vehicle Preparation

The steer moment characteristic of a self-steering axle affects both low-speed turning and high-speed dynamic performance. NRC/CSTT used hydraulic actuators, load cells, air bearings and other hardware from a C-dolly test rig to measure the steer moment characteristic of each self-steering axle on the 131 semitrailer at the same axle load, and for the same 103, 241 and 379 kPa (15, 35 and 55 psi) and locked settings of the centring device that were used in the test.

Outriggers were installed on each semitrailer to prevent rollover, as seen in Figure **2** for Configuration 12S131, and anti-jackknife cables were fitted between the tractor and each semitrailer. Instrumentation was installed on the tractor to measure forward speed, steer angle of the front axle, longitudinal acceleration, lateral acceleration, roll angle, yaw rate, and articulation angle between the tractor and semitrailer. Instrumentation was installed on each semitrailer to measure lateral acceleration, roll angle, yaw rate, steer angle of each self-steering axle, and air pressure in the self-steering axle and tridem axle brake chambers. Water drip devices were installed to mark the path of the front axle of the tractor and the rearmost axle of the semitrailer.

3.3 Data Processing and Analysis

Measured data from each test run were imported into a Microsoft Excel worksheet, where signals were de-trended to remove extraneous zero offsets and drift, and filtered to remove noise. Key responses were identified and performance measures were extracted.

A simulation of each run was conducted using the steer input and forward speed measured during the run, measured vehicle dimensions and weights, moments of inertia estimated from properties of the vehicle and payload, representative suspension characteristics, tire characteristics from the tire manufacturer, and measured centring force characteristics of the self-steering axles. Input data files for a simulation run were created from the Excel worksheet for that run, and the results were loaded back into the worksheet for comparison with test results.

3.4 The Friction Demand Performance Measure

A semitrailer with widely spaced axles produces a high lateral force at the tractor fifth wheel in a low-speed turn. It was hypothesized that semitrailer forward momentum could overcome the lateral force capability of the tractor drive axle tires, and the semitrailer would push through the fifth wheel and provoke a tractor jackknife. The friction demand performance measure was developed to address this, though tests conducted with a tri-axle semitrailer were unable to produce a jackknife (Ervin and Guy, 1986). Jackknife induced by friction demand is unknown, because the driver of a vehicle with high friction demand raises its liftable axles on entering a turn, which reduces the friction demand for an easy turn. Friction demand of the candidate SPIF vehicles was somewhat higher than for self-steer quad semitrailers, so it was necessary to determine whether jackknife induced by friction demand might be a hazard for these vehicles.

Friction demand of the two test vehicles could be adjusted over a wide range by raising, changing the centring force or locking the self-steering axles. A series of runs was made through a 90 deg right-hand turn with a radius of 14 m (46 ft) on a wet jennite pad with a nominal peak braking coefficient of about 30, and a slide coefficient of about 10. Runs were made at increasing speed, until a vehicle ploughed out of the turn, or the tractor jackknifed.

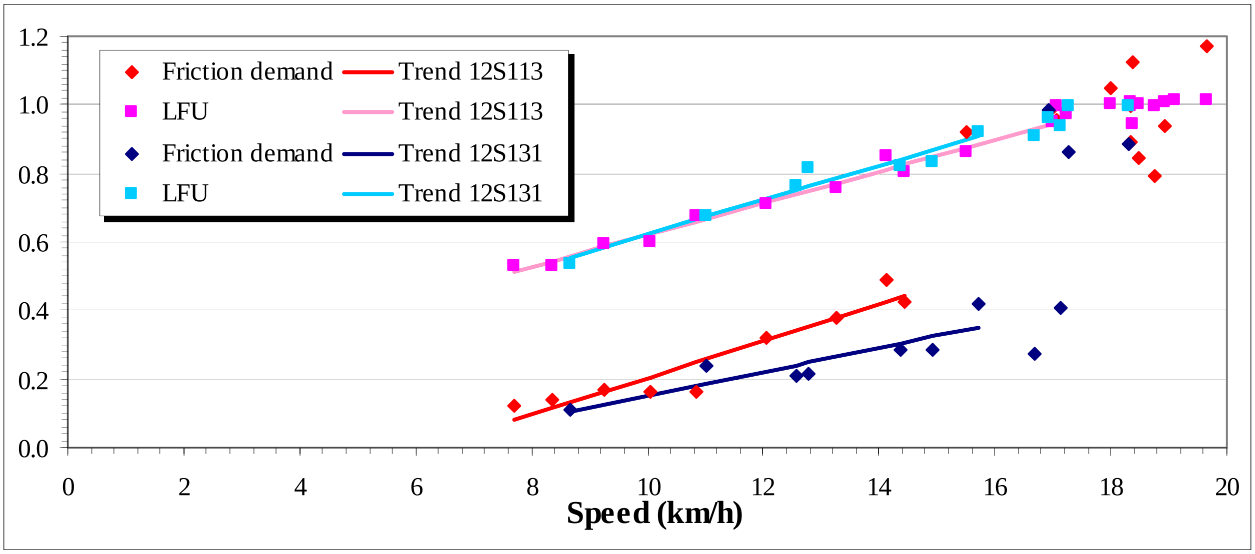

Figure 3**: Effect of Speed on Performance Measures**

Both vehicles jackknifed, which would seem to confirm the warrant for the friction demand performance measure. Both vehicles also ploughed out. There was no consistent outcome for Configuration 12S113. Configuration 12S131 jackknifed consistently for axle configurations with high friction demand. There was a modest but inconsistent trend to diminish the speed of instability as friction demand increased. The driver, the data and the prior simulations all agreed that the preferred configuration for each vehicle had both self-steering axles down with low centring force. Each vehicle in this condition could just make the turn at 17 km/h (10.6 mi/h), which corresponds to a lateral acceleration of about 0.19 g. Figure 3 shows friction demand and lateral friction utilization computed from simulations of test runs in this condition. Friction demand increased with speed to about 0.40, then jumped to 1.0 when the tractor jackknifed. Lateral friction utilization increased with speed to 1.0, when the tractor ploughed out.

Vehicles with friction demand in the range 0.15 to 0.23 or more have operated in Canada for many years without evident problems, possibly because their drivers can reduce friction demand by making a wider turn, or by reducing speed. These tests have shown that a jackknife was possible with either semitrailer, and that the tractor could also plough out. However, these outcomes occurred at speeds far above those at which any driver of such a vehicle would attempt to turn, especially on a slippery road. The friction demand performance measure therefore does not appear strongly related to safety, but reflects the ease with which the driver can turn a vehicle, and perhaps the cost of tire wear. It is expected that carriers and drivers will self-regulate friction demand to a level that each finds tolerable.

3.5 Self-steer Capability

A self-steering axle should not bottom in normal highway operation. The self-steer angle was measured during turns made on roads within the test site, with the self-steering axles at low centring force. The roads were designed for cars, with two 3.66 m (12 ft) wide lanes. The 28 deg steer capability of the self-steering axles on Configuration 12S113 appeared adequate for most normal driving in urban areas, while that of Configuration 12S131, which was apparently limited to about 18 deg, was clearly marginal. This configuration would certainly benefit from more than 18 deg self-steer capability.

3.6 Actual Amount of High-speed Offtracking

The high-speed offtracking performance measure was introduced because the rearmost axle of some combination vehicles could track outward of the front axle in a high speed turn, strike a curb, and provoke a rollover (Ervin and Guy, 1986). Their view was that "high-speed offtracking is patently undesirable, and should be minimized". The performance standard is 0.46 m (18 in), which allows the rearmost axle of a 2.59 m (102 in) wide semitrailer 0.08 m (3 in) from the edge of its own 3.66 m (12 ft) lane with the tractor centred in the lane. Table 2 shows that the candidate SPIF vehicles exceed this by up to 0.08 m (3 in).

Tests showed inward offtracking of the rearmost axle of each vehicle in a 30.5 m (100 ft) radius turn at 27.5 km/h (17.1 mi/h), and outward offtracking in a 250 m (820 ft) radius turn at 80 km/h (49.7 mi/h), each made at a lateral acceleration of 0.2 g. The solid lines in Figure **4** show high-speed offtracking from computer simulations of the two test vehicles, at a lateral acceleration of 0.20 g up to a radius of 393 m (1,290 ft), and at the Ontario speed limit of 100 km/h (62.1 mi/h) for larger radii. Both configurations were run with both self-steering axles set at a low centring force, and the rearmost self-steering axle of Configuration 12S131 was locked for speeds over 60 km/h (37.3 mi/h), which corresponds to a radius of 142 m (464 ft). High-speed offtracking is initially inward, and progressively becomes outward and increases to a maximum at 393 m (1,290 ft) radius, when the speed reaches 100 km/h (62.1 mi/h), then decreases for larger radii because the lateral acceleration diminishes. The method of evaluation of the performance measure therefore represents the most critical condition. Figure **4** also shows a data point for each vehicle from test at a radius of 250 m (820 ft), and another from the prior simulation at a radius of 393 m (1,290 ft).

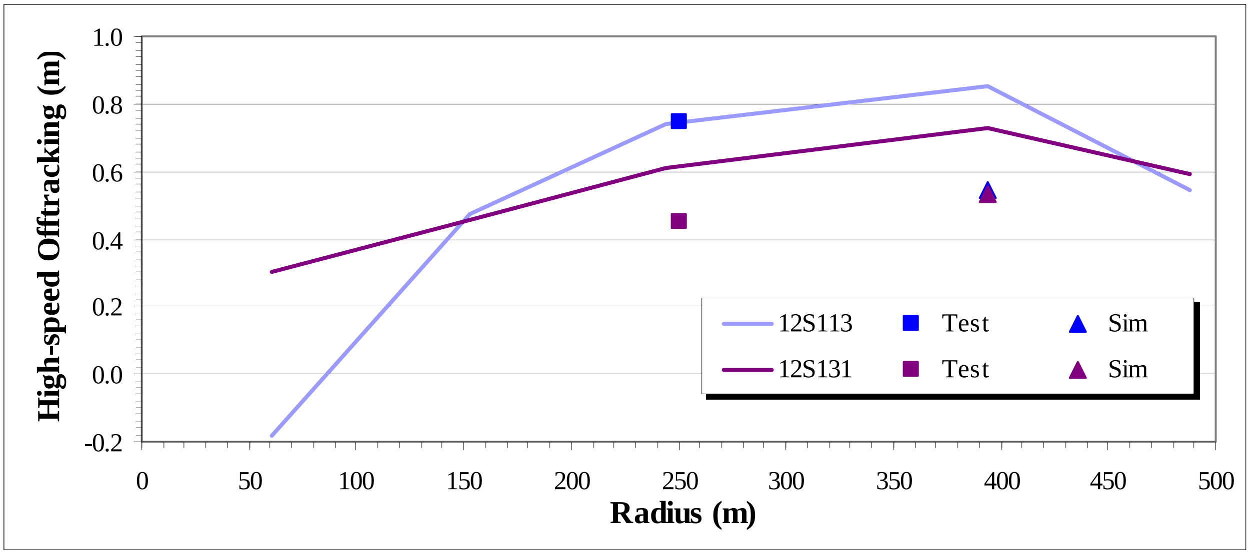

Figure 4: Effect of Curve Radius on High-speed Offtracking

A premise for the performance measure was that the rearmost axle could strike a curb. Urban roads usually have a curb, but Figure **4** shows these vehicles do not develop significant outward offtracking for radii compatible with urban speed limits up to 60 km/h (37.3 mi/h). Lanes on freeway ramps are often widened to allow for low-speed offtracking of vehicles at creep speed, so outward high-speed offtracking should not be an issue. A curb strike is not an issue on high-speed roads, and roads in rural areas, which have a shoulder.

Figure **4** shows that high-speed offtracking is most critical for curves with radii from about 200 to 450 m (656 to 1,476 ft), which correspond to speeds from about 70 to 100 km/h (43.4 to 62.1 mi/h). The performance measure is evaluated at a lateral acceleration of 0.20 g, which is above the range of 0.08 to 0.17 g that results when a vehicle is driven through a ramp or curve at the advisory speed limit posted with a yellow sign. Drivers of vehicles of the class considered here should be sensitive to rollover, so should pay careful attention to speed through ramps and curves. A driver traveling above a posted advisory speed or the legal speed limit tends to cut to the inside of a curve, which increases the radius, reduces lateral acceleration and high-speed offtracking, and also allows additional space for outward high-speed offtracking.

Outward high-speed offtracking did occur for these vehicles, and the vehicles tested exceed the performance standard by a small margin. This aspect of their performance differs little from that of existing vehicles of similar configuration. Conservatism built into the performance measure, the way this class of vehicle is typically operated, and the way roads are constructed together would seem to result in a low probability of sufficient high-speed offtracking for a lane departure and conflict with another vehicle.

3.7 SAE J2179 Lane Change

Lane changes were performed following the Society of Automotive Engineers J2179 test procedure. The vehicle could only achieve a speed of about 90 km/h (55.9 mi/h) through the test area, less than the target speed of 100 km/h (62.1 mi/h), for a lateral acceleration of about 0.12 g. The self-steering axle lock allowed about 1 deg of free play when engaged, which is comparable to the self-steer angle seen in this manoeuvre, so locking the self-steering axles hardly made any difference for either vehicle. Additional lane changes were performed using the same procedure, but with double the side-step, for a lateral acceleration about 0.25 g. Locking the rearmost axle of Configuration 12S131 showed a small benefit over leaving it unlocked. The lock would become more effective as the manoeuvre became more aggressive. All test results were within the performance standard of 0.80 m (32 in).

3.8 The Need to Lock Self-steering Axles at High Speed

Outward high-speed offtracking and transient offtracking occurred for both vehicles. Locking the rearmost self-steering axle of Configuration 12S131 was an effective way to moderate these. The lock allowed about 1 deg of steering free play, and would be more effective with less, though this might increase tire wear. Locking the self-steering axles of Configuration 12S113 had little effect, as these axles hardly steer in high-speed manoeuvres.

3.9 Effect of Forced Steer on Vehicle Response

If a self-steering axle steers independently for some reason, it may cause a vehicle response. The self-steering axles were forced to steer artificially by braking the left-hand wheels of each self-steering axle, and by driving one side of the vehicle over a speed bump. However, an incident during a high-speed test with Configuration 12S113 was more severe than any of these planned tests. The driver steered sharply and braked hard at about 80 km/h (49.7 mi/h) to avoid running off the paved surface of the test area, which locked the left-hand wheels of each self-steering axle, and each axle steered hard over. The driver moderated the brake pressure, allowing the locked wheels to start rolling and straighten, and then braked hard again to stop the vehicle, which caused another hard-over. The tires on both sides of each self-steering axle were dragged on their sidewalls, but the driver readily maintained control of the vehicle. The self-steering axles on this vehicle may have been over-braked, so a 2S/1M antilock brake system on each self-steering axle should reduce the risk of self-steer hard-over and tire damage.

It appears that an alert driver should be able to control a vehicle even if both self-steering axles steer in the most adverse manner possible. A similar finding emerged from previous tests of self-steering axles (Corbin, Grandbois and Richard, 1995).

3.10 Computer Simulations

A computer simulation was run for every test run, using the measured steer angle and forward speed as inputs. Comparison of test and simulation responses showed that the simulation program can represent the dynamic response of an individual vehicle of this class to a specific manoeuvre quite closely, can represent trends that occur across a series of runs, and can reflect differences between vehicles of different configurations during a specific manoeuvre.

4 REGULATORY DEVELOPMENT AND IMPLEMENTATION

A safe, productive and infrastructure-friendly semitrailer should be configured according to (at least) the following principles:

- All semitrailer axles must have equal axle loads when the vehicle operates in Ontario;
- Self-steering axles should have sufficient steer for the application;
- A semitrailer must have more fixed axles than self-steering axles;
- A self-steering axle may be fitted with single tires or dual tires;
- A self-steering axle may be liftable, but any lift control or air dump valve must not be accessible to a driver in the cab;
- A self-steering axle may lift automatically when the driver reverses the vehicle;
- Certain self-steering axles should lock automatically for travel at highway speed;
- Load equalization may be disabled for operation in other jurisdictions; and
- Rigid liftable axles may be fitted for use elsewhere, but must always be raised in Ontario.

The steer angle of a self-steer axle depends on the offset of the self-steering axle from the turn centre of the semitrailer. Based on this work, MTO established a minimum of 20 deg of steer for offset up to 4.65 m (183 in), 25 deg for offset up to 5.85 m (230 in), 28 deg for offset up to 7.10 m (280 in), and 30 deg for greater offset.

MTO introduced a regulation effective on 1 January 2006 defining SPIF configurations 12S113, 12S114, 12S131, 12S141 and 13S13, with a schedule of gross weight reductions for existing non-SPIF configurations.

An independent study identified a number of issues with the braking system of this class of vehicle. MTO worked closely with industry to address these, and the regulation requires a split braking system so that at least half the brakes are available in the event of a single failure, a low-pressure warning light on the semitrailer, ABS on all axles, and gladhand filters.

Crash data generated by MTO shows that semitrailers with 5 or more axles have 1.03 collisions per million vehicle kilometers of travel. This is estimated to drop to 0.79 after SPIF vehicles replace the existing fleet, a significant improvement in safety performance from the improvement in dynamic performance (Corredor, Groskopf and Madill, 2005).

5 CONCLUSIONS

Computer simulations found existing tractor-semitrailer configurations with eight or more axles failed many of the standards for dynamic performance, especially with their rigid liftable axles raised. Further simulations identified specific requirements for candidate safe, productive and infrastructure-friendly (SPIF) configurations with self-steering axles to replace these vehicles. Full-scale tests of two SPIF configurations validated these requirements. A regulation is now in force in Ontario which defines the configuration of 5- and 6-axle SPIF semitrailers, and reduces the allowable gross weight of non-SPIF semitrailers. Analysis of crash data suggests these measures should significantly reduce collisions for 5- and 6-axle SPIF semitrailers.

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