DYNAMIC TESTING OF SELECTED CANADIAN LOG-HAULING CONFIGURATIONS

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Abstract

A wide variety of productive log hauling configurations have been implemented throughout Canada over the years which has benefited the forest industry through improved transport efficiency. Since the early 1990s, FPInnovations has cooperated with the forest industry and transportation regulators to ensure that these configurations achieved the prescribed safety criteria either through computer simulation or testing. The primary computer model utilized in this process was the University of Michigan Transportation Research Institute's (UMTRI) yaw/roll model as well as a similar model developed specifically for compensating pole trailers (NRC western log truck configurations model). Increased weight allowances and modifications to truck and trailer specifications in the intervening years since the models' development require further validation to ensure that the estimates of configuration performance remain accurate. Advancements in computer processing and software enable more complex models with increased capabilities to be implemented and thereby improve the confidence in modeling results. To this end, FPInnovations has initiated development of a computer model that can be adapted to the multitude of truck configurations currently utilized by the industry. This paper summarizes the results of validation testing conducted for a variety of log-hauling configurations in October 2011.

Keywords: truck configurations, computer modeling, dynamic testing

1. Introduction

1.1 Background

FPInnovations has successfully implemented many productive heavy truck/trailer configurations throughout Canada by working closely with industry and government regulators. Much of this success has been due to expertise developed by FPInnovations in the computer modeling of these truck/trailer configurations, enabling the optimization of vehicle parameters prior to implementation. This greatly streamlines the process towards introducing productive and safe configurations.

The software used by FPInnovations for this task[1] remains effective, but has become dated and there are limitations in the analysis in which the software can be applied. The primary computer model utilized by FPInnovations for this analysis is the University of Michigan Transportation Research Institute's (UMTRI) yaw/roll model as well as a similar model developed specifically for compensating pole trailers (Preston-Thomas 1994). Increased weight allowances and modifications to truck and trailer specifications in the intervening years since the models' development require further validation and potential model adjustment to ensure that the estimates of configuration performance remain accurate. Recent advancements in computer modeling software together with the improved computational speed of current computer technology would enhance the heavy truck/trailer dynamics software currently available and improve the scope of the analysis of proposed truck/trailer configurations. Existing commercial truck dynamics software currently lacks the flexibility for investigating new vehicle designs. FPInnovations sought to develop software that would give researchers the required flexibility to accomplish this task.

2. Methodology

It is critical that the developed heavy vehicle models provide accurate results. Therefore, correlation of model output with full scale test data is necessary. A full-scale testing and validation program was initiated in September 2012 with this objective.

2.1 Full-scale testing

Full scale testing was conducted at the Hanna Test Centre (HTC) located in Hanna, Alberta for the following configurations:

A. Super B-train
B. J-train
C. Truck/Full trailer
D. Tri-drive B-train (winter weights)
E. Tri-drive B-train (legal weights)
F. Tri-drive/pole trailer (winter weights)
G. Tri-drive/pole trailer (legal weights)

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[1] FPInnovations has utilized the University of Michigan Transportation Research Institute (UMTRI) yaw/roll model since 1992. This model has been extensively validated for a wide range of configurations, but is not user friendly requiring expert knowledge to run.

Note that configuration E is the same as configuration D, but with some load removed. Similarly configuration G is the same as configuration F with some load removed. The configuration weights and dimensions are summarized in Table 1. The configurations are illustrated in **Error! Reference source not found.** to **Error! Reference source not found.**.

Table 1 – Summary of test configuration weight and dimensions

Configuration	Number of axles	Gross Combination Weight (tonnes)	Overall length (m)
A. Super B-train	8	62.8	24.2
B. J-train	8	63.8	25.2
C. Truck/Full trailer	7	43.3	20.7
D. Tri-drive B-Train (winter)	8	70	25.7
E. Tri-drive B-train (legal)	8	63.3	25.7
F. Tri-drive pole trailer (winter)	7	62.9	22.6
G. Tri-drive pole trailer (legal)	7	55.7	22.6

Figure 1. Super B-Train (A)

Figure 2. J-train (B)

Figure 3. Truck/Full-trailer (C)

Figure 4. Tri-drive B-train (legal) (E)

Figure 5. Tri-drive/pole trailer (winter) (F)

Test Procedure

The testing followed developed and accepted test protocols that ensured that the vehicle remained within safe operating limits throughout testing. A test engineer was present in the tractor to provide the driver with real time feedback during testing. The instrumentation was monitored by the engineer throughout testing to assist in this process.

Dynamic Lane Change Manoeuvre
The vehicle followed a marked test course designed to develop a single sine-wave lateral acceleration input[2] with a peak acceleration of 0.15 g, and period of 2.5 seconds at the steering axle at a speed of 80 km/h. The installed instrumentation allowed rearward amplification[3] as well as roll angles to be determined.

Constant Curve Radius Manoeuvre
This manoeuvre was intended to evaluate the steady state characteristics of these truck configurations. However the state of the test track with many ruts and potholes made it impossible to achieve steady state characteristics, but useful validation data was collected. The configurations followed a constant radius turn (305 m) on the test track at a steady speed at speeds ranging from 60 km/h to a maximum speed of 80 km/h.

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[2] Manoeuvre based on International Standard (ISO) 14791- (Road Vehicles-Heavy commercial vehicle combinations and articulated buses- lateral stability test methods) section 7.5 Single lane change.

[3] Rearward amplification is computed from The peak rear trailer lateral acceleration divided by the peak lateral acceleration at the steering axle.

For selected runs, the off-tracking was determined by measuring the average tire track swept path left on duct tape located radially at 4 locations in the curve (Figure 6).

Figure 6. Tape on test track for measuring off-tracking

2.2 Model validation

MATLAB® Simmechanics models were developed for the test configurations, using dimensional and load data collected during the testing phase. The truck/trailer physical performance properties were estimated using data from previous testing (Preston-Thomas, 1994) as well as default UMTRI model data.

For each model, a number of test runs were simulated using the actual speed and steering data collected during testing. The steering tire lateral force characteristics were linearly adjusted to obtain the yaw performance observed during testing. For each run (including the evasive and constant curve radius manoeuvres) the following parameters were compared between the test and simulation data:

Steering axle lateral acceleration
Rear trailer CG lateral acceleration
Computed rearward amplification
Rear trailer CG roll angle

To date validations have only been completed for the Truck/Full trailer (C) and the Tri-drive B-train (E) hauling legal weights.

3. Results and Discussion

3.1 Full-scale testing

Full-scale testing demonstrated the variability of performance between configurations and drivers. The J-train and Tri-drive B-train had the same driver (3 conditions), while the Tri-drive/pole trailer , Super B-train, and truck/Full/trailer had different drivers. All drivers were within 5 km/h of achieving the target speed of 80 km/h for the evasive manoeuvre (Table 2), with average speeds ranging between 75.2 and 81.7 km/h for the J-train and Super B-train respectively. Two of the drivers (Super B-train and J-train/Tri-drive B-train) were less aggressive than the other two tending to cut corners of the test path resulting in slightly reduced input lateral accelerations at the steering axle (0.11 to 0.13 g). The drivers of the Truck/Full trailer and Tri-drive/pole trailer achieved higher input lateral accelerations of between 0.16 to 0.18 g.

Table 2 – Summary of evasive manoeuvre test results

Configuration	Number of runs	Average speed (km/h)	Average peak lateral acceleration @ steer axle (g)	Average peak lateral acceleration @ trailer CG (g)
Super B-train	15	81.7	0.11	0.18
J-train	24	75.2	0.11	0.18
Truck/Full trailer	24	78.3	0.16	0.36
Tri-drive B-Train (winter)	26	76.3	0.12	0.20
Tri-drive B-train (legal)	20	80.6	0.13	0.21
Tri-drive pole trailer (winter)	29	78.9	0.16	0.21
Tri-drive pole trailer (legal)	38	81.4	0.18	0.26

The full scale testing showed essentially three distinct levels of dynamic performance for the test configurations. The three fifth-wheel coupled configurations (Super B-train, J-train, and Tri-drive B-train) exhibited moderate levels of rearward amplification (RA) of between approximately 1.5 and 1.8 (Figure 7), while the tri-drive/pole trailer and Truck/Full trailer exhibited reduced RA levels (<1.5) and very high RA levels (>2) respectively. The lowest roll angles during this manoeuvre were measured for the fifth wheel coupled configurations, while moderate and high roll angles were measured for the Tri-drive/pole trailer and Truck/Full trailer respectively (Figure 8). The higher roll angles observed for the Tri-drive/pole trailer and Truck/Full trailer are partially due to the increased lateral input accelerations at which these configurations were driven through the manoeuvre. As well it is important to note that the increased roll angle measured for the Tri-drive pole trailer hauling legal weights relative to winter weights is due to the higher lateral acceleration and speed at which the manoeuvre was conducted for the legal load. Overall these results show that similar dynamic performance can be expected from all the test configurations (accounting for differences in manoeuvre execution) except for the Truck/Full trailer where its dynamic performance is distinctly marginal.

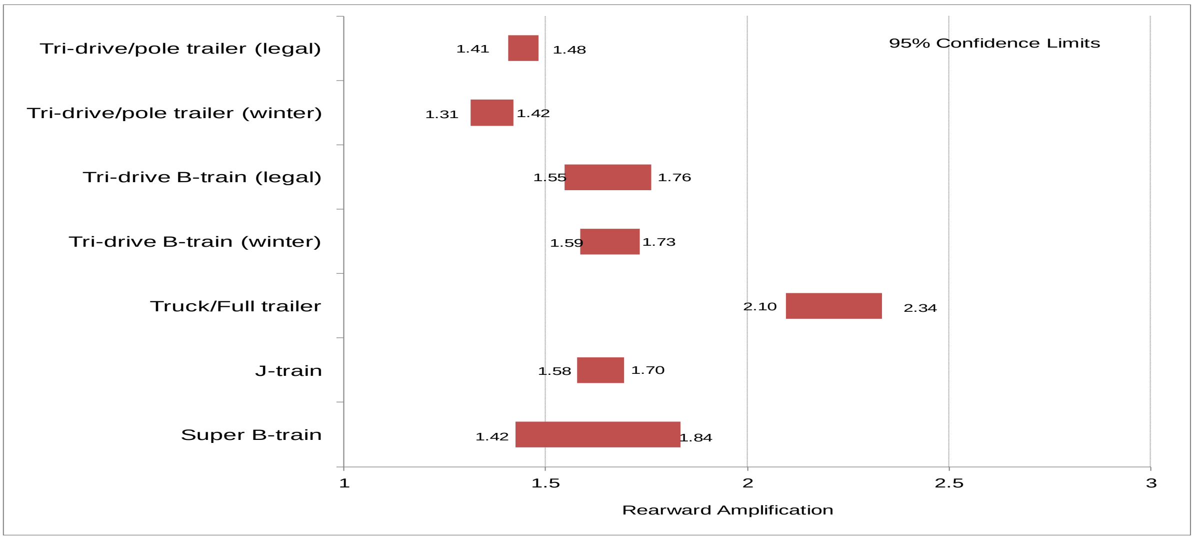

Figure 7. Evasive manoeuvre – rearward amplification

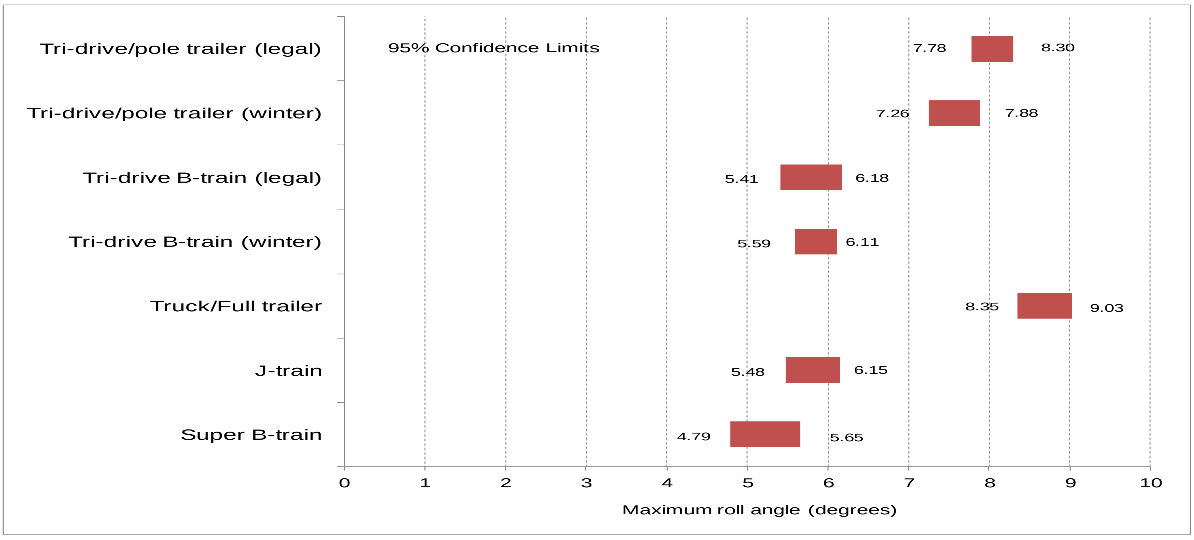

Figure 8. Evasive manoeuvre – trailer roll angle

Similar speed and lateral acceleration trends were observed between configurations and drivers for the constant radius manoeuvre as were seen in the evasive manoeuvre (Table 3). The J-train experienced the lowest lateral acceleration (0.09 g), while the Truck/Full trailer experienced the highest lateral acceleration of 0.18 g. The measured off-tracking ranged between 0.14 m to 0.30 m for the Super B-train and Truck/Full trailer respectively. It should be noted however that the high off-tracking levels seen for the Truck/Full trailer were due mostly to the increased lateral acceleration. For both configurations tested with legal and winter loads, the increased winter load resulted in increased off-tracking as expected. Increased speed and lateral acceleration resulted in an increase in off-tracking as demonstrated for the Truck/Full trailer where off-tracking increased from 0.17 to 0.30 m, when the speed was increased from 70 to 80 km/h.

Table 3 – Summary of constant radius manoeuvre test results

Configuration	Number of runs	Average speed (km/h)	Average peak lateral acceleration @ steer axle (g)	Average off-tracking (m)
Super B-train	2	65.9	0.11	0.14
J-train	4	58.5	0.09	0.18
Truck/Full trailer	2	70.8	0.12	0.17
	2	80.4	0.18	0.30
Tri-drive B-Train (winter)	3	69.2	0.11	0.18
Tri-drive B-train (legal)	3	73.7	0.13	0.14
Tri-drive pole trailer (winter)	4	70.3	0.12	0.25
Tri-drive pole trailer (legal)	5	72.8	0.13	0.18

3.2 Model validation

Comparisons between model predictions and test results are shown for the Truck/Full trailer and Tri-drive B-train (legal loads) in Table 4 and Table 5 respectively. The model predicted peak steering axle lateral accelerations relatively close to the test data for the Truck/Full trailer. For the Tri-drive B-train model, the predicted peak lateral accelerations at the steering axle were more variable with up to a 24.8% underestimate (E12). The peak lateral accelerations at the rear trailer CG predicted by the Truck/Full trailer model ranged between a 16.5 overestimate to a 28.2% underestimate. For the Tri-drive B-train the rear trailer peak lateral accelerations were more consistent ranging between a 7.0 to14.3% underestimate. The Tri-drive B-train model predicted more consistent roll angles compared to the Truck/Full trailer model with peak roll angles ranging from 14.8 to 22.1% above the test values. The roll angles predicted by the truck/Full trailer model ranged between a 2.9% underestimate to a 24.5% overestimate.

Table 4 – Comparison of evasive maneouvre measures – Truck/Full trailer

Run	Peak lateral acceleration @ steer axle (g)			Peak lateral acceleration @ trailer CG (g)			Peak trailer roll angle (deg)		
	Test	Model	% diff	Test	Model	% diff	Test	Model	% diff
C2	0.148	0.152	2.7	0.279	0.325	16.5	8.18	10.18	24.5
C9	0.168	0.179	6.4	0.345	0.289	-16.2	9.59	9.31	-2.9
C12	0.158	0.177	11.9	0.322	0.303	-5.9	8.29	9.52	14.8
C13	0.169	0.179	5.7	0.374	0.311	-16.9	8.65	10.78	24.6
C17	0.163	0.175	7.2	0.449	0.322	-28.2	9.46	9.93	5.0
C22	0.157	0.170	8.2	0.298	0.285	-4.4	7.82	9.67	23.7

Table 5 – Comparison of evasive maneouvre measures – Tri-drive B-train (legal)

Run	Peak lateral acceleration @ steer axle (g)			Peak lateral acceleration @ trailer CG (g)			Peak trailer roll angle (deg)		
	Test	Model	% diff	Test	Model	% diff	Test	Model	% diff
E2	0.121	0.124	2.5	0.198	0.171	-13.6	5.75	6.60	14.8
E5	0.133	0.124	-6.8	0.221	0.189	-15.5	5.66	6.91	22.1
E12	0.157	0.118	-24.8	0.214	0.199	-7.0	6.01	7.23	20.3
E14	0.133	0.140	5.3	0.252	0.216	-14.3	6.34	7.61	20.0

The resulting rearward amplification (RA) values predicted by the Truck/Full trailer model were between 11 and 21% below the test values for 4 of the 6 sample runs (Figure 9). The remaining sample runs C2 and C17 resulted in a 13% overestimate and 33% underestimate respectively. Overall the Truck/Full trailer model predicted relatively consistent RA levels (1.61 to 1.73) for all runs except run C2 (2.13). The test results were more variable with RA values between 1.89 and 2.75.

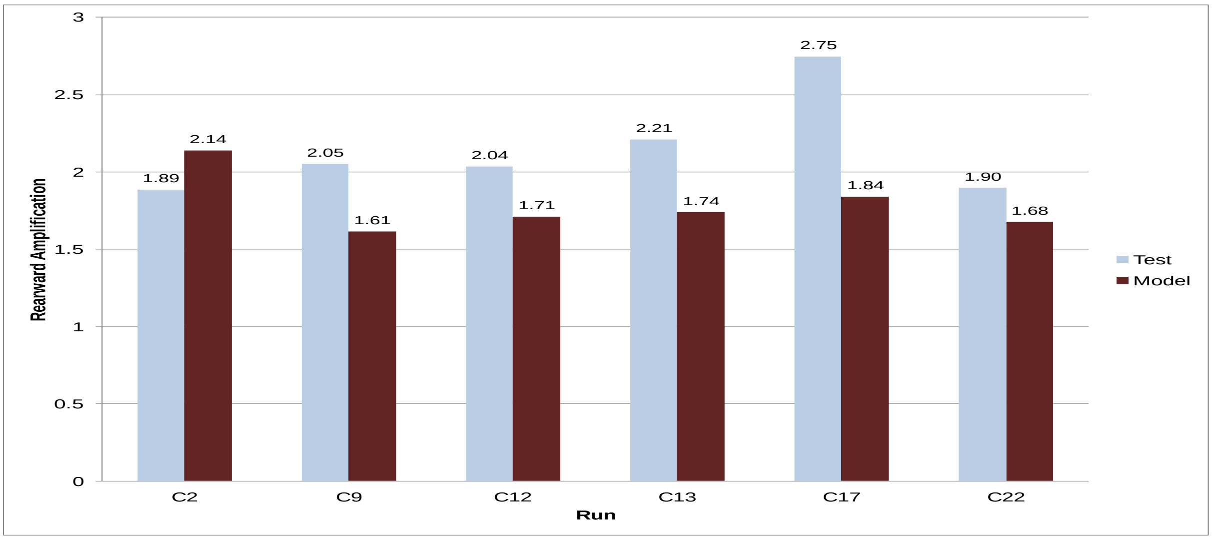

Figure 9. Rearward amplification comparison – Truck/Full trailer

The RA values predicted by the Tri-drive B-train model were between 8 and 19% below the test values for 3 of the 4 sample runs (Figure 10). The remaining comparison test run E12 resulted in a 24% overestimate, a result of the discrepancy between the model and test steering input lateral acceleration. Overall the Tri-drive B-train model predicted relatively consistent RA levels (1.38 to 1.68) for all runs. The test results were slightly more variable with RA values between 1.36 and 1.89.

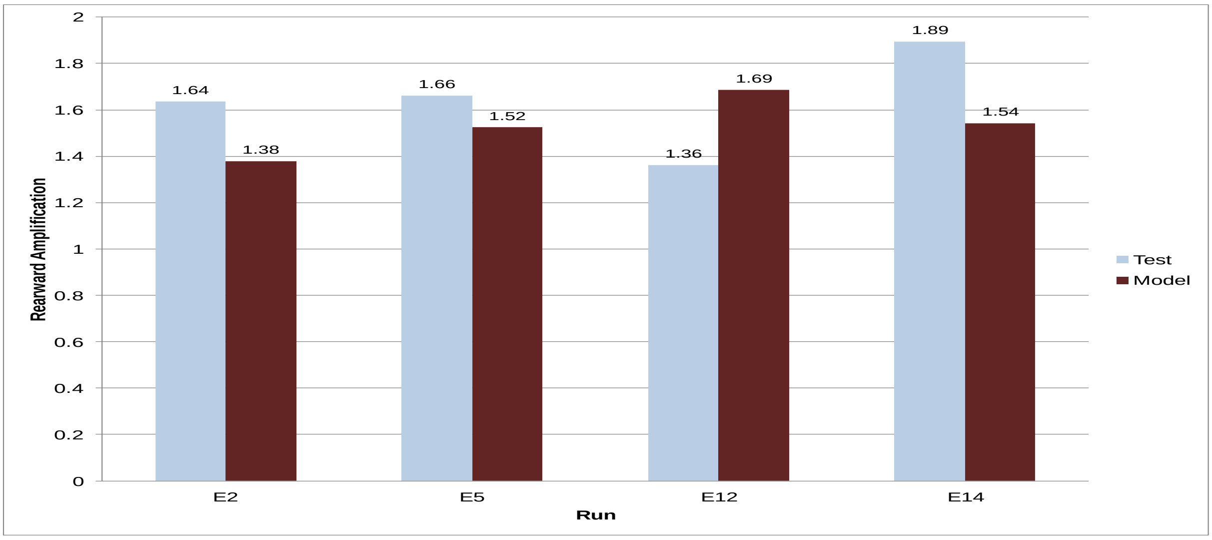

Figure 10. Rearward amplification comparison – Tri-drive B-train (legal)

A limited number of comparisons were made of the two models' off-tracking prediction capability. The off-tracking predicted by the Truck/full-trailer model was 0.04 and 0.06 m below the average measured off-tracking at speeds of 70 km/h and 80 km/h respectively (Figure 11). The Tri-drive B-train model predicted off-tracking very close to that measured during testing with 0.01 m increased off-tracking.

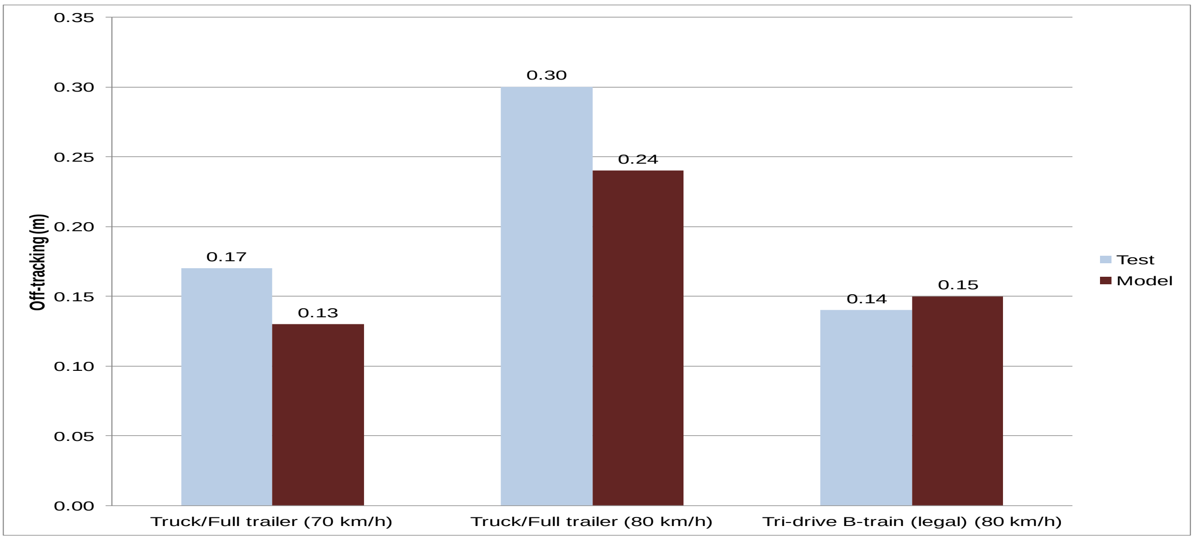

Figure 11. Comparison of off-tracking results.

Overall the two models developed yielded similar results to the test data particularly given the complexity of the many parameters involved and the potential variability in their properties. The test configurations were all several years old with variably worn components (tires, suspensions) and compliance in the trailer frames, load attachment and articulation points allowing for variability between the actual physical properties and those used in the models. In addition the test track’s surface variations (potholes, ruts) were not accounted for in the models. To confirm that the developed models yield accurate results, it is recommended that additional simulations be conducted with existing models and their outputs compared with the models developed here.

4. Conclusions

- Full-scale testing demonstrated the variability of performance between configurations and drivers. The variability in manoeuvre speeds and path execution made direct comparison between configurations difficult, but did provide good baseline data for developing enhanced models for evaluating these configurations.
- Full-scale testing demonstrated that all configurations tested except for the Truck/Full trailer had similar dynamic performance. The Truck/Full trailer's performance was distinctly marginal with a rearward amplification above 2.
- Full-scale testing confirmed that increased loads and lateral acceleration increase off-tracking.
- Two vehicle dynamics models were developed for the Truck/Full trailer and Tri-drive B-train.
- The Tri-drive B-train model predicted more consistent roll angles compared to the Truck/Full trailer model with peak roll angles ranging from 14.8 to 22.1% above the test values. The roll angles predicted by the truck/Full trailer model ranged between a 2.9% underestimate to a 24.5% overestimate.
- The resulting rearward amplification (RA) values predicted by the Truck/Full trailer model were between 11 and 21% below the test values for 4 of the 6 sample runs. The RA values predicted by the Tri-drive B-train model were between 8 and 19% below the test values for 3 of the 4 sample runs.
- Overall the two models developed yielded similar results to the test data particularly given the complexity of the many parameters involved and the potential variability in their properties.
- To confirm that the developed models yield accurate results, it is recommended that additional simulations be conducted with existing models and their outputs compared with the models developed here.

5. References

- Preston-Thomas, J. (1994) Measured Characteristics and Dynamic Performance of Two Configurations of Western Canadian log Truck. National Research Council Canada Technical Report