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Transports de Surface

NRC·CNRC

Test Report

Packed Snow Performance of Low Rolling Resistance Class 8 Heavy Truck Tires

Prepared for:
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Abstract

In heavy duty trucking applications, research and testing has shown that the installation of low rolling resistance (LRR) tires on a tractor-trailer combination could result in a potential fuel and greenhouse gas emission savings of 4% to 11%. However, there have been concerns expressed amongst some tractor-trailer owners and operators that LRR tires may have reduced winter road traction performance compared to non-LRR tires, particularly in snow and ice conditions. No definitive study has quantified the effect that LRR tires have on winter traction performance of HD trucks.

The EPA and the U.S. National Highway Traffic Safety Administration (NHTSA) recently finalized their Heavy-Duty National Program that established fuel economy and greenhouse gas emissions standards for medium-duty and heavy-duty engines and vehicles. Environment Canada published the proposed *Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations in the Canada Gazette*, Part I on April 14, 2012. The standards contained in these proposed regulations align with the U.S. program, while also considering the specific characteristics of the Canadian fleet and related safety standards.

To comply with the proposed Canadian regulations, it is expected that truck manufacturers and importers will increase the penetration of fuel saving technologies, including LRR tires, to equip vehicles available for sale in Canada. Because there were limited data available to assess this issue, TC asked the NRC to undertake a preliminary study of LRR tire traction for Class-8 long-haul vehicles, based on a cross-section of commercially available LRR tires in Canada.

The methods, results and conclusions stemming from this testing are presented in this report.

Executive Summary

The National Research Council's (NRC) Surface Transportation (ST) portfolio, at the request of Transport Canada (TC), conducted a study of several brands of Class-8 long-haul low rolling resistance (LRR) tires, previously verified under the U.S. Environmental Protection Agency's (EPA) SmartWay program, to assess their performance in 'packed snow' winter conditions.

LRR tires, often characterized by unique materials, treads, dimensions and weights, are designed to reduce the amount of rolling resistance, and in turn, the amount of energy consumed as the tires roll along the road. In heavy-duty trucking applications, research and testing has shown that the installation of LRR tires on a tractor-trailer combination could result in a potential fuel savings of 4 to 11% [7] and offer corollary reductions in greenhouse gas emissions.

The United States Environmental Protection Agency (EPA) and the U.S. National Highway Traffic Safety Administration (NHTSA) recently finalized their *Heavy-Duty National Program* that established fuel economy and greenhouse gas emissions standards for medium-duty and heavy-duty engines and vehicles. Environment Canada published the proposed *Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations* in the *Canada Gazette,* Part I on April 14, 2012. The standards contained in these proposed Regulations align with the U.S. program, while also considering the specific characteristics of the Canadian fleet and related safety standards.

To comply with the proposed Canadian regulations, it is expected that truck manufacturers and importers will increase the penetration of fuel saving technologies, including LRR tires, to equip on vehicles for sale in Canada. While some manufacturers, importers and truck owner-operators already equip selected vehicles with LRR tires in Canada, some members within the Canadian trucking industry have expressed concerns that LRR tires may have reduced winter road traction performance compared to non-LRR tires, particularly in snow covered road conditions.

Because there was limited data available to assess this issue, TC asked the NRC to undertake a preliminary study of LRR tire traction for Class-8 long-haul vehicles, based on a cross-section of commercially available LRR tires in Canada.

To undertake this study, several laboratory tests were performed by Smithers-Rapra, on a selection of LRR and non-LRR SmartWay verified tires, specifically:

- rolling resistance was measured using two different dynamometer-based test procedures, specifically SAE J1269 and ISO 28580;
- durability was tested using the FMVSS 119 test procedures, and tested until failure;
- snow traction was measured using a modified version of the ASTM F1805 test standard.

In addition to the laboratory tests, NRC also performed vehicle-based track testing at the General Motors Cold Weather Development Centre in Kapuskasing, Ontario. Loaded trailer and unloaded trailer straight-line braking tests, and unloaded trailer turning tests were performed to compare the performance of a Class-8 tractor and a 53-foot van body semi-trailer with five different configurations of SmartWay verified LRR test tires and one configuration of non-SmartWay verified tires. Snow conditions were relatively consistent throughout the testing, with

penetrometer measurements between medium pack and medium-hard pack snow as defined by ASTM F1805-06. Grooming was performed at the end of every test day.

Based on the testing performed, several key results emerged:

- The lab testing demonstrated that, on average, tires marketed as low rolling resistance have 29% lower rolling resistance than their conventional counterparts;
- All LRR and non-LRR tires passed the FMVSS minimum durability requirements**.** Additionally, when tested to failure, there was no discernible trend of performance bias towards LRR or non-LRR tires; and,
- During laboratory (ASTM F1805[1]) and vehicle-based track testing LRR tires demonstrated comparable levels of snow traction to non-LRR tires.

With the exception of the tires that are specifically marketed by their respective manufacturers as a high-traction tire, the results of this preliminary study indicates that the current generation of LRR tires can offer a similar level of snow traction performance as conventional tires, while reducing fuel consumption and emissions. Put in the context of Canadian trucking, there are many factors that must be considered when purchasing tires for a tractor and trailer combination. The advent of low rolling resistance tires has given owners and operators one more tire characteristic to consider.

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[1] Modified ASTM F1805 test procedure.

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1 Introduction

1.1 Purpose/Objective

Transport Canada (TC) has retained the National Research Council of Canada (NRC), as represented by the Surface Transportation portfolio (ST), hereafter known as NRC-ST, to develop and undertake a test program to evaluate the winter performance of low rolling resistance tires and non-low rolling resistance tires on a Class-8 long-haul truck. The low rolling resistance tires in this test program were selected from the Environmental Protection Agency (EPA) SmartWay verified technologies master list. A separate project was also undertaken to evaluate new-generation single wide-based tires and was reported on separately.

1.2 Background

The Government of Canada (GoC) is committed to reducing Canada's total greenhouse gas (GHG) emissions, and published under the *Canadian Environmental Protection Act*, 1999 (CEPA 1999), the proposed *Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations* in the *Canada Gazette*, Part I on April 14, 2012 [1]. The proposed Regulations are aligned as closely as possible with the United States (US) EPA, while considering the specific characteristics of the Canadian fleet and appropriate safety standards. The proposed regulations would establish separate emission standards for the engine and the rest of the vehicle. The proposed Regulations would allow vehicles to comply with applicable emission standards using the US EPA supplied "Greenhouse gas Emission Model (GEM), which considers variables such as tractor aerodynamics, tire rolling resistance, weight reduction measures, etc.

Low rolling resistance tires have materials, treads, dimensions and weights designed to reduce the amount of energy wasted as a tire rolls along the road. In heavy-duty trucking applications, the US Department of Energy estimates that low rolling resistance tires can reduce rolling resistance by 15-20% [8]. Effective as of January 1, 2010, the California Air Resources Board (CARB) requires aerodynamic devices and low rolling resistance tires on 2011 model year (MY) or newer heavy-duty tractors and 53-foot or longer box-type trailers operating in California. Pre-2011 MY tractors and trailers operating in California have been required to comply with the regulations since January 1, 2012 [2].

In 2004, the EPA launched the SmartWay program to identify ways in which GHG emissions from transportation could be reduced. One of the results of the SmartWay program was the SmartWay Technology Program that identified technological solutions that could be implemented on heavy-duty trucks to help reduce GHG emissions. One of the identified solutions was the use of low-rolling resistance (LRR) tires for long-haul trucking.

However, there are limited studies regarding the effect that EPA SmartWay verified LRR tires have on heavy duty vehicle performance in winter conditions. Considering that material composition, tire dimension, and tread pattern are specifically designed to reduce the rolling resistance, it is important to quantify the effects that these features have on traction in snow conditions.

1.3 Scope

The scope of this test program was to assess the performance of Class-8 long-haul tires, both EPA SmartWay verified LRR tires and conventional non-LRR tires under controlled laboratory conditions. The laboratory testing covered the measurement of rolling resistance, tire durability, and snow traction using a variety of SmartWay verified and non-SmartWay verified tires.

A parallel program was run simultaneously to perform winter testing with selected tires on a vehicle at a suitable test track facility. The vehicle testing used a subset of the tires being tested in the laboratory, and focused primarily on SmartWay verified tires with a non-SmartWay verified control set.

It was not the intention of this test program to audit the EPA SmartWay methodology, or the validity of the EPA SmartWay verified program. Indeed, the SmartWay verified technologies master list was used to select the low-rolling resistance tires to be used for this test program. The results of the rolling resistance testing performed were to be used primarily for quantitative comparisons between non-LRR and LRR tires, and to compare the rolling resistance against the results from snow traction, durability, and vehicle based testing.

1.4 Strategy

NRC-ST engaged Smithers-Rapra (Smithers) to perform rolling resistance testing as outlined in SAE J1269 and in ISO 28580; as well as endurance testing using procedures outlined in FMVSS 119 on sample tires. Additionally, winter traction testing using a modified version of ASTM F1805 [3] was also performed. Smithers Ravenna, OH facility performed the rolling resistance and endurance testing while Smithers Raco, MI facility executed the winter traction testing.

For the vehicle based winter testing, NRC-ST used the General Motors Cold Weather Development Center in Kapuskasing, ON. The General Motors facility is a privately managed facility with a closed test track and suitable shop area to perform the required testing. NRC-ST provided the necessary personnel and equipment required.

1.5 Limitations

1.5.1 Limits of Laboratory Testing

Each test (rolling resistance, traction, and durability) was performed on fresh tires; no tires were used for more than one test. Only three samples of each tire model were tested, one for each test. Every effort was made to ensure that the tires were from the same production batch to minimize potential batch-to-batch variations. Steps were also taken to ensure that the test tires are no more than five years old as indicated by the DOT date code on the tire. All tires were in the new condition and purchased from the respective manufacturer's local retailer/distributor.

The endurance testing prescribed by FMVSS 119 only establishes a minimum acceptable level of durability for tires to be considered roadworthy. While some tires may last substantially longer than the minimum requirement, caution should be exercised when drawing conclusions regarding the in-service life of a tire based on the endurance test results as it is not the intention of the FMVSS 119 to estimate or model service life.

The ASTM F1805 standard that Smithers used to determine snow traction was primarily intended for tires used in passenger vehicle applications. Currently, the American Society for Testing and Materials is currently reviewing the F1805 standard to include test procedures for heavy truck tires. At the time of testing, there was no currently ratified standard for determining snow traction with heavy truck tires, and Smithers has created a proprietary test using a modified version of ASTM F1805 to determine snow traction performance of heavy truck tires. The repeatability of this test is heavily dependent on snow conditions.

1.5.2 **Limits of Vehicle Based Testing**

Testing was conducted using a single tractor-trailer supplied by a commercial fleet operator, with one set of each of the selected tires. While general conclusions were drawn, the results are only applicable to the test tires.

Due to the number of environmental factors that affected snowpack conditions and therefore affected the repeatability of fine grained data collection, the purpose of this testing was not to rank the performance of various LRR tires but to investigate any potential correlations between rolling resistance and other tire properties when operating in winter conditions. If significant deviations in performance that can be directly attributed to environmental factors were observed, then further study with more rigorous control over environmental variability may be warranted. However, if no significant deficiencies were identified, then it may be better to focus further study on other areas.

2 Theory

The LRR tires tested in this study help to reduce fuel consumption in heavy duty (HD) truck fleet operations by minimizing rolling resistance. Some of the fundamental concepts related to this potential fuel savings are presented in Sections 2.1 and 2.2.

2.1 Fuel Consumption in Heavy-Duty Trucks

Fuel is consumed by the engine of a truck as it propels the vehicle and its load down the road. There are five major factors that contribute to this fuel consumption:

- Rolling resistance;
- Aerodynamic drag;
- Changes in grade or elevation;
- Internal power train losses; and
- Accessory losses (e.g. air conditioning, alternator loads, etc.).

The percentage contribution to the rate of fuel consumption for each of the five factors varies based on vehicle characteristics and drive cycle. The contribution from aerodynamic drag of a vehicle increases exponentially with an increase in speed. The rolling resistance (and accessory losses), while also increasing with speed, constitute a proportionally smaller percentage of the total drag on a vehicle as its speed increases. This speed-loss relationship is shown in Figure 1.

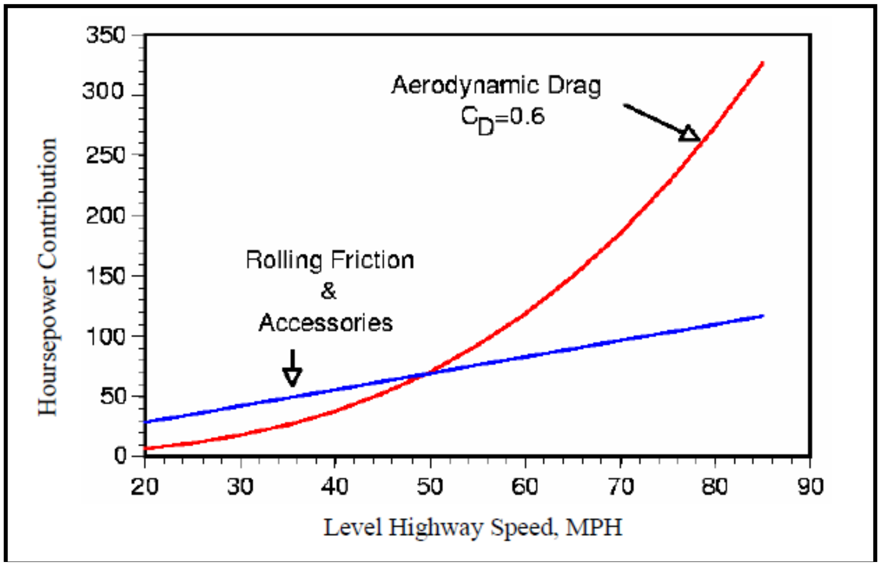

Figure 1: Relationship of Vehicle Speed versus Drag Force [8]

Table 1 illustrates the estimated contributions to fuel consumption at various speeds, assuming a zero grade, properly maintained tires, and internal power train losses modeled as a constant relative to vehicle speed.

Table 1: Distribution of Power Consumption at Various Speeds

Loss	40 km/h (25 mph)	80 km/h (50 mph)	121 km/h (75 mph)
Rolling Resistance	53%	41%	18%
Aerodynamic Drag	30%	47%	72%
Accessory	17%	12%	10%

Adapted from 21st Century Truck Program, 2000 [8]

Given that there are multiple factors contributing to the fuel burn, it stands to reason that reducing rolling resistance by 10%, for example, would not result in a 10% reduction in overall fuel consumption. Rather, this percentage reduction would be multiplied by the percentage contribution of rolling resistance effects at a particular speed. For example, a 10% reduction in rolling resistance would yield an overall fuel consumption reduction of 1.8% at 121 km/h, 4.1% at 80 km/h and 5.3% at 40 km/h.

2.2 Rolling Resistance

Rolling resistance is the force that is required to maintain the forward movement of a tire in a straight line and at a constant speed. Three main factors contribute to the resistive forces on a rolling tire, they are [9]:

- Hysteresis losses in the material (80–95%);
- Tire/road and tire/wheel friction (0–15%); and
- Aerodynamic losses and air circulation (0–5%).

Hysteresis losses in tire material, caused by the internal friction from tire continually deforming and reshaping in order to maintain contact with the road, is the primary cause of rolling resistance. A secondary cause is the friction force between the tire and the road, which allows for traction, cornering, acceleration, and braking. Aerodynamic and air circulation losses are present, but are minimal. Figure 2 provides an illustration of the forces contributing to tire rolling resistance.

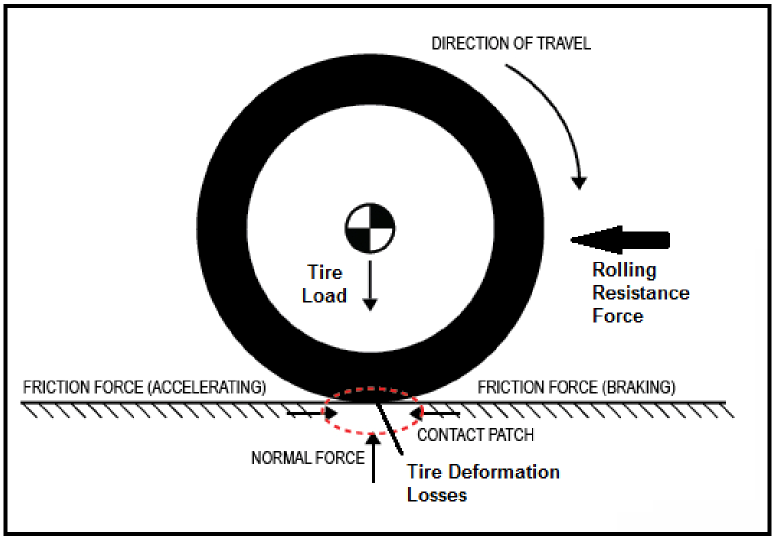

Figure 2: Rolling Resistance Forces (adapted from [10])

The rolling resistance coefficient, C_{rr}, is the ratio of the rolling resistance to the load of the tire; this value is dimensionless. For various types of HD truck tire, C_{rr} ranges between 0.004 and 0.009 [11]. However, for convenience, C_{rr}, is often expressed in values of newtons of force of rolling resistance per kilonewton of load (N/kN), which converts the C_{rr} values to 4.0 N/kN and 9.0 N/kN. The lower the C_{rr}, the less force required to roll the tire forward.

Each wheel position of a tractor-trailer combination contributes a portion to the total tire rolling resistance. In the US, the rolling resistance contributions for the typical tractor-tandem trailer configuration are 42.5% for each of the drive and trailer axle groups and 15% for the steer axle, as shown in Figure 3. These contributions, which are directly in line with standard load weight allowances for each axle position, are related to SmartWay verification criteria for LRR tires, as discussed in Section 2.3. However, in Canada, there are many tractor-trailer configurations that differ from the typical US configuration (e.g. tridems, tri axles and quads), and the percentage contributions to rolling resistance by each axle group for these configurations vary slightly. As a result, many Canadian configurations will have a higher percentage of rolling resistance attributed to the trailer when compared to typical US tandem configuration.

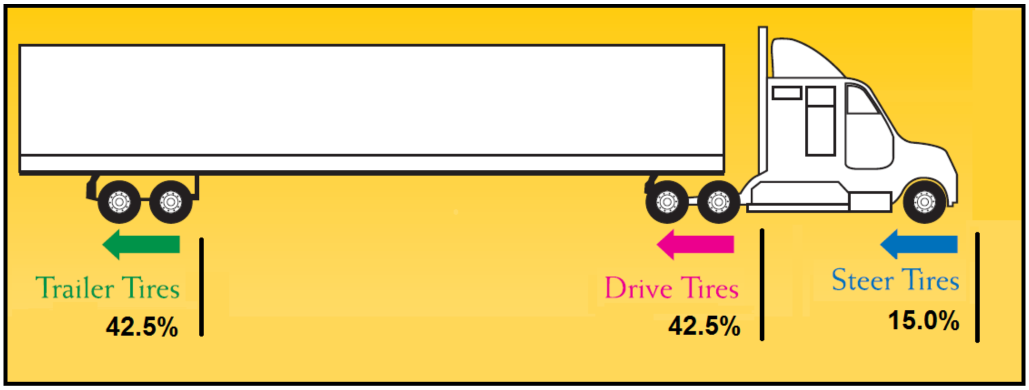

Figure 3: Contribution to Rolling Resistance by each Axle Position for Typical US Configurations (adapted from [12])

Baseline (non-LRR) steer, drive, and trailer positions have approximate C_{rr} values of 7.8 N/kN, 8.2 N/kN and 6.5 N/kN, respectively [13]. Since the drive and trailer tires account for an estimated 85% of total rolling resistance, tire manufacturers focus on these axle positions when designing LRR tires.

2.3 Low Rolling Resistance Tires

A number of factors affect the rolling resistance of a tire, including operating conditions (road surface, inflation pressure, alignment, speed, ambient temperature, etc.) and the tire construction.

2.3.1 *Tire Construction*

Tire construction plays a significant role in reducing rolling resistance. Approximately 35% to 50% of the rolling resistance of the tire construction is due to the tread compound and tread design, while 50% to 65% is caused by the design and compounding of the casing (including sidewalls, beads, and belts) [14]. Sections 2.3.1 through 2.3.4 outline the main parameters that influence the design of a LRR tire, the contribution of design to fuel savings, and the relationship between LRR tire design and traction.

2.3.2 *Tread and Sidewall Compounds*

Every manufacturer has unique tread and sidewall compound formulations to achieve lower rolling resistance. These compounds often include natural and engineered synthetic rubber, combined with special additives such as silica. Silica increases the stiffness of the rubber, which reduces hysteresis losses, the primary cause of rolling resistance.

In addition, some LRR tires have a dual-compound configuration, also known as cap-and-base tread (Figure 4), which further reduces rolling resistance. The cap region (which makes contact with the road) is constructed of a compound with abrasion-resistant and high-traction properties, while the base of the tread (closest to the tire casing) uses a compound with low hysteresis loss characteristics. This dual-compound configuration has a reported 5% improvement in rolling resistance reduction over the single compound tread [15].

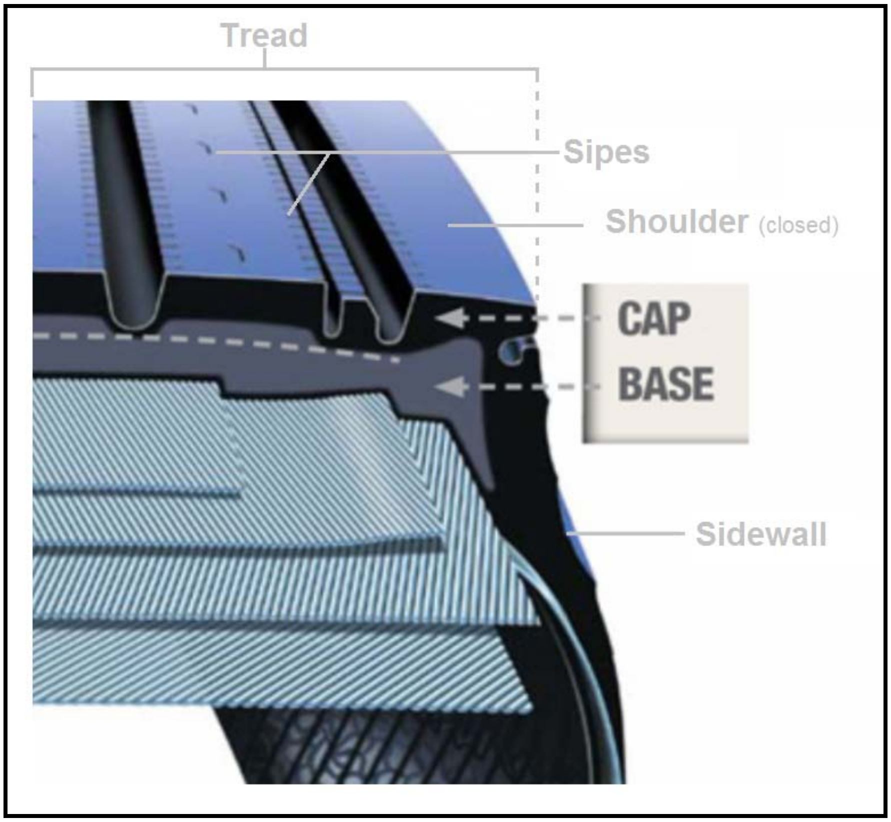

Figure 4: Cap and Base Configuration (adapted from [14])

2.3.2.1 Tread Depth and Tread Pattern

Tread depth has a significant effect on rolling resistance. A large portion of the tire material, which has high hysteresis loss potential, is present in the tread. A reduction in the amount of tire material, by reducing tread depth (as shown in Figure 5), lowers the hysteresis loss potential and, thus, the rolling resistance of the tire. In addition, a reduction in tread depth (measured in 32^{nds} of an inch) will decrease the overall weight of the tire, which translates into a further decrease in rolling resistance from a reduction in frictional forces. For these reasons, LRR tires often have lower tread depths than standard radial tires (see Figure 5 for LRR tread depth examples).

It is important to note the relationship between tread depth and tread wear. In general, LRR tires wear out faster than standard tires as a result of the often reduced tread depth [14]. However, with improved compounds and effective tread designs, the tread wear can be reduced.

Figure 5: Tread Depth Reduction

Tread patterns of LRR tires can vary from model to model; however, most LRR tires have a common rib design, as opposed to a lug pattern (Figure 6 illustrates the difference). Rib patterns tend to hold their position, while lugs, designed primarily for traction, tend to shift or “squirm” when loaded, resulting in hysteresis loss and rolling resistance.

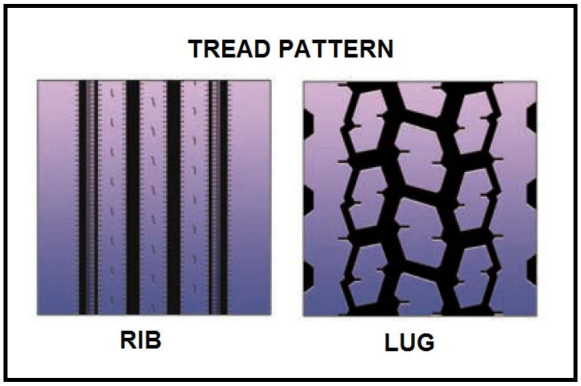

Figure 6: Tire Tread Pattern Comparison

Tread squirm is further exacerbated by large tread depth regardless of pattern because of the rubber's reduced column stiffness. Reducing tread depth assists in lowering hysteresis losses associated with tread squirm.

2.3.2.2 Casing Design

Although the topics of radial ply versus bias ply, and tubeless versus tube tire technologies are somewhat dated, it is worth noting the relationship between these technologies and rolling resistance. The newer radial ply tires, which account for the majority of tires on the road today, have a single radial ply and a multiple belt system. In contrast, the bias ply has six to eight diagonally oriented plies and no belts. See Figure 7 for an illustration of these two tire types. The advantage of the single radial ply tire is that there is less internal friction, which translates to less hysteresis loss, and an estimated 30% lower rolling resistance than bias ply tires [16]. In addition, the transition from tube to tubeless tire technology for HD trucks has impacted rolling resistance for HD LRR tires. Tube tires have been shown to consume 2% more fuel than tubeless tires, when used on all wheels of the tractor-trailer [17].

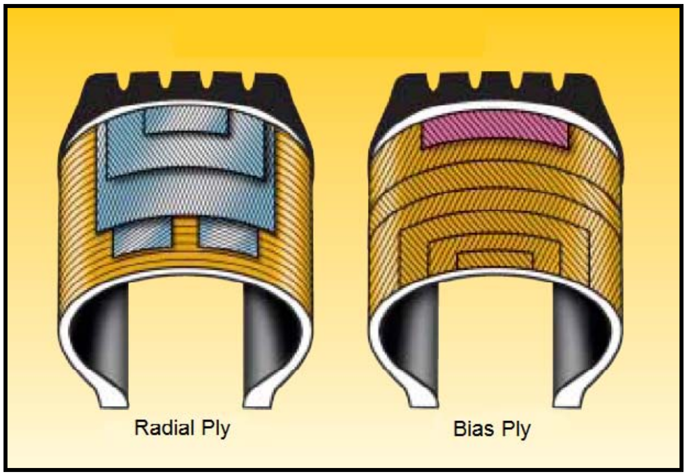

Figure 7: Radial Ply versus Bias Ply Tire Casing (adapted from [16])

2.3.3 *LRR Tire Traction*

An important consideration regarding LRR tires is that there is an unknown relationship between rolling resistance and other factors such as traction and braking performance. The methods employed to achieve lower rolling resistance in a tire could affect other performance parameters. Tires designed for optimal mud or snow traction often have deeper tread depths, more voids and tread grooves, sipes, lug patterns, and softer compounds. LRR tires stray away from these tire characteristics and often focus on rib patterns and shallow tread depths in order to achieve lower rolling resistance. A comparison between a high-traction (snow/mud/hill) drive tire and a LRR drive tire can be seen in Figure 8.

Figure 8: Comparison between High-Traction Drive Tire and LRR Drive Tire

To improve traction, LRR tire tread designs often include siping (thin slits across a rubber surface to improve traction in wet or icy conditions), and sometimes have unique groove patterns and open-shoulder designs for water, snow and mud dispersion (see Figure 8 for an illustration of these design features). A balance must be realized between the lowest practical rolling resistance and tire traction, to maintain vehicle performance and safety.

2.3.4 *Fuel-Saving Potential*

The fuel-savings potential of HD LRR tires can be expressed in three ways:

(1) a percentage of fuel savings;
(2) a percentage reduction in rolling resistance; and
(3) a reduction in the coefficient of rolling resistance, C_{rr}.

There are various factors that contribute to each of these measures, therefore, it is sometimes difficult to directly compare one measure to another. However, there is a distinct relationship between all three, as demonstrated below.

Most research shows that HD LRR tires can achieve a fuel savings between 4% and 11% [7], [11], [19], when installed on all three axle groups of a tractor-trailer. Based on the estimated power consumption values presented in Table 1, this fuel-savings range translates to a 9% and 26% reduction in rolling resistance, at a speed of 80 km/h. Using the baseline C_{rr} values from Section 2.2 for each axle group (Steer: 7.8 N/kN, Drive: 8.2 n/kN and Trailer: 6.5 N/kN), this rolling resistance reduction range translates to the following C_{rr} values:

- Steer: 7.1 N/kN to 5.8 N/kN;
- Drive: 7.5 N/kN to 6.1 N/kN; and
- Trailer: 5.9 N/kN to 4.8 N/kN.

3 Apparatus

3.1 Test Vehicle

The vehicle used to test the drive position tires was a class-8 tractor supplied by Penske Leasing. The stock tires that were equipped on the vehicle did not form part of the test articles. The stock tires were only used to drive the tractor-trailer to the test facility and return to NRC-ST. Selected details of the test tractor are as follows:

- Make: Freightliner
- Cab Type: Sleeper
- Engine: Detroit Diesel, 14 l displacement, 455 hp
- Transmission: Eaton 10 speed automatic

The trailer used to test the trailer position tires was supplied from Trailcon leasing. The stock tires that were equipped on the vehicle did not form part of the test articles. The stock tires were only used to drive the tractor-trailer to the test facility and return to NRC-ST. Selected details of the test trailer are as follows:

- Make: Great Dane
- Length: 53 ft dry van body
- Axle/Suspension configuration: Tandem slider, air ride
- Axles: Hendrickson HITRAAX, 77.5 in track, HP (straight) spindles
- Tires: Continental HTL-1 wide-based singles, aluminum 2" offset wheels

Both the tractor and trailer were thoroughly inspected by ST heavy vehicle mechanics to ensure that the vehicle was suitable for testing purposes. Any remedial action required was performed by the respective leasing companies or their authorized agents before releasing the test vehicle for instrumentation.

3.2 Instrumentation

The instrumentation necessary for the tests was installed by NRC-ST, procuring or manufacturing brackets and adapters as required. As a minimum, the instrumentation listed in Table 2 was installed on the tractor-trailer.

Table 2: Instrumentation

Parameter	Units	Sensor	Location
Forward Speed	km/h	GPS Speed Sensor (with built-in accelerometers)	CG of Tractor
Longitudinal Acceleration	g		
Lateral Acceleration	g		
Yaw Rate	°/s	Yaw Rate Sensor	CG of Tractor
Longitudinal Acceleration	g	Inertial Measurement Unit	CG of Trailer
Lateral Acceleration	g		
Yaw Rate	°/s		
Steering Wheel Angle	°	String Potentiometer	Steering Column
Throttle Pedal Travel	mm	Rotary Potentiometer	Vehicle network
Brake Pedal Travel	mm	String Potentiometer	Brake Pedal
Articulation Angle	°	String Potentiometer	Kingpin
Engine Speed	rpm	Tachometer	Vehicle network
Indicated Vehicle Speed	km/h	Rotary Speed Sensor	Vehicle network

A heads-up display was connected to the GPS speed sensor to present the GPS speed to the driver.

Other data items available on the vehicle data network were also recorded, but not listed here. These include items such as intake air temperature, manifold absolute pressure, boost pressure, transmission selected/requested gear, etc. All vehicle network data was accessed using the vehicle's J1587 data port connection.

Figure 9: IMU Installation

Since testing was conducted with the trailer in a loaded and unloaded configuration, the inertial measurement unit (IMU) mounted in the trailer was moved as required to the appropriate CG location for the trailer. The IMU location for the loaded and unloaded configuration was marked on the floor of the trailer. Figure 9 shows the installation of the IMU in the ballasted trailer.

3.3 Data Acquisition

The data acquisition system was installed inside the cab of the tractor. The system consisted of a laptop, a data acquisition system, software and appropriate cables, connectors and a power supply. Data acquisition was started and stopped manually for each test, and data was captured at 200 Hz. The data acquisition system had a quick-look capability so that the test engineer could review the results of each run to determine whether the objectives for that run were accomplished. Data from each run was captured into memory, and then saved on the laptop hard drive. Data was archived onto a back-up storage media at the end of each test day.

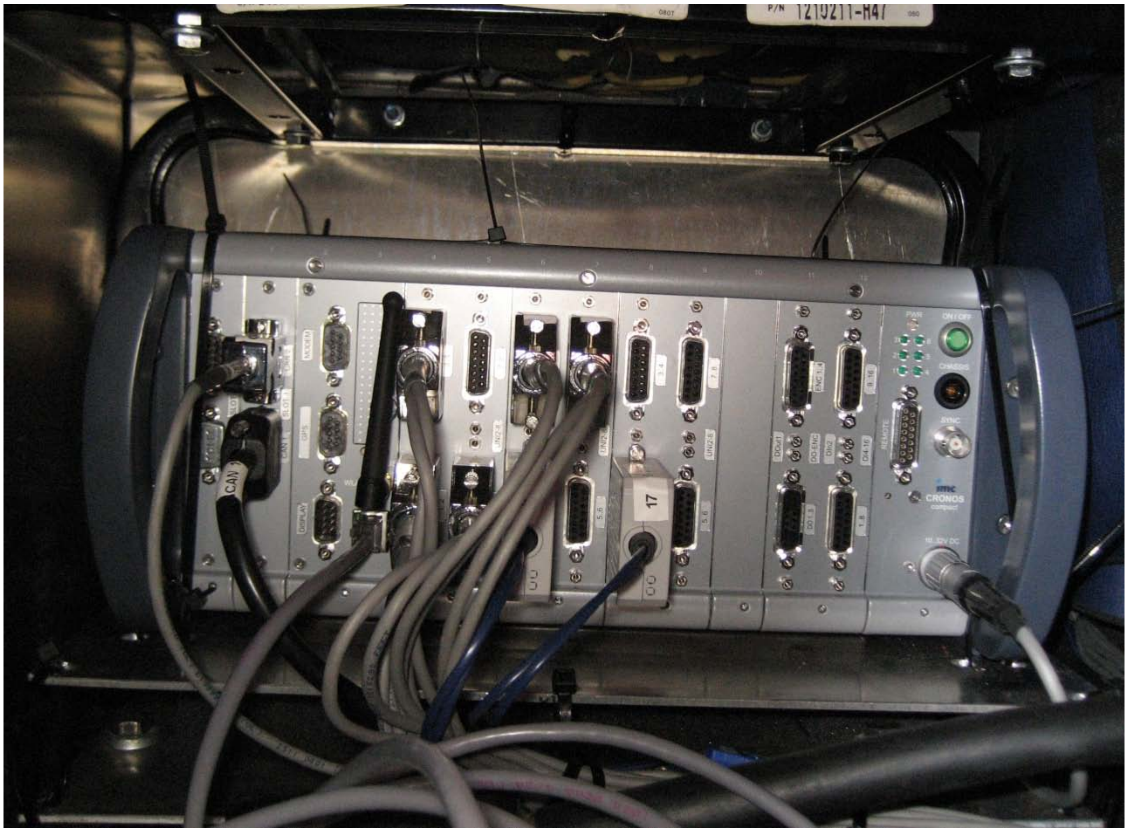

Figure 10: Data Acquisition Unit Installation

Figure 10 shows the installation of the data acquisition unit in the tractor trailer. It was secured to the structure of, and located underneath, the passenger seat.

3.4 Ballast Configuration

The trailer was loaded with ballast totalling approximately 21 000 kg. Figure 11 shows the ballast installed in the trailer, along with the wood blocking used to secure the ballast and prevent it from shifting. The total mass of the ballast was not the primary governing parameter; the primary goal was to distribute enough ballast throughout the trailer such that the individual axle loads (one steer, two drive, and two trailer) would not exceed permissible limits.

For operations in the province of Ontario, the permissible axle limits for drive and trailer positions equipped with dual tires is 9 550 kg, however this trailer was equipped with wide-based single tires for transit to and from the test facility and the load limit for wide-based tires is 9 000 kg. Table 3 shows the axle load distribution with the trailer ballasted. The supplied tires would be changed to the test tires once on site. The tractor was equipped with dual tires and could have been loaded to 9 550 kg per axle, however, this tractor was also to be used for testing of wide-based and so loading had to be limited to less than 9 000 kg per axle.

Figure 11: Ballast Installation

The axle loads were verified at the ST facility using drive-on wheel scales and the ballast positions were marked to facilitate removal and replacement during testing. Once the final location of the ballast was determined, wooden blocking in the form of 2x10 dimensional lumber was used to secure the ballast and prevent shifting. The blocking was also constructed in such a way so as to allow removal and replacement without major disassembly, making the loading/unloading process more efficient.

Table 3: Axle Load Distribution

Axle Position	Load (kg)
Steer	5 170
Drive 1	7 159
Drive 2	7 605
Trailer 1	7 745
Trailer 2	8 755
Total	**36 434**

4 Test Procedure

4.1 Laboratory Testing

4.1.1 Test Site

NRC-ST contracted Smithers-Rapra of Ravenna, OH to provide testing services in order to measure rolling resistance (SAE J1269 and ISO 28580) and accelerated durability (FMVSS 119) of the selected test tires. Additionally, Smithers also performed snow traction performance (ASTM F1805) measurement at their Raco, MI facility.

4.1.2 On-site Preparations

The tire sets were shipped from various tire supplier warehouses to Smithers, and were conditioned as required prior to testing by Smithers. All preparations to equipment and/or tires prior to testing was the responsibility of Smithers. The NRC-ST Test Engineer audited the site to ensure that the tests were performed in a consistent and repeatable manner.

4.1.3 Test Articles

Transport Canada purchased the test tires and arranged for their shipment to Smithers. Any tire older than five years old, as indicated by the manufacturing date code, was rejected as a test tire. No wheels were required. Additionally, at the conclusion of testing, Transport Canada has arranged to have the test tires disposed of in a manner consistent with appropriate environmental procedures.

Table 4: Drive Tire Test Population

ID	Smart Way	Size	Tread Depth (/32”)	Shoulder	Remarks
A	YES	295/75R22.5	26	Closed	(visually similar to J)
B	YES	295/75R22.5	26	Closed	
C	YES	275/80R22.5	26	Closed	
E	YES	275/80R22.5	28	Closed	
F	NO	275/80R22.5	30	Closed	
H	NO	275/80R22.5	32	Closed	
J	NO	295/75R22.5	29	Open	(visually similar to A)
K	YES	295/75R22.5	30	Closed	
M	NO	295/75R22.5	30	Open	
N	NO	275/80R22.5	27	Open	

Drive tires A and J had visually similar tread patterns, differing only in the shoulder detail of the tire. Tire J had transverse grooves in the shoulder, but these grooves were not the full depth that would be normally found in a classic open shoulder design. As a result, as a new tire J wears, the shoulder would eventually become closed prior to the tread life being exhausted.

The tires selected for testing were outlined in the market scan report previously submitted as a deliverable for this project. The list of selected tires (Table 4 and Table 5) is reproduced here for reference; readers interested in the selection methodology are advised to consult the document that was delivered to Transport Canada in November 2011.

For the purposes of reporting, all mention of tire manufacturer and branding was removed and tires were referred to only by an assigned ID letter. This ID letter was assigned sequentially, while avoiding the letters that could be mistaken for numbers; namely: I, L, O, S, Q, and Z.

Table 5: Trailer Tires Test Population

ID	Smart Way	Size	Tread Depth (/32”)	Shoulder	Remarks
A	YES	295/75R22.5	19	Closed	All-position / Steer
B	YES	295/75R22.5	12	Closed	
C	YES	275/80R22.5	16	Closed	All-position / Steer
D	YES	275/80R22.5	13	Closed	
E	YES	295/75R22.5	11	Closed	
F	NO	275/80R22.5	16	Closed	
P	NO	295/75R22.5	11	Closed	
R	NO	295/75R22.5	18	Closed	All-position / Steer

ID letters A through F inclusive were reused for trailer and drive tires for the purposes of the vehicle based tested that took place. Each drive tire was matched with a trailer tire from the same brand to create a test tire configuration for the complete tractor-trailer unit. Each tire configuration (drive + trailer) for the test vehicle could be described by using the ID letter for each position, e.g. configuration C/D had tire drive tire C in the drive position and trailer tire D in the trailer position.

Three samples of each tire model listed were required: one each for rolling resistance, durability, and snow traction.

4.1.4 **Laboratory Test #1: Rolling Resistance Measurement**

This test was based on the procedures outlined in SAE J1269 and ISO 28580 and is summarized here in a high level overview.

4.1.4.1 Purpose

The purpose of this test was to determine the rolling resistance coefficient of a tire under load; tires with high rolling resistance require more energy to move a given load and have a direct influence on fuel consumption.

4.1.4.2 Setup

The prescribed setup is detailed in the relevant standards; any preconditioning of the tires was performed as per the individual test standards. This test involves mounting a tire on a wheel, running the assembly under load against a rolling drum, and varying the load and measuring the effort required to continue driving the drum or tire assembly.

4.1.4.3 Apparatus

For SAE J1269, there are three different setups for measuring rolling resistance, depending on the desired measurement quantity: force, torque, or power. Depending on the desired results, each apparatus is slightly different as the instrumentation locations and types change to reflect the monitored parameters. ISO 28580 is substantially similar in term of apparatus and setup. For the purposes of this project, the apparatus was configured to measure force.

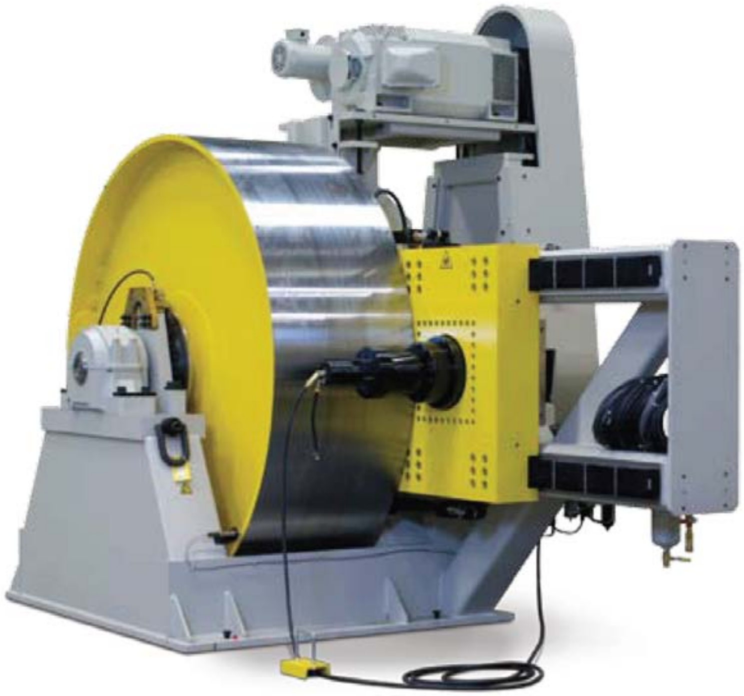

Figure 12: Rolling Resistance Apparatus (MTS Corp)

Figure 12 shows an example of the apparatus that was used to measure rolling resistance. For rolling resistance measurement, the drum surface was covered in 80-grit sandpaper (not shown).

4.1.4.4 Procedure

The procedure for rolling resistance testing is governed by SAE J1269 or ISO 28580, however the salient parts are highlighted below.

- Tires were mounted on the test rig and inflated to their proper pressure;
- Tires were subjected to varying load while running and the efforts to keep them rolling were measured;
- Tire inflation pressure was monitored and depending on the test sequence, the pressure was adjusted to compensate for pressure rise due to frictional heating or allowed to rise as in normal operation; depending on the test sequence; and
- ISO 28580 was run at a single load and speed, with inflation capped. This contrasts with SAE J1269 which was run at different loads and with a regulated inflation pressure.

4.1.4.5 Data Analysis

Smithers provided test data and also provided an average rolling resistance coefficient for each tire. The rolling resistance coefficient was reported as resistance per unit load.

4.1.4.6 Data Presentation

The rolling resistance for each tire (as supplied by Smithers) was compiled into a table and then plotted against one another to show the relative difference in rolling resistance.

4.1.5 **Laboratory Test #2: Durability**

4.1.5.1 Purpose

The purpose of this test is to determine the durability or endurance life of the tire in question under accelerated conditions, using the procedures laid out in FMVSS 119. Additionally, FMVSS 119 does not provide any model by which the expected life of the tire can be estimated based on the results of this test; the only conclusion that may be inferred from passing FMVSS 119 is that the tire is suitable for highway use under the intended application and loading.

4.1.5.2 Setup

Each tire was pre-conditioned prior to the start of testing per FMVSS 119 requirements. The actual test commenced once the tire completed this pre-conditioning stage.

4.1.5.3 Apparatus

Generally, the apparatus consisted of a load frame capable of loading the tire to at least 114% of the tire's rated load, as indicated by the manufacturer on the tire's sidewall (for FMVSS 119). The apparatus looked substantially as shown in Figure 12. Unlike rolling resistance measurement where the drum surface was covered in sandpaper, for durability testing the drum was left as bare metal.

4.1.5.4 Procedure

The procedure for tire durability testing is governed by FMVSS 119, however the salient parts are highlighted below.

- Each tire was mounted on a test wheel and inflated to a pressure corresponding to the tire's maximum permissible load.
- The tire was pre-conditioned by running under moderate load and moderate speed for approximately 3 hours at an ambient temperature of 35 °C.
- After pre-conditioning, the inflation pressure was measured and within 30 minutes of the end of pre-conditioning the actual test must begin.
- The test tire was run at a constant speed (150 rpm) with the load progressively increasing in three discrete steps. Each new load was held for a specific period of time that correlates to particular to a class of tire. For heavy truck tires, the loads were 66% for 7 hours, 84% for 16 hours, and 101% for 24+ hours. The total runtime was a minimum of 47 hours for each test. All loads are percent of rated maximum as indicated on the sidewall of the tire.
- Once the minimum 47 hours elapsed, the load was progressively increased by 10% every 8 hours until the destruction of the tire; which was estimated to occur at approximately 80 hours.

4.1.5.5 Data Analysis

FMVSS 119 does not specify that tires must be tested until destruction, only that the tires must survive for a minimum of time with no outward defects in order to be classified as roadworthy. However, once the prescribed procedure for FMVSS 119 is completed and the tires are tested to failure, then certain broad generalizations may be made.

4.1.5.6 Data Presentation

The test data was compiled into a table that lists the total run time that each tire was subjected to during the endurance test. Additionally, any notable observations before, during, or after the test was also reported.

4.1.6 **Laboratory Test #3: Snow Traction**

4.1.6.1 Purpose

The purpose of this test is to determine the tractive ability of a tire when driving over snow or snow covered roads. For passenger car and light truck tires, ASTM F1805 defines the test procedure for determining the relative snow traction of those tires. For heavy trucks, ASTM F1805 forms the basis for the test procedure; however the procedure has been modified by Smithers to better reflect the dynamics at tire-ground interface encountered in heavy truck applications.

4.1.6.2 Setup

A single tire was mounted on a wheel then fixed to a specially prepared test tractor designed to maintain a constant low speed and measure the tractive effort of a single tire. A variety of instrumentation measures the pertinent parameters and records them with a data acquisition system.

4.1.6.3 Apparatus

The equipment for this test consisted of a specially modified and instrumented class 8 tractor that Smithers owns and maintains (Figure 13). The drivetrain was modified such that only one side of one drive axle is driven, all others freewheel. The instrumentation measures the tractive effort generated by the single driven tire. The vehicle is maintained at a steady state low speed through the application of brakes on the freewheeling tires. The test surface was regularly groomed to maintain a medium pack snow surface.

Figure 13: Snow Traction Apparatus (Smithers)

4.1.6.4 Procedure

The procedure for snow traction testing is governed by ASTM F1805; however ASTM F1805 is intended to measure traction for passenger vehicle tires. Smithers has adapted the concepts in F1805 for heavy truck applications; modifying the procedures where applicable. The salient parts of this test are highlighted below.

- New tires were broken in by driving on them for approximately 100 km then mounted in the driving position of the test rig.
- The test rig was driven at low speed with constant wheel slip of ~8 km/h. The service brakes on the remaining wheel positions and throttle were modulated to maintain this slip speed.
- On-board instrumentation records appropriate parameters such as wheel speed, ground speed, torque, etc.
- A control tire was selected from among the test population and all the results were normalized against it. The control tire was tested multiple times throughout the test program in order to account for surface variability.
- Snowpack was maintained at a medium pack consistency, as defined by F1805.

4.1.6.5 Data Analysis

The test yields tractive effort of a tire (force), with the results normalized against a control tire. This control tire was selected from the test population with the assistance of Smithers in determining a suitable candidate. The overall test population was divided into drive and trailer position tires, with a suitable control tire selected from each subset.

4.1.6.6 Data Presentation

The various tractive efforts generated by each tire were compiled into a chart for reference. The relative tractive ability of each tire was normalized against a control tire, thus making comparison easier.

4.1.7 **Deviations**

For the laboratory based testing portion of this report there were no deviations from the test plan.

4.2 Vehicle Based Track Testing

4.2.1 **Test Articles**

Table 6 shows the selected test population for the vehicle based testing portion of this project. The selected tires were grouped into a test configuration which consisted of a complete change of drive tires and trailer tires. The tires were grouped by manufacturer where possible, to reflect the preferences of a typical fleet operator. All of the selected tires were listed on the SmartWay verified technologies list at the time the testing was performed.

Table 6: Tire Population for Vehicle Testing

Configuration	Drive Tire	Trailer Tire
A/A	A	A
B/B	B	B
C/C	C	C
C/D	C	D
E/E	E	E
F/F	F	F

Tire test configuration F/F consisted of non-SmartWay verified drive and trailer tires and represents the baseline configuration for the braking and turning tests.

All test configurations were broken in by operating them for approximately 100 km at highway speeds. The breaking in process was performed by ST vehicle mechanics around the Ottawa area on local highways.

4.2.2 **Test Site**

NRC-ST had determined that the General Motors Cold Weather Development Center (GMCWDC), located at Kapuskasing, ON, was the most suitable venue for the required tests. GMCWDC is a privately managed test and research centre which NRC-ST has contracted for the use of the facility, and certain support services including track preparation (snow plowing and grooming).

GMCWDC provided access to a suitable garage and shop equipment to facilitate storage and installation of tires. The garage was at least 69 ft long to accommodate the connected tractor-trailer unit, test tires were stored outdoors on pallets. GMCWDC also had a forklift available, and access to a suitable loading dock or ramp, to facilitate the loading and unloading the trailer.

4.2.3 **On-site Preparations**

The test tires, shipped from Ottawa to GMCWDC via third party shipper, were removed from the shipping container and stored outdoors (at ambient temperature).

Cones or other markers were positioned as required before each test, and were removed after the test. GMCWDC provided assistance with track preparations (snow plowing and/or grooming) as required.

NRC-ST mechanics installed the appropriate tire configuration for each series of tests, and removed and installed ballast as required.

4.2.4 **Vehicle Based Track Test #1: Straight-Line Braking Test**

This test was based on the SAE J299 Stopping Distance Test Procedure standard [4]. It was performed with both a loaded and unloaded trailer.

4.2.4.1 Purpose

The purpose of this test is to determine the distance required for the tractor-trailer to decelerate from a specified nominal velocity of 65 km/h to 0 km/h and to observe the tractor-trailer trajectory under braking. The actual terminal velocity may be lower in practice, depending upon conditions, tire performance, and available test area.

4.2.4.2 Setup

All operating components and adjustments likely to influence test results were inspected to ensure that they meet the manufacturer’s specifications. All components were properly adjusted and secured, all instrumentation and ballast were secured for safety and to prevent shifts in vehicle loading or center of gravity. During warm-up, the brakes were cycled several times to ensure that the brakes were functioning properly.

4.2.4.3 Apparatus

The instrumentation was installed as outlined in Table 2. Traffic cones were set up to mark the test course as required. The test track at GMCWDC was shared with the Kapuskasing airport's general aviation airstrip. During the winter, the field adjacent to the general aviation airstrip is converted into a snow field for snow testing. Figure 14 shows a schematic of the typical traffic flow on the test track for the braking test. The gray rectangle represents the paved airstrip. The snowfield is immediately adjacent to the airstrip.

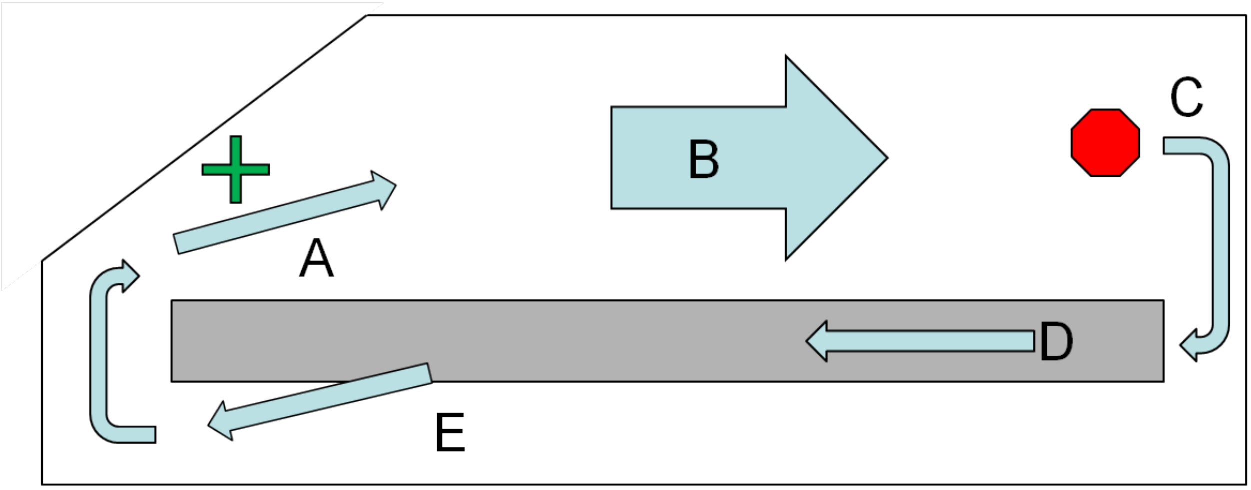

Figure 14: Braking Test Traffic Flow (Schematic)

4.2.4.4 Procedure

- With the vehicle fully instrumented and all tires and drive-train warmed up, the vehicle was driven down the test track and turned around to allow for a rolling start;
- As the vehicle exited the final turn into the test section of the track, the driver executed a maximum effort acceleration (Figure 14, "A") to achieve a velocity of approximately 5-8 km/h above the nominal test speed of 65 km/h, as indicated by the GPS heads-up display;
- The driver then released the throttle and immediately applied the service brakes fully, allowing the ABS system to activate (Figure 14, "B").
- The driver attempted to maintain the vehicle heading in a straight line, during the entire braking event.
- The driver monitored the response of the tractor-trailer, ensuring that a fishtail or other dangerous situation did not occur. The driver maintained the brake application until the tractor-trailer came to a complete stop (Figure 14, "C");
- The stopping distance measurement was GPS based;
- The driver was asked to comment on the vehicle's behaviour;
- After reaching a complete stop, the data from the run were examined to ensure the test was valid, the driver was instructed to return for another test run (Figure 14, "D"); and
- If the data from the run was not satisfactory or the tractor-trailer experiences any loss of control, it was noted and the test was either repeated or aborted.

4.2.4.5 Data Analysis

The data was analyzed to determine the total braking distance over each test run, and an average braking distance for the two test runs at each terminal velocity. If it was determined that the driver braked too early or too late for any particular test run, the run was removed from the data set. Longitudinal and lateral acceleration, yaw rate, steering wheel angle and wheel slip were also monitored and documented.

4.2.4.6 Data Presentation

Graphs of stopping distance and speed versus time were presented in order to quantify the braking performance of each of the sets of tires. Data were also presented in a tabular format, showing the braking distance for each run. Any significant operator feedback was also included.

4.2.5 **Vehicle Based Track Test #2: Low Speed Turning Traction Test**

4.2.5.1 Purpose

The low speed turning traction test assesses the ability of the tractor-trailer to maintain the desired course on a simulated highway exit ramp.

4.2.5.2 Setup

All operating components and adjustments likely to influence test results were inspected to ensure that they met the manufacturer's specifications. All components were properly adjusted and secured. All instrumentation was secured for safety and to prevent shifts in vehicle loading or center of gravity.

4.2.5.3 Apparatus

The instrumentation was installed as outlined in Table 2. Traffic cones were set up as required to mark the test course as shown in Figure 15. According to the Geometric Design Guide for Canadian Roads [6], the minimum turn radius for a speed of 30 km/h, on a level surface, and with a lateral friction force factor of 0.31 is 22.87 m. A turn radius of 23 m for a 180° turn was used to evaluate the turning traction of the tractor-trailer with all tire configurations at various speeds. The tractor was equipped with a traction control system and the system was engaged to assist the driver in minimizing wheel slip.

Figure 15: Typical Turning Test

Figure 16 shows the typical traffic flow on the test track for the turning test. All the turning tests started on the paved portion of the airstrip and turned off onto the snow field for the actual turning test. At each speed, the same U-shaped portion was used for all runs. A new U-shaped portion was laid out for each speed and for each tire configuration.

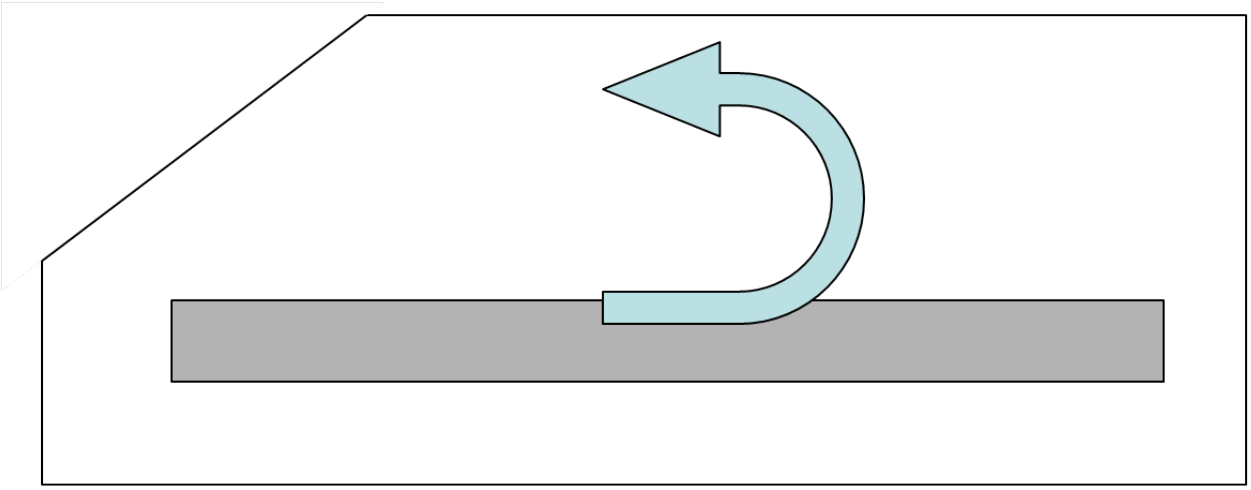

Figure 16: Turning Test Traffic Flow (Schematic)

4.2.5.4 Procedure

- After a suitable warm-up period, the test vehicle was driven to the starting position;
- The Data Acquisition System and video camera were started;
- The driver was signaled to begin the test run;
- The tractor-trailer was driven in a straight line to attain the desired test speed;
- The driver attempted to maintain the test speed and follow the course of the simulated ramp indicated by the cones. The driver was to monitor the response of the tractor-trailer, ensuring that a fishtail or other dangerous situation did not occur;
- Once the turn was completed, the driver straightened out the tractor-trailer and came to a complete stop;
- After reaching a complete stop, the data from the run were examined to ensure the test was valid, the driver was instructed to return for another test run;
- The path of the tractor-trailer was observed during the manoeuvre and recorded on video;
- The procedure was conducted a total of three times for each speed increment (20 km/h, 25 km/h, 30 km/h, 35 km/h, and 40 km/h) or until turning traction is lost; and
- The driver was also asked to comment on the vehicle's behaviour.

4.2.5.5 Data Analysis

The results of the turning test were mostly visual. However, longitudinal and lateral acceleration, yaw rate, steering wheel angle and wheel slip were monitored and documented.

4.2.5.6 Data Presentation

Test results were primarily visual and were distilled down to pass/fail at each test speed.

4.2.6 **Deviations**

4.2.6.1 Straight-line Braking Deviations

The straight-line braking test procedure was altered from the procedure originally specified in the test plan for the following reasons:

- Starting condition was changed to rolling starts due to an inability to safely achieve the originally specified speed of 70 km/h (plus overage) from a standing start due to the limited length of the test track
- Target speed was changed to 65 km/h (plus overage) for both loaded and unloaded states also due to the limited length of the track

4.2.6.2 Turning Test Deviations

The turning test procedure was altered from the procedure originally specified in the test plan for the following reasons:

- The test speed increments were changed to better determine the threshold of traction
- The turning angle was increased to 180° as past experience had shown that the events of interest from lost traction tended to occur around 120° into the turn.

All turning tests were performed in the unloaded state. The original test procedure implied, but did not explicitly state, that the turning test would be performed with the trailer loaded. However, it was only ever the intention to perform the turning test with the trailer unloaded.

4.2.6.3 Other Deviations

Snowpack temperature was not measured due to equipment malfunction. Ambient temperature was recorded before and after each test configuration as well as being monitored by on-board equipment.

5 Results

5.1 Laboratory Testing Results

5.1.1 Rolling Resistance

5.1.1.1 General Comments

Two test methods were used to measure the rolling resistance of the test tires, SAE J1269 and ISO 28580. The primary difference between the two methods is the number of data points used to determine rolling resistance. Additional differences include the load on the tire and the regulation of tire pressure during testing. From the test results, the ISO method results in slightly lower rolling resistance coefficients in terms of absolute numbers, but the results from the SAE and ISO methods do agree well. In terms of percentages, the results of the SAE and ISO methods are between 3-10 % of each other. Given the fact that only one of each tire model was tested, the results of the SAE and ISO methods do not appear to differ widely from each other.

5.1.1.2 Drive Tire Rolling Resistance

The results from laboratory testing showed that drive tires marked as SmartWay verified have lower rolling resistance than non-SmartWay verified tires. This is based on the average rolling resistance measurement for LRR tires and the average for non-LRR tires for the driving position (Table 7).

Table 7: Average Rolling Resistance

	SmartWay verified	non-SmartWay verified	Change
Average Rolling Resistance (SAE)	6.93	9.81	- 29 %
Average Rolling Resistance (ISO)	6.41	9.08	- 29 %

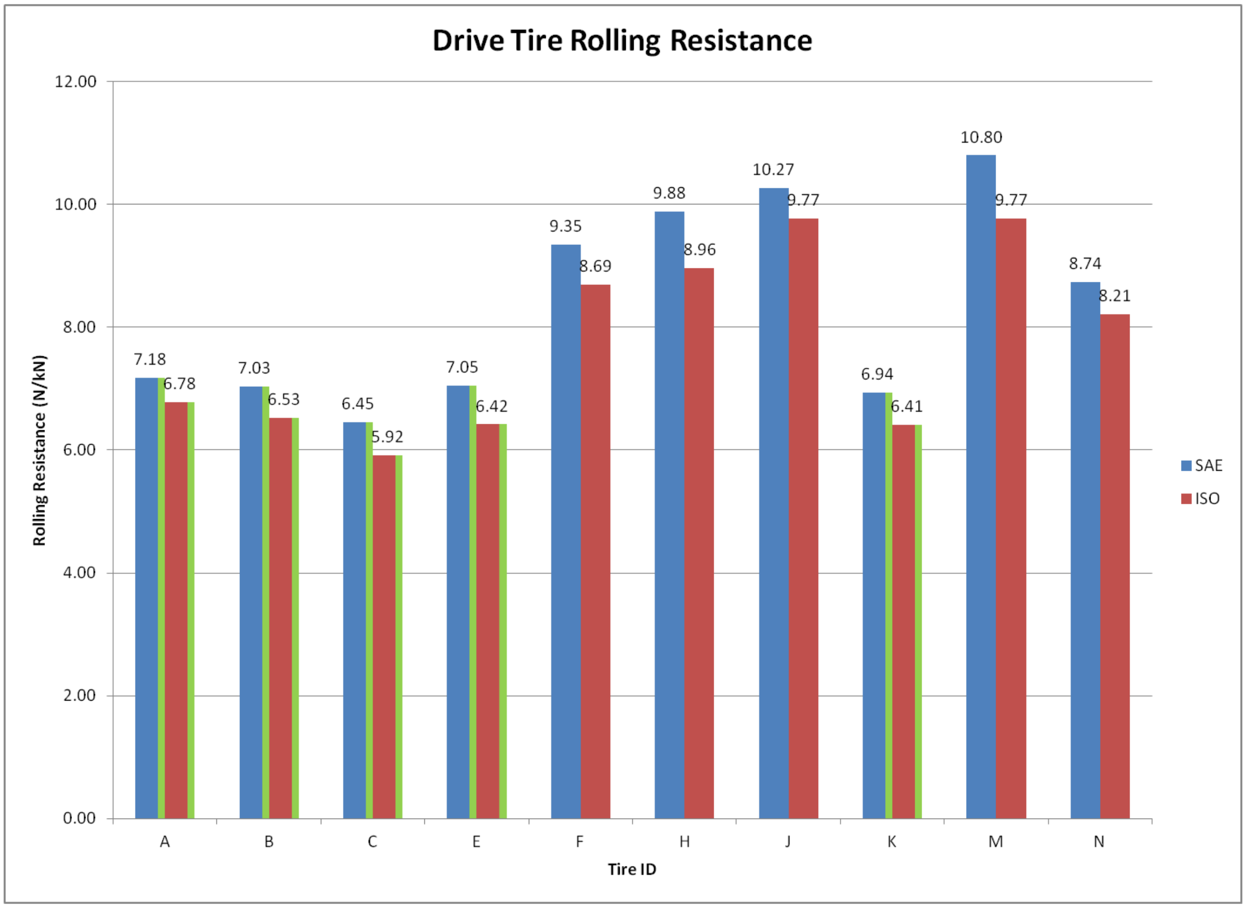

Figure 17: Rolling Resistance, Drive Tires

Figure 17 shows the individual results from the rolling resistance measurement, tires that are SmartWay verified have their bars accented with a narrow green stripe to the right of their respective bars. The results from the two different test methods are shown together for each sample tire for comparison. The blue bars represent the SAE five-point test method and the red bars represent the ISO test method. Notice that all the LRR tires have a significantly lower rolling resistance than their non-LRR counterparts.

5.1.1.3 Trailer Tire Rolling Resistance

In Figure 18, tires that are SmartWay verified have their bars accented with a narrow green stripe to the right of their respective bars. The results from the two different test methods are shown together for each sample tire for comparison. The blue bars represent the SAE five point test method and the red bars represent the ISO test method.

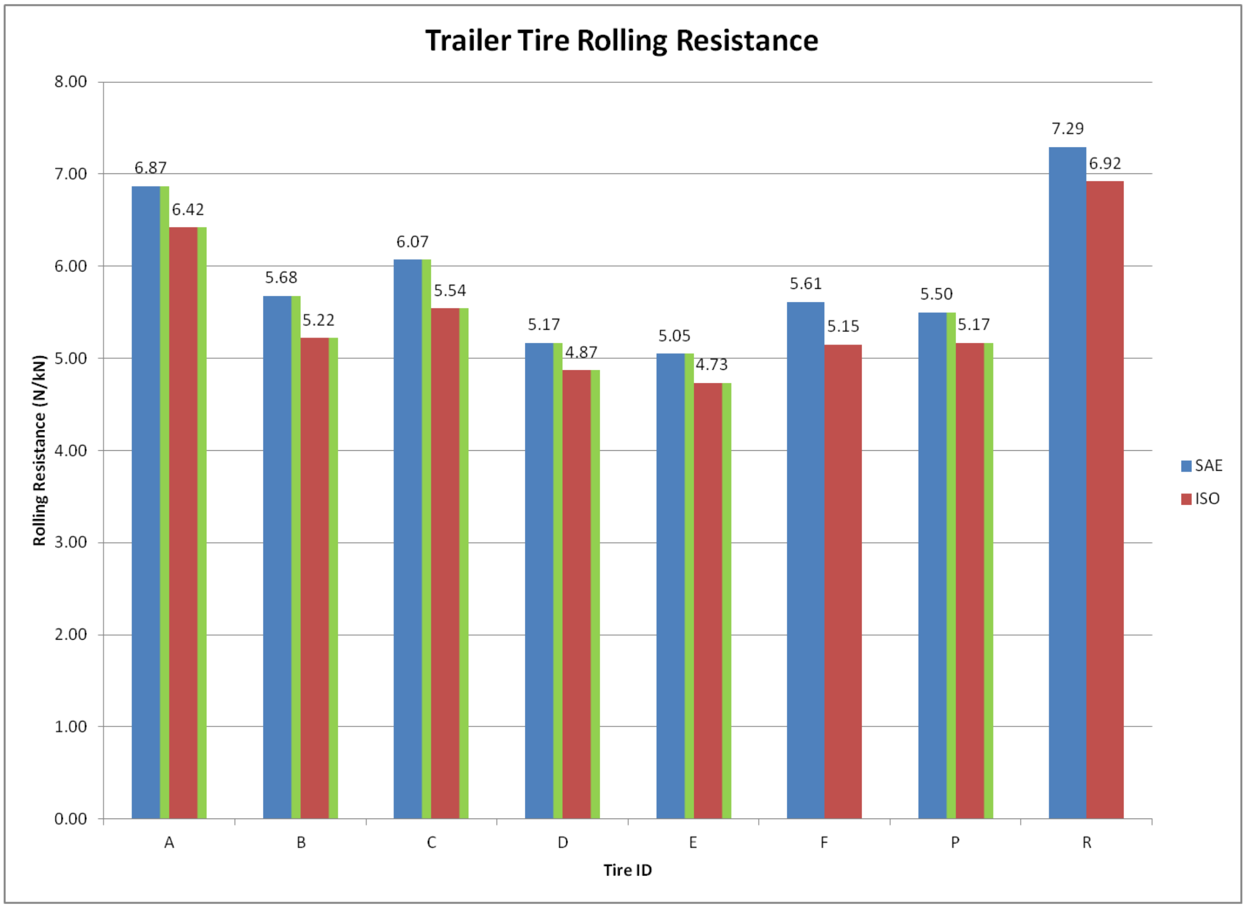

Figure 18: Rolling Resistance, Trailer Tires

There was an inconsistency in the results with tires A and F. Tire A is a SmartWay verified tire but has a higher rolling resistance value than Tire F, which is a non-SmartWay verified tire. The respective tire manufacturers were contacted for an explanation and their responses are included in the discussion section.

5.1.2 **Durability**

5.1.2.1 General Comments

The US FMVSS 119 specifies that tires designed for on-highway use must meet minimum durability standards. FMVSS 119 also details three different methods by which this durability can be measured, one of which is the endurance method which continually rolls the tire on a test stand. Tires using the endurance method of durability qualification must undergo a minimum of 47 hours on a rolling test frame under a specific speed and load schedule.

5.1.2.2 Drive Tire Durability

In Figure 19, tires that are SmartWay verified have their rolling resistance values plotted with green bars, the non-LRR tires are represented by blue bars. The line marked "min pass" indicates the minimum 47 hours required by FMVSS 119 to be considered roadworthy.

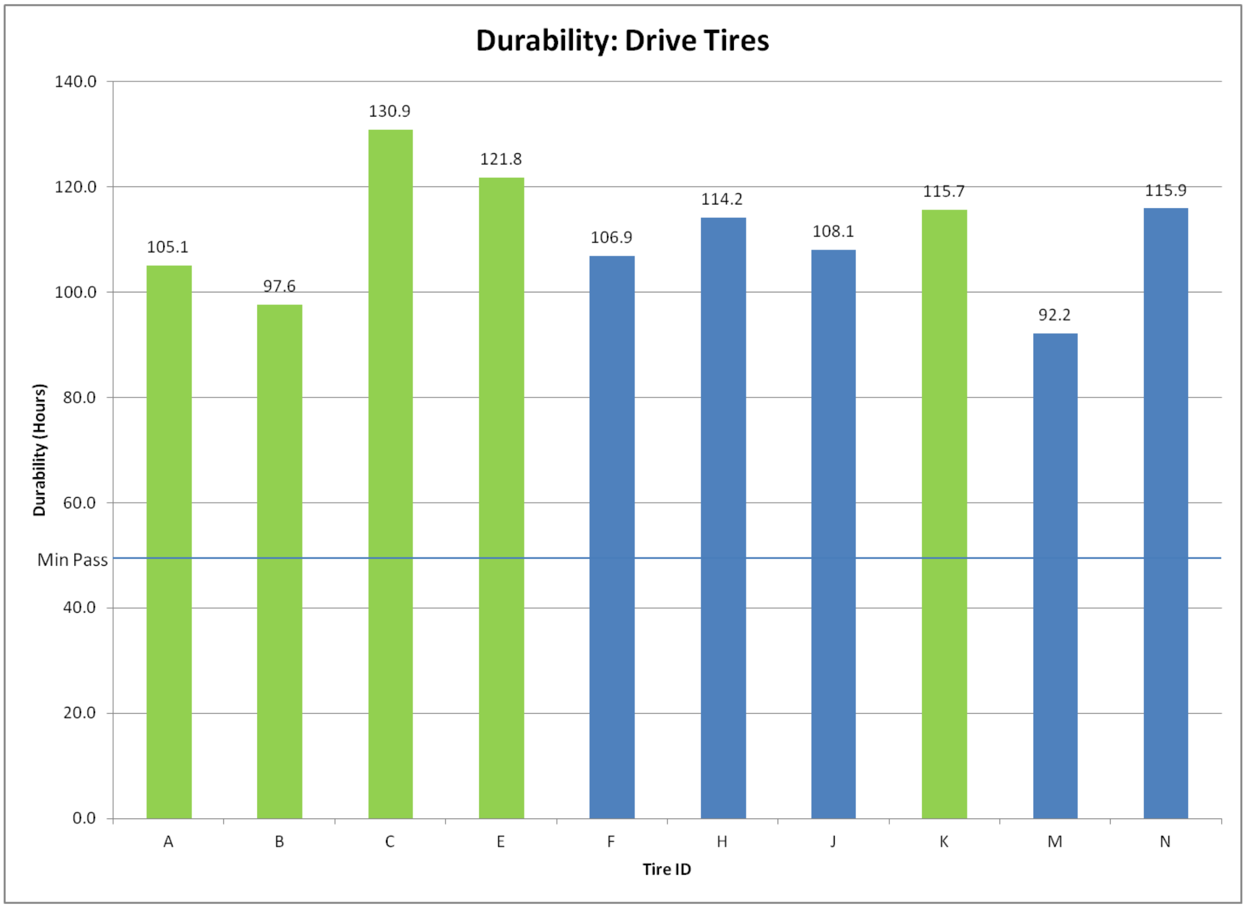

Figure 19: Durability, Drive Tires

For drive tires, SmartWay verified status does not appear to influence the strength and durability of a tire. From the test population, a SmartWay verified tire lasted the longest, a non-SmartWay verified tire lasted the shortest. The rest of the tire population was well distributed with no apparent pattern or bias.

5.1.2.3 Trailer Tire Durability

In Figure 20, tires that are SmartWay verified have their durability in hours plotted with green bars, the non-LRR tires are represented by blue bars. The line marked "min pass" indicates the minimum 47 hours required by FMVSS 119 to be considered roadworthy.

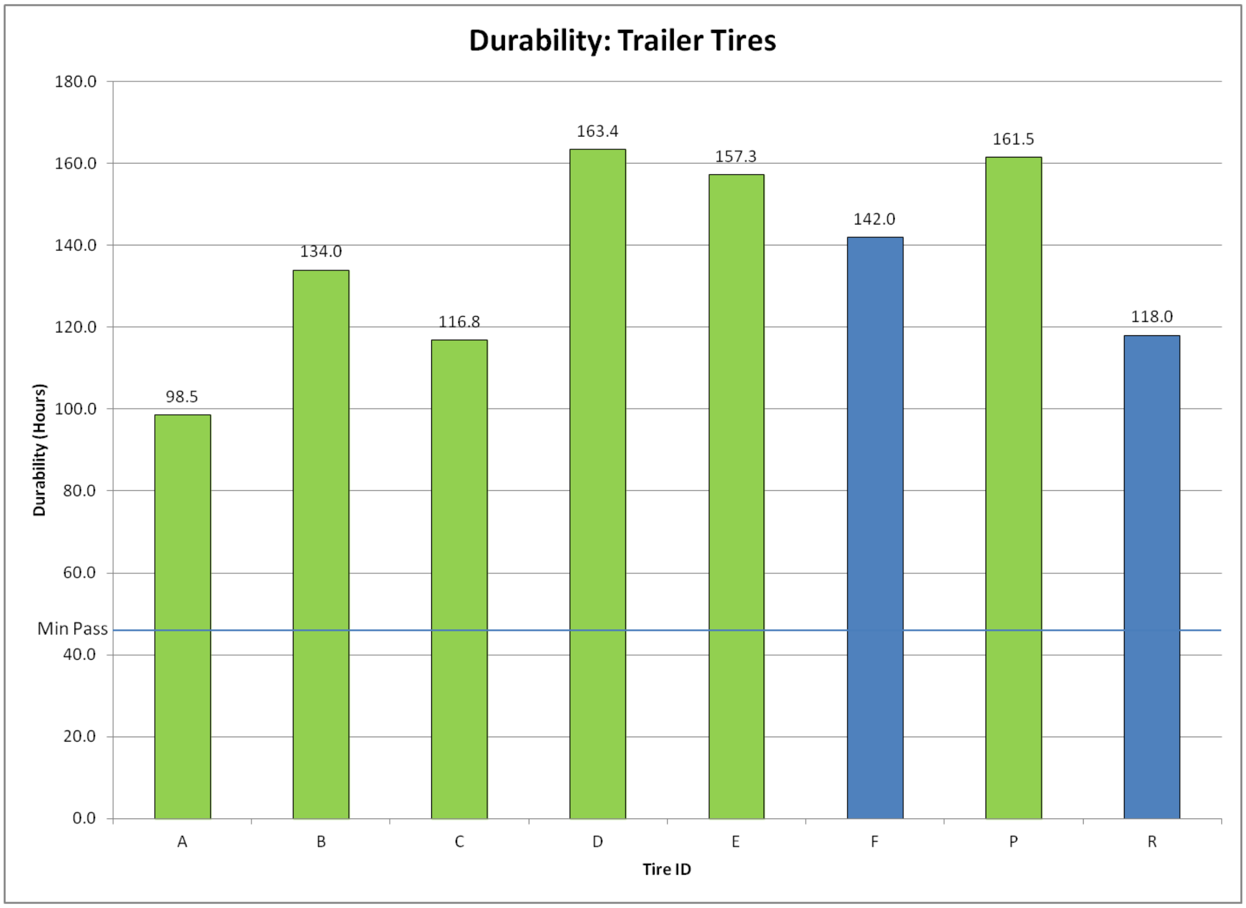

Figure 20: Durability, Trailer Tires

For trailer tires, SmartWay verified status does not appear to influence the strength and durability of a tire. From the test population, a SmartWay verified tire lasted the longest and the shortest. The rest of the tire population was well distributed with no apparent pattern or bias.

5.1.3 **Snow Traction**

5.1.3.1 General Comments

All snow traction performance is normalized against a control tire that was selected with the assistance of Smithers. There were no special requirements for the control tire, other than selecting a suitable candidate that was expected to yield a min-range performance number. This would ensure that the results would not be artificially skewed to one end. Because the results are normalized against a control tire, the results of two different test groups cannot be compared directly against each other unless the control tire is the same.

5.1.3.2 Drive Tire Snow Traction

In Figure 21, tires that are SmartWay verified have their snow traction values plotted with green bars, the non-LRR tires are represented by blue bars. The gold/blue bar is the non-LRR tire used as the control tire to which all traction results are normalized against.

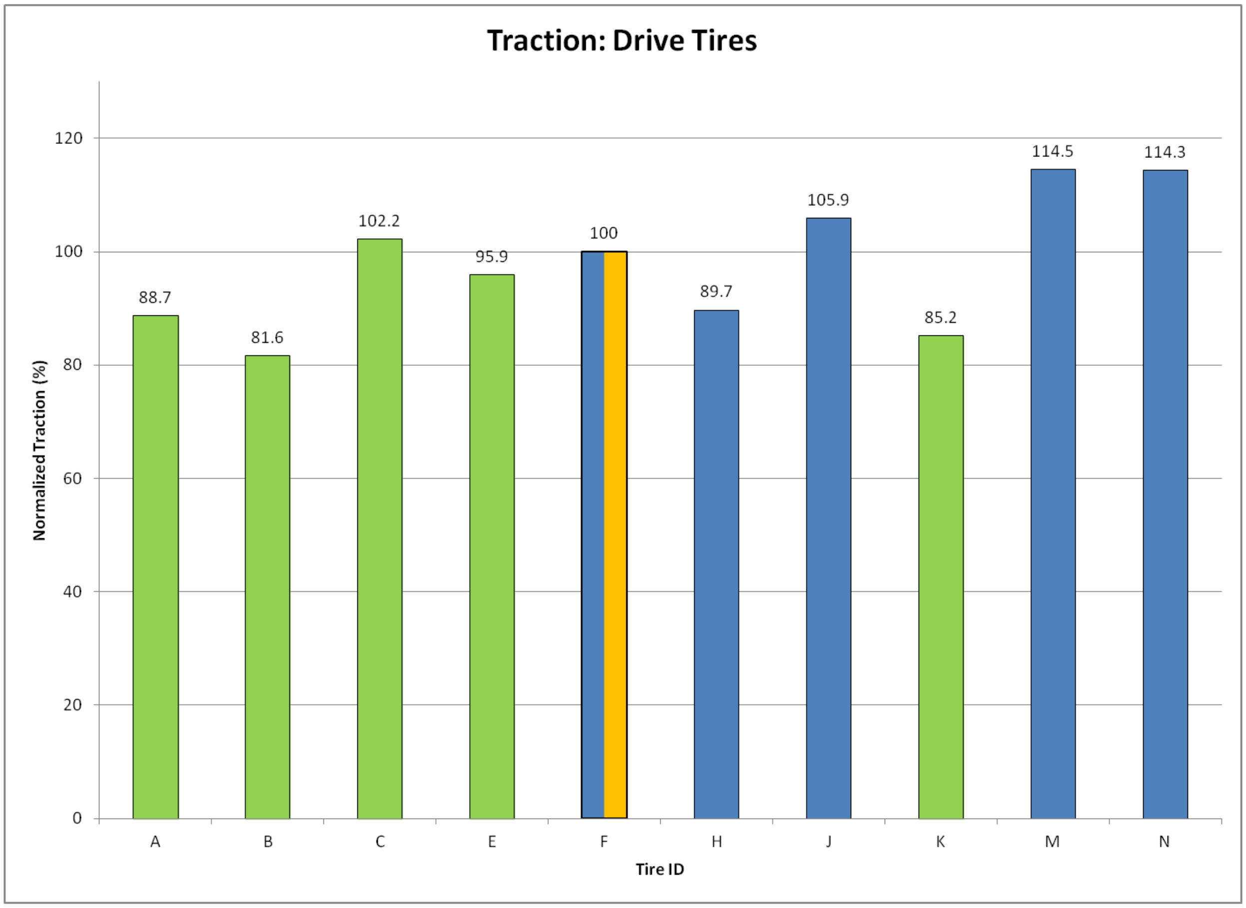

Figure 21: Snow Traction, Drive Tire

The relative snow traction of SmartWay verified drive tires is comparable to the snow traction of non-SmartWay verified drive tires. Tires M and N have unique properties that made their relative traction higher than the rest of the test population. The factors that affected the results were explained in Section 6.1.3.

5.1.3.3 Trailer Tire Snow Traction

In Figure 22, tires that are SmartWay verified have their snow traction values plotted with green bars, the non-LRR tires are represented by blue bars. The gold/blue bar is the non-LRR tire used as the control tire to which all traction results are normalized against.

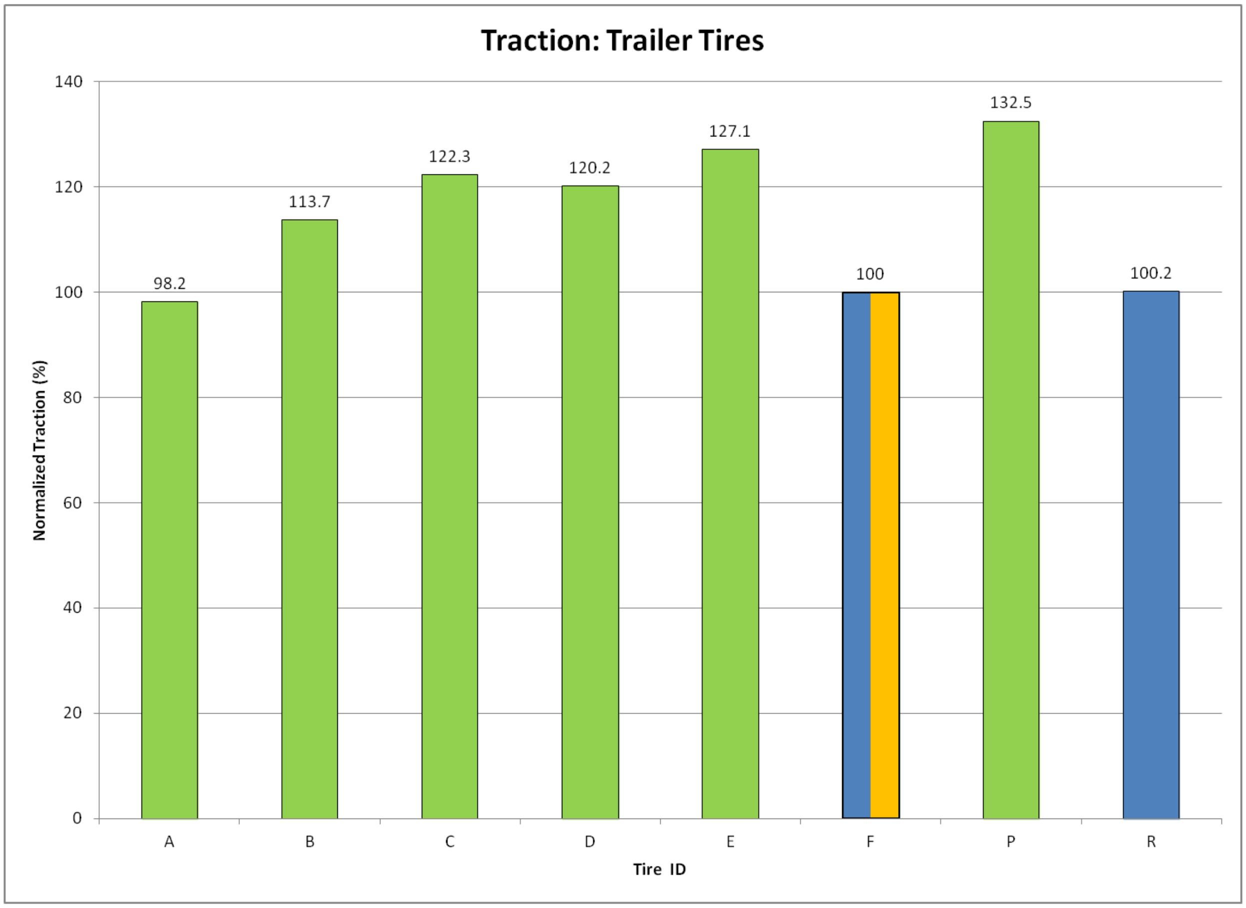

Figure 22: Snow Traction, Trailer Tires

The relative snow traction of SmartWay verified trailer tires is comparable to the snow traction of non-SmartWay verified trailer tires. In many cases, the SmartWay verified trailer tires produced higher relative traction when compared to non-SmartWay trailer tires.

5.2 Vehicle Based Track Testing Results

5.2.1 Braking Test Results

By virtue of having the braking tests commence with a maximum effort acceleration to the target speed, it was originally planned to have acceleration results to report along with braking test results. The rationale behind measuring acceleration performance and braking performance was that the tire-to-ground interface dynamics are different during acceleration than during braking. However, due to the difficulty in accelerating to the target speed because of the limited track length, the test procedure for braking was modified to have rolling starts instead of the originally planned standing start so acceleration results were not available.

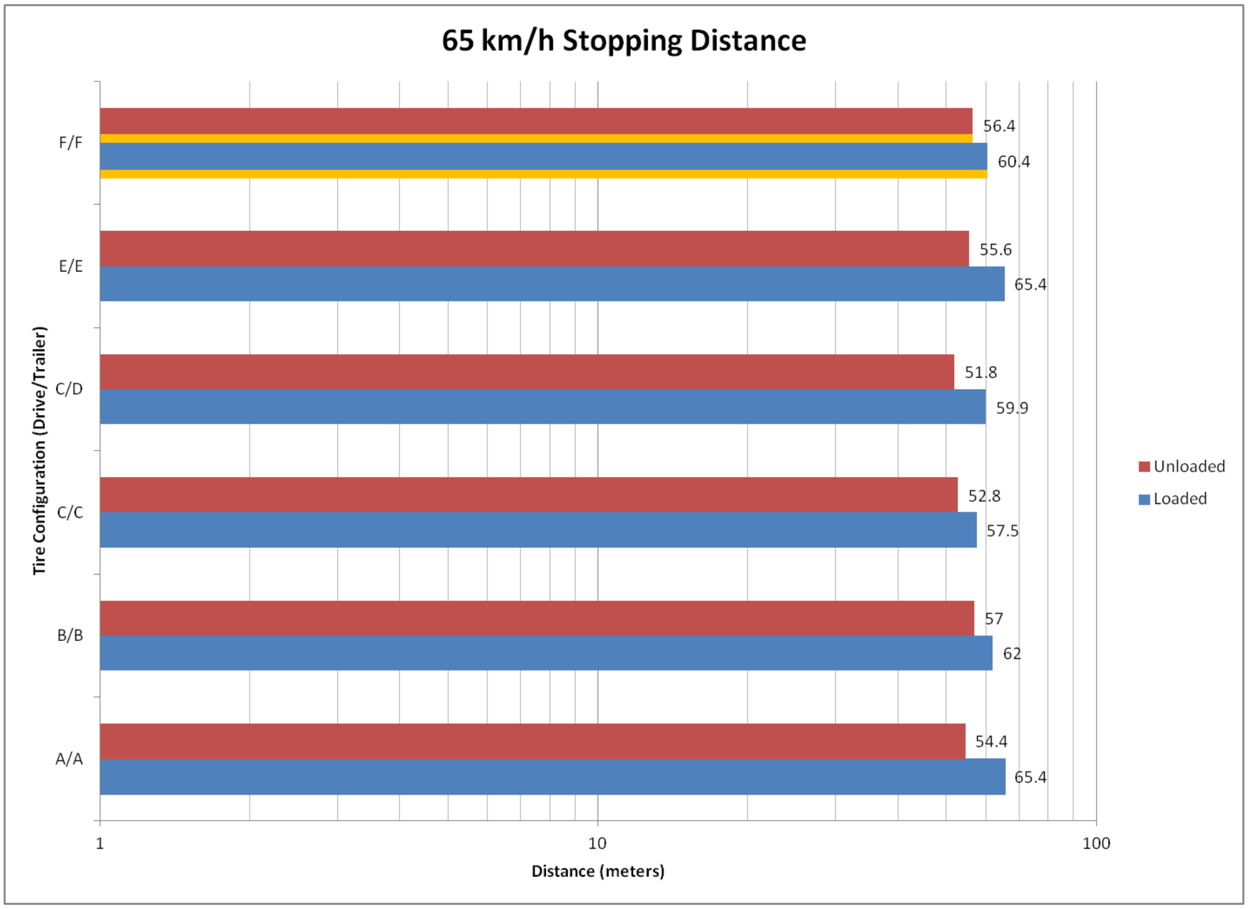

Figure 23: Stopping Distance

Figure 23 shows the results from the braking tests in both loaded and unloaded conditions. The gold highlight indicates the non-SmartWay control tire. The stopping distances are in metres and are the average of all of the runs. The results in Figure 23 were plotted using a log scale to better highlight any potential gross deficiencies that might manifest themselves.

Table 8: Stopping Distance Summary

	Longest		Shortest		
	Configuration	Distance	Configuration	Distance	Delta
Unloaded	F/F	56.4 m	C/D	51.8 m	4.6 m
Loaded	A/A & E/E (tie)	65.4 m	C/D	59.5 m	5.9 m

Table 8 summarizes the longest and shortest stopping distances measured for both a loaded and unloaded trailer. For an unloaded trailer, the longest stopping distance was 56.4 m for tire configuration F/F and the shortest stopping distance was 51.8 m for tire configuration C/D. When loaded, the longest stopping distance measured was 65.4 m for tire configurations A/A and E/E. The shortest stopping distance was 59.5 m for tire configuration C/D.

For all test configurations, the driver did not report any unusual vehicle behaviour, nor was any unexpected behaviour observed externally.

5.2.2 **Turning Test Results**

The data analysis for this test is primarily a pass/fail result. In order to be considered a pass, the tractor-trailer must hold the road as the driver intends. The driver's feedback is important to determining whether a particular tire configuration passes the turning test.

Additional factors that help indicate whether a particular configuration passes include the engine pitch and articulation angle of the trailer. Generally when the tractor-trailer loses control due to insufficient tire traction, the stability system decreases engine power which causes a change in engine noise. Additionally, there is a significant change in the articulation angle that is visually evident to the stationary observer.

Table 9: Turning Test Summary

	Turning Test Entry Speed			
Configuration	**20 km/h**	**25 km/h**	**30 km/h**	**35 km/h**
A/A	Pass	Pass	Pass	**FAIL**
B/B	Pass	Pass	**FAIL**	not attempted
C/C	Pass	Pass	Pass	**FAIL**
C/D	Pass	Pass	Pass	**FAIL**
E/E	Pass	Pass	Pass	**FAIL**
F/F	Pass	Pass	Pass	**FAIL**

The results from the turning test are summarized in Table 9 with pass/fail condition at the various entry speeds. All tire configurations passed at 20 and 25 km/h entry speeds. Tire configuration B/B did not pass at an entry speed of 30 km/h. All tire configurations did not pass at an entry speed of 35 km/h.

The observed failures at speed were often quite dramatic as they produced large changes in articulation angle that was very evident to the stationary observer. Additionally, there is also significant corrective action on the part of the driver in the form of counter-steering to correct the tractor-trailer attitude. It was therefore very evident as to whether a tire passed or failed at a specific entry speed.

For all test configurations, the driver did not report any unusual vehicle behaviour, nor was any unexpected behaviour observed externally.

6 Conclusions

6.1 Laboratory Testing Conclusions

6.1.1 **Rolling Resistance**

For drive position tires, there is a strong correlation between the tire's SmartWay verification status and the measured rolling resistance. Drive tires marked LRR or SmartWay verified have markedly lower rolling resistance measurements when compared to their non-SmartWay verified counterparts, 29% lower on average.

Drive tire A and J both have very similar tread patterns with the only obvious visual difference being a slightly modified shoulder pattern. Ostensibly there are greater differences in materials, tread depth, and internal construction, and this shows that a tire's rolling resistance can be strongly influenced by factors that are not always visible or obvious to the consumer.

For trailer position tires, the correlation between a tire's SmartWay verification status and the measured rolling resistance is less clear. Trailer tire A is listed on the SmartWay verified technologies master list as an approved LRR tire. However, the measured rolling resistance for tire A is significantly higher than for other SmartWay verified tires.

Further clouding results is the trailer tire F, for which SmartWay verified status was retired for tires with a date code of 1011 or later. However, tires with a date code older than 1011 still retain their verified status.

Based on the collected data, trailer position tires, regardless of their SmartWay verification status, have lower rolling resistance values than drive tires. Possible factors for this are numerous, however the outwardly visible reasons include tread depth and tread pattern (i.e. rib pattern typical of trailer tires vs. the lug pattern typical of drive tires).

6.1.2 **Durability**

All of the tires tested for this project passed the FMVSS minimum requirements. To further examine the design limits of a particular tire the test was continued until the ultimate failure of the tire after the initial prescribed 47 hours had elapsed. Every eight hours, the load on the test tire was increased to accelerate potential failures. During the additional test time, the tire was inspected periodically to check for signs of impending failure. All tires (LRR and non-LRR) tested showed considerable durability beyond the 47 hours required by US FMVSS 119. There was no discernible trend of a particular brand or type of tire lasting longer than another, nor was there a discernible trend of performance bias towards LRR or non-LRR tires. This is the case for both drive position and trailer position tires.

Regarding the failure mode of the tires during durability testing; because the tires are loaded against a rotating drum, the contact patch and carcass of the tire is subject to a continuous bending reversal. This load condition does not accurately reflect the normal service conditions of a tire. Bending reversals do occur in a tire's normal service, such as when encountering large rocks, potholes, etc. For long haul tires these bending reversals do not generally form a large portion of the tire's duty cycle; however, the durability testing subjects the tires to continuous reversed bending and as a result, caution should be exercised when examining the failure mode.

Finally, it is important to understand that the durability testing does not attempt to model the expected service life of the tire carcass or the tread life of any tire. The durability test is only an acceptance test and is one of three approved methods for determining the road-worthiness of a tire for use of public roads.

6.1.3 **Snow Traction**

For tractor tires, it appears that snow traction generally favours the non-SmartWay verified tires, especially drive tires M and N. However, both of those tire models have important qualifiers on their results, specifically:

- Drive tire N is designed to provide maximum traction in slippery conditions and is described by the manufacturer as: "...premium drive tire optimized for exceptional traction with no compromise on tread wear."
- Drive tire M is optimized primarily for single axle drive tractors but is still classified as a long-haul service tire.

If these two model tires are excluded from the traction results then the results show that SmartWay verified tires offer comparable levels of snow traction to non-SmartWay verified tires.

For trailer tires, the normalized results show that SmartWay verified tires, on average, produced higher measured snow traction levels than their non-SmartWay verified counterparts, with the exception of one model. However, that one model, trailer tire A, was only 1.8% lower than the control tire and could be considered to be statistically equal in performance to the control.

6.1.4 **Summary**

With the exception of tires that are specifically marketed by their respective manufacturers as a high-traction tire, the results of this preliminary study indicate that the current generation of SmartWay verified LRR tires can offer a similar level of snow traction performance as non-SmartWay verified tires, while reducing fuel consumption and emissions.6.2 Vehicle Based Testing Conclusions

6.2 Vehicle Based Testing Conclusions

6.2.1 **Stopping Distance**

For an unloaded trailer, the longest stopping distance was 56.4 m for tire configuration F/F and the shortest stopping distance was 51.8 m for tire configurations C/D. When loaded, the longest stopping distance measured was 65.4 m for tire configurations A/A and E/E. The shortest stopping distance was 59.5 m for tire configuration C/D. For all braking test configurations, the driver did not report any unusual vehicle behaviour, nor was any unexpected behaviour observed externally. There was no discernable difference in braking performance between LRR and non-LRR tires on packed snow.

6.2.2 **Low-Speed Turning Test**

All tire configurations passed at 20 and 25 km/h entry speeds into the turning tests. Tire configuration B/B did not pass at an entry speed of 30 km/h. All tire configurations did not pass at an entry speed of 35 km/h. For all test configurations, the driver did not report any unusual vehicle behaviour, nor was any unexpected behaviour observed externally. There was no discernable difference in turning performance between LRR and non-LRR tires on packed snow.

6.3 Overall Conclusions

Put in the context of Canadian trucking, there are many factors that must be considered when purchasing tires for a tractor and trailer combination. The advent of low rolling resistance tires has given owners and operators one more tire characteristic to consider. The testing has demonstrated that tires marketed as 'low rolling resistance' have less rolling resistance than their conventional counterparts which should result in reduced fuel consumption when compared to similar, but non-LRR, tires.

However, other operational requirements, such as heat dissipation, tread wear, snow traction and brand commonality within the existing fleet are all still valid factors that must be considered in addition to the rolling resistance when fleet operators are purchasing tires. In other words, operators who already require a high traction, or dedicated snow tire for their operations, should continue to purchase those types of tires to satisfy their operational needs, however, they can now select a tire that is also low rolling resistance and rest assured that the performance factors tested in this program will remain largely unchanged. Operators should be encouraged to continue to consider all of the factors that influence tire purchases including, but not limited to, the degree of low rolling resistance.

With the exception of tires that are specifically marketed by their respective manufacturers as a high-traction tire, the results of this preliminary study indicate that the current generation of SmartWay verified LRR tires can offer a similar level of snow traction performance as non-SmartWay verified tires, while reducing fuel consumption and emissions.

7 Discussion

7.1 Laboratory Testing Discussion

7.1.1 Rolling Resistance

The EPA retired the trailer tire F's SmartWay verified status as of March 6, 2011. The tire manufacturer's product web page for the trailer tire F still lists the tire as SmartWay verified. A recent manufacturer brochure that lists the line-up of SmartWay verified tires offered does not include trailer tire F. However, both the EPA (through the SmartWay program) and the manufacturer state that trailer tire F tires with date codes prior to 1011 are still considered to be verified. The trailer tire F sample tested in this project carried a date code of 3111 and is therefore not considered to be SmartWay verified.

Trailer tire A is listed on the SmartWay verified technologies list as an approved LRR tire. However, trailer tire A's manufacturer website does not mention this tire as an LRR tire, and its rolling resistance results would seem to confirm that this tire is not an LRR tire. In fact, trailer tire F has a lower measured rolling resistance value and yet is not SmartWay verified (its verification was retired).

Regarding the results of trailer tire F and trailer tire A, phone calls were made and emails were sent to their respective representatives for comment. Trailer tire A's manufacturer response to the test results of trailer tire A was that trailer tire A is primarily a steer tire that can also be used for the trailer position. Under the EPA SmartWay program, the rolling resistance for steer tires is permitted to be slightly higher than for trailer specific tires.

With that information, trailer tire A may have higher rolling resistance than the other trailer tires, but it is still within the permissible range for steer tires. By way of comparison, the trailer tire C also has a similar classification in that it is primarily a steer tire but can be used in any position if required. Trailer tire C's rolling resistance is much closer to the measured rolling resistance of the other trailer tires.

The reason(s) for the retirement of trailer tire F's SmartWay verification status is less clear. The response from the manufacturer's representative did not mention any specific reasons for the retirement. Whether trailer tire F was removed at the request of the manufacturer or was removed by the EPA is also unknown.

7.1.2 Durability

No significant observations to discuss.

7.1.3 Snow Traction

Drive tire A and drive Tire J both have outwardly identical tread patterns and differ (ostensibly) only in materials, tread depth, and internal construction. This suggests that a tire's winter traction performance is strongly influenced by factors that are not always reported, visible, or obvious to the consumer. However, it must be noted that there is insufficient information to definitively conclude that an LRR tire automatically means lowered winter traction. Other LRR tires tested do show levels of winter traction that are comparable to non-LRR tires.

7.2 Vehicle Based Track Testing Discussion

7.2.1 General Remarks

The prevailing weather conditions play a major role in the consistency of the snowpack conditions, making precise measurements difficult to collect. However, the intention of vehicle testing was to determine if there were any gross performance deficiencies, well beyond any statistical errors, in LRR tires when compared to their non-LRR counterparts. From the data collected and the follow-up analysis, there does not appear to be any gross performance deficiencies between LRR and non-LRR tire types, regardless of weather.

7.2.2 Stopping Distance

No significant observations to discuss.

7.2.3 Low-Speed Turning Test

Visually, the most outwardly apparent difference between tractor tire B and the other SmartWay verified tires is that tractor tire B does not appear to have a comparable number or density of lateral edges as the other SmartWay verified tires. This disparity between tractor tire B and the other tractor tires may have contributed to the reduced performance of Configuration B/B in the low-speed turning test.

7.2.4 Lessons Learned and Future Improvements

The relatively short length of the snow covered track forced an adjustment to the test procedure. The planned standing start was abandoned in favour of rolling starts because there was not enough track length to achieve the terminal speed required for braking distance measurement. Standing starts would have allowed the measured snow traction performance as reported in laboratory testing to be compared to the actual distance and/or time required to achieve the terminal braking velocity. If this test were to be repeated, it would be beneficial to have a significantly longer track surface (at least 1000 m, and preferably 1500 m or more).

8 Acronyms, Abbreviations, and Units

8.1 Acronyms and Abbreviations

ASTM	American Society for Testing and Materials
CARB	California Air Resources Board
CEPA	Canadian Environmental Protection Act
DOT	Department of Transportation
FMVSS	Federal Motor Vehicle Safety Standard
GHG	Greenhouse Gas
GoC	Government of Canada
GPS	Global Positioning System
IMU	Inertial Measurement Unit
LRR	Low Rolling Resistance
MY	Model Year
NRC	National Research Council Canada
EPA	Environmental Protection Agency
SAE	Society of Automotive Engineers
ST	Surface Transportation
US	United States
USA	United States of America

8.2 Symbols and Units

°	degree (angular)
°/s	degrees per second
ft	foot, feet
g	gravitational acceleration (g= 9.81 m/s^2)
hp	horsepower
in	inch
kg	kilogram
km	kilometre
km/h	kilometres per hour
kPa	kilopascal
l	litre
lb, lbs	pound, pounds
m	metre
mm	millimetre
psi	pounds per square inch
rpm	revolutions per minute

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