Test report: evaluation of tire pressure monitoring systems (TPMS): phase 2

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Test Report

Evaluation of Tire Pressure Monitoring Systems (TPMS) – Phase 2

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Abstract

A test campaign was conducted where a tire pressure monitoring system (TPMS) was installed on seven identical Class 8 tractors, to assess the benefits of the system as well as its accuracy and reliability in Canadian environmental conditions. Data were collected through driver and mechanic checklists as well as telematics. Three identical tractors were also included as a control group. Approximately 3.7 million test kilometres were accumulated over a one year period, with the tractors performing weekly trips between Canada and the United States. Only two tire incidents were experienced, where the damaged tires were replaced in a timely manner without any highway incidents. There was no noticeable difference in treadwear or fuel economy between the test and control trucks, but this would likely have been affected by the proactive maintenance and inspection schedule followed by the fleet. The TPMS proved to be accurate and reliable. The drivers and fleet management staff were surveyed at the end of the test campaign and they both provided positive feedback – they recommended the use of such a system on all tractors and trailers.

Executive Summary

The purpose of this study was to evaluate the impact of a modern tire pressure monitoring system (TPMS) integrated with telematics, on tire tread wear, maintenance, fuel economy, downtime/operations, and safety. A goal of the project was to assess how accurate and reliable the system is on a long-term basis, and how its performance is affected by Canadian environmental conditions (e.g., cold ambient temperatures and salt corrosion). The test campaign was conducted during the period November 2020 to November 2021, and approximately 3.7 million test kilometres were accumulated. The TPMS provided accurate and reliable data in all weather conditions, and the participating drivers and fleet management staff provided positive feedback, recommending the use of such a system on all tractors and trailers.

Methodology

A Continental ContiPressureCheck™ TPMS was installed on seven identical 2019 Kenworth T680 Class 8 tractors operated by TransWest Group in Lachine, Quebec. The TPMS sensors were bonded to the inner tire liners of new Michelin tires which were installed on both the steer and drive axles. A display unit was installed in the cab of the truck, and the TPMS was integrated with the existing Isaac Instruments telematics system. Three additional identical tractors were included in the test campaign as a control group to compare findings. Both the test and control trucks were operated in normal revenue service, travelling from Quebec to the Canadian west coast, to California, and back to Quebec on a weekly basis.

The drivers were requested to complete checklists at the mid-point of each trip, recording manually measured tire inflation pressures and temperatures, as well as temperatures and pressures reported by the TPMS (not applicable for the control trucks). Any warnings were also noted. A similar checklist was completed by the Trans-West mechanic before each trip, with the tread depth of each tire also recorded. The telematics data were downloaded on a regular basis from the trucks to a Trans-West server, and then subsequently transferred to the NRC.

Checklist entries were transposed to a spreadsheet to facilitate analysis of the manually recorded data. The telematics data were examined as required to investigate specific incidents. At the end of the test campaign surveys were completed by the drivers and fleet management staff.

Findings

The accumulated mileage on the test and control trucks ranged from approximately 330,000 to 460,000 km. Throughout the entire test campaign only two tire incidents were experienced. The first event, where a metal object was embedded in a tire and the tire was replaced by roadside service, occurred early in the test campaign when there was no available telematics data. The second event involved a damaged tire which began rapidly leaking air while the truck was in motion. A warning was presented to the driver, who stopped the truck within minutes. The driver proceeded directly to a repair facility and the tire was replaced without any incident.

A TPMS does not automatically adjust tire inflation pressures (unlike other tire pressure management systems); unless it is used to initiate unscheduled tire pressure adjustments it will have no impact on tire

wear or fuel economy. Trans-West follows a very proactive maintenance and inspection schedule, with each truck receiving a full mechanical inspection every month. Any issues related to suspension, wheel alignment, tire condition and tire pressure are addressed in a timely manner. So for this fleet the TPMS merely acted as a warning system, and as expected there was no noticeable difference in treadwear or fuel economy between the test and control trucks. The return on investment (ROI) for a TPMS solution would likely be longer for a fleet such as Trans-West, compared to a fleet with a less proactive maintenance and inspection schedule.

It was difficult to collect reliable data from all of the drivers, and the completion and submission of checklists became more sporadic towards the end of the test campaign. Approximately 30% of the expected checklists for the test trucks were submitted. However, the checklists completed by the Trans-West mechanic were of a high quality. The test campaign was conducted during a period where provincial COVID-19 lockdowns and travel bans were in place, so it was not possible to liaise directly with fleet management staff or drivers.

At the end of the test campaign the drivers were interviewed to solicit their feedback regarding the use of the installed TPMS. They unanimously reported that the system was accurate, reliable and easy to use, and that they viewed the display often. They recommended the use of such a system, and suggested that it would be very useful if sensors were installed on the trailers as well as the tractors.

Trans-West fleet management staff involved in the test campaign also provided positive feedback regarding the use of the system. They acknowledged the challenges installing and integrating the system, and training drivers and maintenance staff to use and maintain it. They also noted that most of the tire issues experienced during the test campaign involved trailer tires (which did not have an installed TPMS). The fleet management staff reported that the TPMS was useful in minimizing irregular tire wear due to early detection of slow air leaks, and that it may also have improved highway safety by possibly avoiding a tire blowout.

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1 Introduction

1.1 Purpose

Transport Canada (TC) retained the National Research Council of Canada (NRC) to evaluate the impact of a modern tire pressure monitoring system (TPMS) integrated with telematics, on tire treadwear, maintenance, fuel economy, downtime/operations, and safety. A goal of the project was to assess how accurate and reliable the system is on a long-term basis, and how its performance is affected by Canadian environmental conditions (e.g., cold ambient temperatures and salt corrosion).The work was performed by NRC's Automotive and Surface Transportation Research Centre.

1.2 Background

TC, through its ecoTECHNOLOGY for Vehicles program, undertakes testing and evaluation of current and emerging vehicle technologies to help inform various stakeholders that are engaged in the development of regulations, codes and standards for the next generation of advanced light and heavy-duty vehicles. Results are used to aid the development of environmental and safety regulations to ensure that new technologies can be introduced in Canada in a safe and timely manner.

The American Trucking Association's Technology & Maintenance Council (TMC) and the Federal Motor Carrier Safety Administration (FMCSA) of the United States Department of Transportation (DOT) have been studying commercial truck tire pressure management and maintenance systems since 2001. During the period 2008 through 2010, FMCSA conducted a thorough field test involving two commercial truck fleets which accumulated millions of miles on the test systems and encountered numerous tire incidents. Findings from the field test for each fleet were thoroughly analyzed for fuel consumption, tire maintenance actions, tire wear, system accuracy, system reliability, and user feedback. It was concluded that the use of tire pressure management and maintenance systems is very likely to reduce the operating costs of a fleet, with a return on investment (ROI) period of less than two years. The use of such equipment encourages mechanics and drivers to monitor tire inflation pressures and report abnormal tire conditions. Interviews with drivers confirmed their acceptance of the equipment and a desire to expand use to the entire fleet [1].

Maintaining proper tire inflation pressures contributes to improved fuel efficiency and reduced tire wear, and reduces the risk of unexpected vehicle breakdowns and damage. It can also improve highway safety by maintaining vehicle stability and significantly reducing the likelihood of a tire blowout due to an underinflated tire. Tire underinflation leads to approximately 5-12% degradation in tire wear for an individual tire which is 10 psi underinflated, and 0.5-1.0% increase in fuel consumption (degradation in fuel economy) for a vehicle running with all tires underinflated by 10 psi. Studies have shown that [2]:

- About one out of five tractors/trucks is operating with one or more tires underinflated by at least 20 psi;
- Nearly 3.5% of all tractors/trucks operate with four or more tires underinflated by at least 20 psi;
- Approximately 3% of all trailers, and more than 3% of all tractors/trucks, are operating with at least one tire underinflated by 50 psi or more; and

- Only 46% of all tractor tires and 38% of all trailer tires inspected were within ±5 psi of the target pressure.

Tire manufacturers provide load inflation tables to inform users about the proper inflation of their tires, based on the load that will be supported by a tire. Generally, the required minimum inflation pressure is set to ensure that the tire will not be operated under low-pressure conditions that could compromise the life of the casing. A tire must be inflated to at least the required minimum inflation pressure for a given load, but can feasibly be inflated to any level up to the maximum inflation pressure. The target pressure selected by a fleet is based on optimized performance – not just for wear, but also for braking, handling, ride comfort, stability, and fuel consumption [2]. Since inflation pressure varies with temperature, the lowest inflation pressure occurs when a tire is cold (i.e., before a vehicle begins moving and the tires warm up). Therefore tire inflation pressures are specified as a cold inflation pressure, and to achieve the desired cold inflation pressure it may be necessary to add or remove air as seasons change. As a tire warms up the inflation pressure increases, and the amount of heat generated by the tire (and hence the increase in inflation pressure) is affected by such factors as inflation pressure, load, speed, etc. Therefore the only accurate inflation pressure measurement (and the lowest available inflation pressure reading) is a cold inflation pressure.

Tires will lose air pressure over time, and therefore it is an essential maintenance practice to measure and adjust inflation pressures. The primary causes of tire underinflation (excluding rapid air loss due to tire damage) are [2]:

- Natural air loss due to diffusion through the tire casing, estimated at up to 2 psi per month (at normal tire operating pressures of around 100 psi);
- Air seepage due to a malfunctioning valve, leaking valve seals, or improper bead seating, up to approximately 2 psi per week to 2 psi per day;
- Slow to moderate leaks primarily due to small punctures (but may also be caused by valve or bead seat irregularities), up to the range of about 5 psi per hour; and
- Rapid air loss, at rates of approximately 1-5 psi per minute or higher.

Available tire pressure systems include TPMS (the subject of this report), dual tire pressure equalizers, automatic tire inflation systems (ATIS), central tire inflation systems (CTIS), and passive pressure containment approaches (e.g., use of nitrogen and tire sealants). Each of these systems have specific advantages and disadvantages. While ATIS and CTIS can automatically add air as required to inflate tires, a TPMS monitors the inflation pressures and provides a warning if the pressure in a monitored tire drops below a pre-established threshold. It is important to remember that a TPMS does not adjust inflation pressure – someone must take action to remedy a problem for there to be any real value in the system.

Tractors and trailers tend to be operated and managed differently, and there is a common belief that inflation pressure is better maintained on tractors than on trailers. To help address this issue, approximately 70% of all new trailers are sold with a tire pressure management system, with ATIS much more popular than TPMS [2].

Modern TPMS sense both tire inflation pressure and tire temperature, and they are integrated with a telematics system such that the inflation pressures and temperatures are logged and transmitted using a wireless technology for remote monitoring and analysis. The pressure and temperature values and any warnings are also displayed to the operator. A pre-set target inflation pressure, which may be different for different tire positions, is programmed into the TPMS, and warnings are issued based on the difference between the target pressure and the actual measured pressure in the tire. A reliable TPMS can potentially eliminate the need for manual tire pressure checks – a labour-intensive exercise, especially on tractors or trailers with dual wheels.

TPMS sensors can be mounted inside or outside the tire, with advantages and disadvantages regarding installation difficulty, vulnerability and accessibility. Sensors may be mounted on the wheel or valve stem (either internally or externally), or they may be mounted directly to the inside of the tire (as was the case for this test campaign).

1.3 Scope

This phase of the test program, Phase 2, involved executing a test plan that was previously developed by the NRC. A modern TPMS was installed on seven identical Class 8 tractors from a single fleet, engaged in essentially identical long-haul service which involved high mileage. Three more identical tractors were included in the test program as control trucks, to permit a comparison to trucks which were not equipped with the TPMS. The TPMS was integrated with an existing telematics system to facilitate data capture from the TPMS as well as other relevant truck operating parameters. The trucks were operated in normal revenue service and data were collected for a test period of approximately nine months. A total of approximately 3.7 million km were accumulated on the test and control trucks (an average of approximately 370,000 km on each truck).

The test campaign was a collaborative venture between TC and FPInnovations PIT Group (hereafter referred to as FPI), and the NRC. FPI selected a suitable fleet for the test campaign, liaised with the test fleet, and managed the collection of the test data. The NRC was responsible for general test plan oversight, data analysis and reporting. The test campaign ran from November 2020 to November 2021, with complete data collection starting late February 2021. The collected data were analyzed to assess the following performance factors:

- impact on treadwear;
- impact on maintenance and downtime;
- long-term performance and durability (in Canadian environmental conditions);
- system accuracy;
- expected ROI; and
- system usability (based on surveys).

2 Test campaign

2.1 Approach

The test campaign involved a series of coordinated activities, starting with the selection of a test fleet. New tires and TPMS were installed on the test trucks, and new tires were installed on the control trucks. The drivers and mechanics were provided training on the use of the TPMS and the inspection and reporting requirements. Telematics data collection commenced once the TPMS were installed and integrated with the telematics system, and continued until approximately the end of November 2021. The submission of driver and mechanic checklists began in January 2021. The official start of the test campaign, after addressing some data collection issues, was February 24, 2021. A summary of the key project milestones and associated timelines is presented in Table 1. These activities are further detailed in the following sections.

Milestone	Resource assigned	Completion date
Truck fleet selection TPMS selection Test tire selection	FPI	July 2020
Test tire installation on trucks	Trans-West / FPI	October 2020
TPMS installation on trucks	Trans-West / Continental	November 2020
Logbooks provided to drivers and mechanics	NRC / FPI	November 2020
TPMS inspection requirements training provided to mechanics	Trans-West / FPI	November 2020
TPMS training provided to drivers	Trans-West / Continental	December 2020
Official start of test campaign	Trans-West / FPI / NRC	February 24, 2021
End of test campaign	Trans-West / FPI / NRC	November 2021

Table 1: Key project milestones and associated timelines

2.2 Test fleet selection

The selection of a trucking fleet was the responsibility of FPI, a private not-for-profit R&D organization working with the Canadian forestry sector and closely affiliated with several Quebec and Ontario based trucking fleets. While multiple fleets and/or multiple operators would have been acceptable, a single fleet and operator was preferred. The following criteria were used to select a suitable trucking fleet:

- test vehicles must be Class 8 tractors operated by commercial fleet operators;
- tractors must accumulate at least 7,500 km per week;
- tractors must be equipped with conventional dual tires (versus single wide-based (SWB) tires) on the tractor drive axles;
- all of the trailers hauled by the tractors must be similar, with a similar payload; and
- ideally tractors will operate over a similar route with a similar duty cycle.

Trans-West Group (Trans-West), based in Lachine, Quebec, was selected as the test fleet participant. It comprises a fleet of approximately 210 privately-owned tractors and more than 400 privately-owned trailers. The selected trucks specialized in the transport of peat moss from Quebec to Alberta and British Columbia, and fruits and vegetables from California to Quebec. They traveled from Quebec to the Canadian west coast and California on a weekly basis. In some instances the trucks returned via the east coast through Florida.

Ten 2019 Kenworth T680 Class 8 trucks, shown in Figure 1, with Cummins X15 engines, Eaton Fuller Advantage series automated 10-speed transmissions and complete aerodynamic packages, were selected for the test campaign. At the time the new tires were installed (as detailed in Section 3.1), the mileage of the trucks ranged from 616,905 to 716,659 km (average mileage 666,431 km).

Figure 1: Kenworth T680 test vehicle

The trucks were divided into two groups: one test group consisting of seven trucks and one control group consisting of three trucks. The test group had TPMS sensors installed in both steer (front) tires and all eight drive tires, for a total of 10 sensors per truck. The control group did not have TPMS sensors installed. A Continental logo sticker was affixed to the test group driver's doors to provide Trans-West mechanics a quick way to distinguish between the test and control trucks during truck servicing. The control trucks were used to obtain a reasonable comparison of tire treadwear and tire wear patterns between the test and control trucks.

The test and control trucks already had an identical Isaac Instruments telematics system installed, and the TPMS was integrated with the telematics system as detailed in Section 3.2. Recorded telemetry data were uploaded to a Trans-West server on a regular basis, and subsequently downloaded by FPI and supplied to the NRC for analysis, as detailed in Section 4.4.

Trans-West implements a very proactive vehicle maintenance and inspection schedule, with each truck receiving a full mechanical inspection each month at the service garage in the Montreal area. This provided an opportunity for Trans-West mechanics to collect test data which supplemented the telematics data and the test data recorded by the drivers.

2.3 Tire pressure monitoring system

The TPMS selected for the test campaign was the Continental ContiPressureCheck™ system. It incorporates a tire-mounted sensor which is bonded to each tire inner liner to continuously measure the tire pressure and temperature. A central control unit (CCU) receives tire sensor signals directly, evaluates the data and provides the status of all tires to the display and the telematics system. The system components are further detailed in the following sections, as well as a summary of the displayed information and warnings. Additional details of the system are available on the Continental website [3]. Continental technical representatives provided assistance with the installation of the TPMS.

2.3.1 TPMS sensor

Each TPMS sensor incorporates a pressure sensor, temperature sensor, acceleration sensor, processor, radio transmitter and a non-replaceable lithium battery packaged in a rubber housing. Continental TPMS sensors are available as individual units which can be mounted to new or used tires, or as part of an *intelligent tire package* which consists of a new Continental tire with the sensor installed from the factory. The TPMS sensor, with the tire sensor container (used to mount the sensor inside the tire) and an example of the sensor installation inside a tire, are shown in Figure 2. TPMS sensor technical specifications are presented in Table 2.

Figure 2: Continental TPMS sensor and installation inside tire

Temperature measuring range	-40 to 120°C
Pressure measuring range	0 to 173 psi (0 to 1,193 kPa)
Typical service life of battery	6 years or 600,000 km
Transmission frequency	433.92 MHz
Reception frequency	125 kHz
Operational temperature range	-40°C to 85°C
Dimensions (L x W x H)	38 x 28 x 22 mm

Table 2: Tire sensor technical specifications

Continental states that their TPMS sensor can be installed in any brand of tire with a rubber inner liner, and that the service life of the TPMS sensor battery, under normal conditions, is approximately six years or 600,000 km. The TPMS sensor service life will decrease if internal tire temperatures are constantly high (caused by high ambient temperatures or low tire pressures).

Each TPMS sensor outputs seven data channels as listed in Table 3. The data were integrated with the vehicle network data and transmitted via the telematics system as detailed in Section 3.2.

Data channel name	Unit	Broadcast data	Description
ID#X_TirePres	psi	Recorded tire pressure	Tire pressure
ID#X_TireTemp	°C	Recorded ambient tire temperature	Tire temperature (internal)
ID#X_CTIWheelSensorStatus	-	Activated = park mode	Sensor is at idle. A telegram is transmitted every 2 minutes.
		Deactivated = shipping mode	Sensor only transmits telegrams when specifically queried.
		START mode	Beginning at a speed of approx. 30 km/h (18 mph), a telegram is transmitted every 16 s. DRIVE mode follows.
		DRIVE mode	When vehicle acceleration is stable, a telegram is transmitted every 2 minutes.
ID#X_CTITireStatus	-	Tire location	Tire leak detected, or sensor loose or turned
ID#X_CTIWheelEndElectricalFault	-	Warning	Sensor low battery
ID#X_CTITireTempStatus	-	Warning	Over temperature
ID#X_CTIPresThresholdDetection	-	Warning	No warning pressure (OK), Under-inflation warning, Extreme under-inflation alarm

Table 3: Data channels broadcast by each TPMS sensor

The TPMS sensor data update rate varies depending on its state (based on measured acceleration, counters, and other parameters), or if a certain magnitude of pressure change is detected between measurements. The standard transmission rate is every 16 s or 120 s, depending on its state. “Unscheduled” transmissions are sent immediately when an event (such as rapid tire pressure loss) is detected, and continue to be sent every 4 s until the issue is resolved.

2.3.2 Central control unit

TPMS sensor data are transmitted to a central control unit (CCU), shown in Figure 3. Each CCU is capable of managing up to 24 tire sensors. For this test campaign the CCU was mounted to the truck frame mid-way between the first and second axle (just behind the cab). The CCU received tire sensor signals directly (i.e., without the use of an additional receiver), evaluated the data, and reported the status of all tires to an in-cab display and broadcast the data via the truck telematics system. The CCU technical specifications are presented in Table 4.

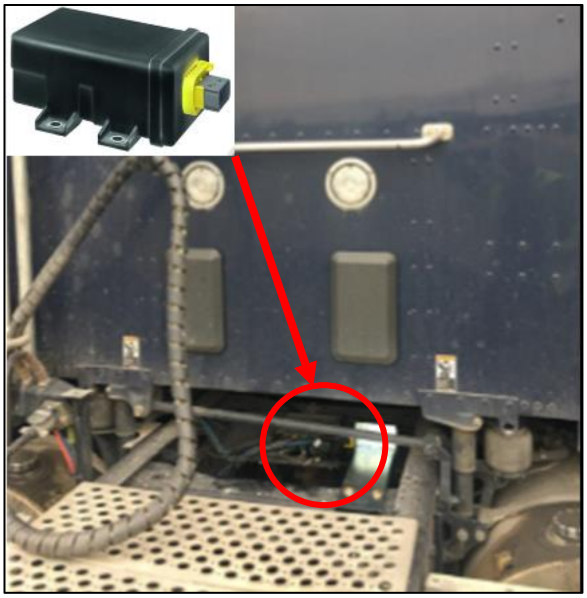


Figure 3: Continental TPMS CCU installed behind cab of truck

Reception frequency	433.92 MHz
Operational temperature range	-40°C to 85°C
Supply voltage	12/24 V
Dimensions (L x W x H)	165 x 121 x 65 mm

Table 4: CCU technical specifications

2.3.3 Display unit

A display unit was installed in the cab of the truck and it enabled the driver to view live inflation pressure and temperature data, and receive real-time sensor warnings. As detailed in Section 3.2, the trucks were previously outfitted with a telematics system manufactured by Isaac Instruments, and the TPMS was integrated into that system. The TPMS display unit as well as the Isaac telematics system tablet installed in a test truck is shown in Figure 4. The display unit technical specifications are presented in Table 5.

Figure 4: Continental in-cab display unit and Isaac Instruments telematics system tablet installed in truck

Operational temperature range	-40°C to 85°C
Supply voltage	12/24 V
Dimensions (L x W x H)	117 x 107 x 40 mm

Table 5: Display unit technical specifications

2.3.4 Hand-held tool

The TPMS were programmed using a Continental TPM-02 hand-held configuration and diagnostic tool, shown in Figure 5. The hand-held tool was used for the following:

- setting up and configuring the TPMS;
- activating the tire sensors;
- verifying the operation of the tire sensors;
- measuring tire pressures and temperatures;
- performing any necessary changes to the initial configuration;
- verifying system performance (test drive);
- reading error codes; and
- logging vehicle and configuration data.

Figure 5: Continental TPMS hand-held tool

The handheld tool can also be used to confirm sensor battery state where a “low battery” status is displayed.

2.3.5 TPMS display and warnings

The display unit permitted the driver to view pressure and temperature readings for each tire based on TPMS sensor data. A visual warning and audible signal tone could also be enabled to alert the driver to TPMS sensor warnings.

A representative display of both low-level sensor warnings and high-level sensor warnings is shown in Figure 6 and Figure 7, respectively. The display permits visualization of numerous simultaneous sensor warnings as well as the ability to scroll through the list of warnings as shown in Figure 8.

Low-level sensor warnings include:

- low tire pressure;
- high tire temperature;
- pressure difference between two twin (i.e., dual) tires;
- no signal from a sensor; and
- a defective sensor.

High-level sensor warnings include:

- fast pressure loss;
- very low tire pressure; and
- check sensor.

Warning type: low-level warning

Warning message: low pressure

Error: The tire pressure falls below the recommended alarm threshold value. The tire could be damaged in the long term.

Action: at the next opportunity (e.g., tire service, gas station, etc.) investigate the cause of low pressure and set the correct pressure. If the tire is damaged by a nail for example, arrange for the tire to be repaired or replaced by a specialist as soon as possible.

Warning type: low-level warning

Warning message: temperature

Error: the measured temperature in the tire exceeds 115 °C (239 °F). The tire sensor no longer functions from 120 °C (248 °F).

Action: stop the truck immediately at a suitable location. Allow the tire concerned to cool down and then check it.

Warning type: low-level warning

Warning: Pressure diff.

Error: The pressure between two twin tires exceeds a fixed threshold. The tires could wear out differently in the long term.

Action: At the next possibility, adjust the pressure of the two twin tires.

Warning type: low-level warning

Warning message: no signal

Error: due to insufficient signal strength, it is not possible to display a sensor protocol.

Action: the garage must clarify the cause for insufficient signal strength. If no signal is received, no pressure/temperature warning is possible.

Warning type: low-level warning

Warning message: sensor defect

Error: the tire sensor is defective.

Action: ask the garage to remove the tire as soon as possible and replace the sensor. (In the case of a defective tire sensor, no pressure/temperature warning is possible).

Figure 6: Display unit low level warnings: low pressure, temperature, pressure difference, no signal and sensor defect

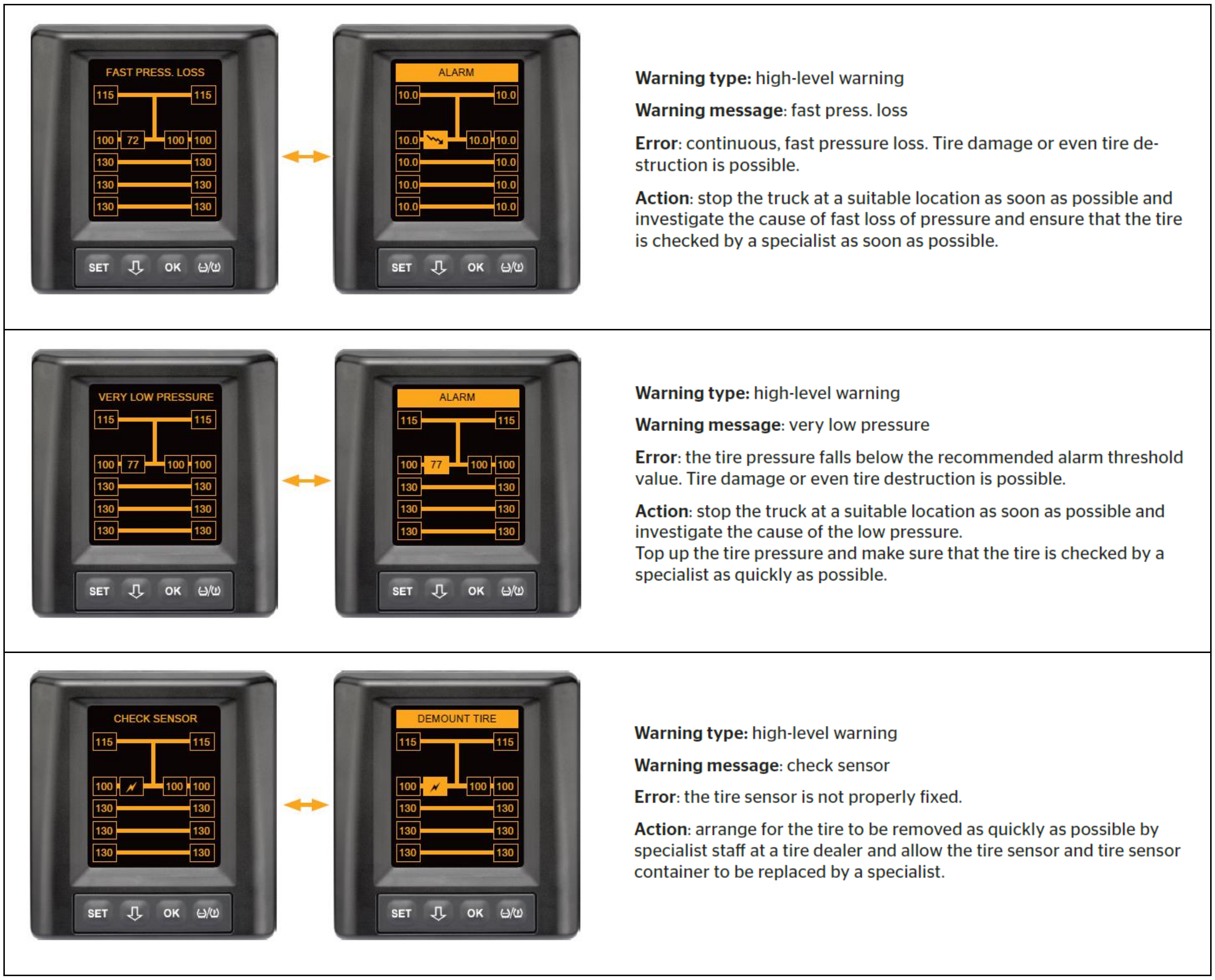


Figure 7: Display unit high level warnings: fast pressure loss, very low pressure and check sensor

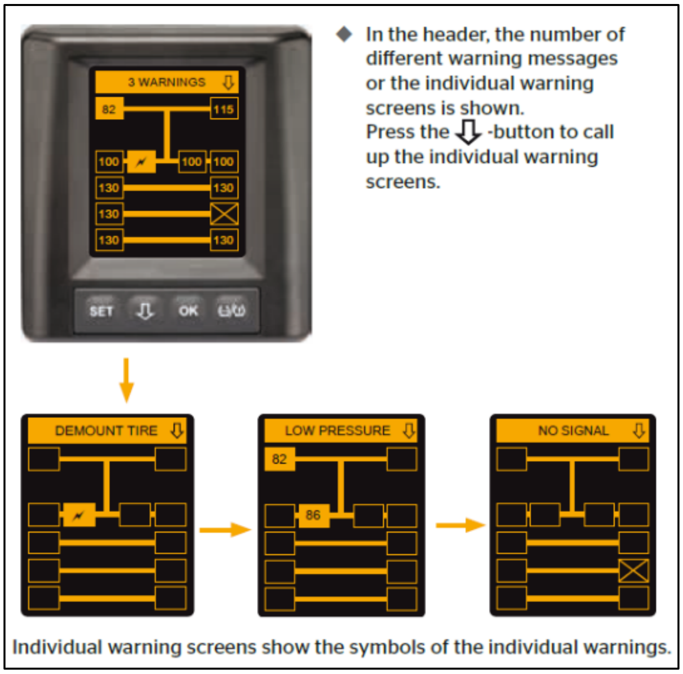


Figure 8: Display of multiple sensor warnings

2.4 Tires

Tran-West requested a specific brand and model of tire to be utilized during the test campaign that matched tires currently in use by their fleet. The tires selected and used were:

Steer: Michelin X-Line Energy Z 275-80 R22.5, 16 ply
Drive: Michelin X-Line Energy D 275-80 R22.5, 14 ply

Transport Canada facilitated the purchase and delivery of 100 new Michelin X-Line Energy tires – 20 steer tires and 80 drive tires – to Trans-West. The installation of TPMS sensors and tire mounting was performed by a commercial tire installation shop in the Montreal area.

2.5 Manual gauges

Each of the ten trucks was equipped with a manual tire pressure/inflator gauge for recording tire pressures, and an infrared thermometer for recording tire sidewall temperatures. The tire pressure/inflator gauge was a Milton Industries model S-506 and the infrared thermometer was a Fluke-59 model MAX NA. Both items were stored in the cab of each truck and used by the drivers to record measurements at the end of each trip. The Milton model S-506 tire pressure/inflator gauge measures pressures ranging from 10-160 psi in 2-psi increments, and it features a 15-in. hose which permitted access to the inner drive tires. The Fluke infrared thermometer gun has a measurement range of -30°C to 350°C and an accuracy of ±2.0°C.

3 Vehicle preparation

3.1 Tire and TPMS installation and activation

The control truck tires, with no TPMS sensors fitted, were installed on October 14, 2020 and the test truck tires, with TPMS sensors fitted, were installed on October 19 to 23, 2020. The sensors were installed inside each test truck tire following instructions provided by Continental, using the supplied Cyberbond CB2250 adhesive. The remaining TPMS components were installed and the TPMS was activated in the seven test trucks on October 20 to November 2, 2020. The truck identification, tire installation date and mileage, and TPMS activation date for each truck is presented in Table 6.

Truck identifier	Vehicle number	Tire installation date	Truck mileage at time of tire installation (km)	TPMS activation date
Test 1	165712	21-Oct-20	675,870	26-Oct-20
Test 2	165713	21-Oct-20	652,960	27-Oct-20
Test 3	165714	20-Oct-20	637,409	28-Oct-20
Test 4	165715	21-Oct-20	697,846	22-Oct-20
Test 5	165716	22-Oct-20	634,138	2-Nov-20
Test 6	165717	23-Oct-20	704,501	23-Oct-20
Test 7	165719	19-Oct-20	703,551	20-Oct-20
Control 1	165718	14-Oct-20	624,471	No sensors installed
Control 2	165720	14-Oct-20	616,905	No sensors installed
Control 3	165711	14-Oct-20	716,659	No sensors installed

Table 6: TPMS and tire sensor installation date and mileage

Two installed TPMS sensors did not adhere correctly to the inner tire surface and required reapplication. The issue was resolved prior to the tires being installed on the trucks. The problem was determined to be due to improper tire surface preparation by the tire installation technician, and after installation methods were corrected no further sensor adhesion issues were encountered when the sensors were initially installed. There was one subsequent instance of a sensor becoming detached as described in Section 6.5.3.

The Continental TPMS allows the operator to program specific warning levels for tire pressure and temperature using a hand-held programmer. For this test campaign the desired pressure for the drive tires was set to 80 psi. A low tire pressure alarm is triggered after a loss of 10% of the programmed tire pressure, in this case when the pressure falls to 72 psi. The desired pressure for the front tires was set to 105 psi, so in this case a low pressure alarm would be triggered at 94 psi. The high temperature warning triggers if the tire temperature exceeds 115°C. The trigger levels were set following the guidance and recommendations of Continental technical representatives.

A consistent means of identifying each tire on the trucks is shown in Figure 9, where L=LEFT, R=RIGHT, F=FRONT, O=OUTSIDE, and I=INSIDE. The first drive axle is identified as axle “2”, and the second drive axle is identified as axle “3”. The checklist forms used by the drivers and mechanics (shown in

Appendix B and Appendix C) were arranged to show each tire in its relative position and included similar labels for each tire.

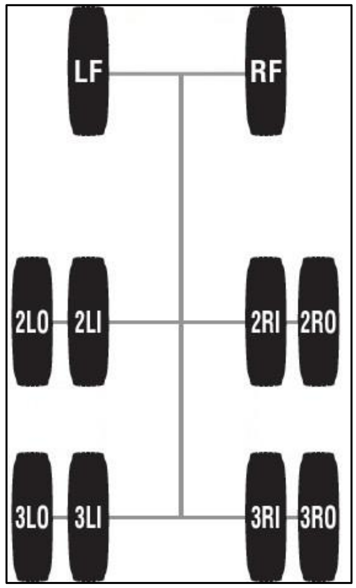


Figure 9: Identification of tire positions

3.2 Integration with Isaac Instruments telematics system

The test and control trucks were previously outfitted with Isaac Instruments telematics systems, model WRU1K2-HN2, which were used to record specific vehicle network data. These data included 87 unique SAE J1939 data channels recorded when the truck was driving, and a truncated list of 69 data channels when the truck was idling. No telematics data were recorded while the truck engines were off or while the ignition key was in the accessory position. A complete list of recorded vehicle network data channels is provided in Appendix E. These data continued to be recorded during the test campaign, and they were provided to the NRC for analysis. Note that one of the data channels is an ambient air temperature measurement, provided by a sensor located at the bottom of the driver's side mirror assembly. This data was displayed on the dash of the truck, and it was manually recorded on the driver and mechanic checklists.

Some challenges were encountered integrating the TPMS data into the Isaac Instruments telematics system on the seven test trucks, as the Continental ContiPressureCheck system was not specifically designed to interface with it. Technical representatives from Isaac Instruments and Continental worked through the issues to achieve a successful integration. In the end the TPMS data were added in CAN format, synchronized and recorded along with the truck J1939 vehicle network data.

4 Data Collection

4.1 Collected data

The collected data included TPMS sensor data and vehicle network data, which was obtained via the telematics system, as well as manually recorded data entered in logbook checklists by both drivers and mechanics.

The recorded TPMS sensor data included the following for each sensor:

- tire pressure;
- tire temperature;
- sensor status;
- tire location; and
- warnings: low battery, high temperature, and/or low pressure.

The TPMS was integrated into the telematics system in November 2020, but during a scheduled over-the-air firmware update in late-November 2020 all TPMS parameters were deleted from the list of data to be recorded. The NRC was unaware of the update until February 2021, so as a result no TPMS data were recorded between late-November 2020 and late-February 2021.

Data which was manually obtained and recorded by the drivers and Trans-West mechanics included the following:

- tire pressure;
- tire temperature;
- tire tread depth (measured monthly by mechanics only);
- ambient air temperature at time of data capture; and
- geographic location of truck at time of data capture.

Surveys were also conducted upon completion of the test campaign by the drivers as well as the Trans-West management staff, to capture their feedback regarding their experience with the TPMS.

4.2 Vehicle logbooks

A logbook was prepared for each of the test and control trucks, which contained information regarding the test campaign, specific instructions, and a booklet of 40 checklists that were to be completed in accordance with a prescribed schedule and submitted to the NRC through FPI. The logbook for the test trucks included information regarding the installed TPMS, and the checklists included cells to record TPMS data shown on the display unit. The checklists were to be completed pre-trip by a Trans-West mechanic, and mid-trip by the drivers. Since each trip was approximately one week long, the objective was to receive four checklists from the drivers and four checklists from the garage for each truck, every month. The logbooks for both the test and control trucks, including the first two checklists, are attached as Appendix A and Appendix B, respectively.

The drivers of both the test and control trucks were instructed to record tire pressures and temperatures using the tire pressure gauges and infrared thermometers supplied by the NRC. The date, truck mileage, and ambient temperature (as displayed on the dash of the truck) were also recorded. The drivers of the seven test trucks also recorded the tire pressures and temperatures displayed on the TPMS display unit.

Trans-West mechanics were supplied with the same tire pressure gauge and infrared thermometer as the drivers, which they used to measure and record tire pressures and temperatures. Like the drivers, they also recorded the date, truck mileage, and ambient temperature, as well as the tire pressures and temperatures displayed on the TPMS display unit of the seven test trucks. The mechanics also measured and recorded the tire tread depth at three locations along the top of each tire – the outer, middle and inside edge.

A summary of data recorded on the driver and mechanic checklists is provided in Table 7. A sample checklist completed by FPI at the Trans-West garage is shown in Figure 10.

Truck	**TPMS display**			**Manual capture**			**Date/ time**	**Exterior temperature**	**Truck odometer**	**Location**
	Pressure	Temperature	Warnings	Pressure	Temperature	Tread depth				
Test	D/M	D/M	D/M	D/M	D/M	M	D/M	D/M	D/M	D/M
Control	-	-	-	D/M	D/M	M	D/M	D/M	D/M	D/M

D – Truck drivers M – Trans-West mechanics

Table 7: Summary of data recorded on driver and mechanic checklists

MONTHLY - TPMS Continental Tire Check List

Front Tire: Michelin X-Line Energy Z 275-80 R22.5

Rear Tire: Michelin X-Line Energy D 275-80 R22.5

Exterior temperature 26 °C

Unit	165717
Date/Time	July 6th, 2021
Odometer KM	932915
Name	Marc Trudeau
Location	Lachine, QC

	Left Front		Right Front	
TPMS Dash Display				
Tire Pressure	105	Psi	105	Psi
Tire Temperature	23	°C	26	°C
Tire Pressure Gauge				
Tire Pressure	105	Psi	105	Psi
Tire Thread Gauge (center)				
12 o'clock position	18	/32	18	/32
Infrared thermometer				
Tire Temperature	31	°C	28	°C

	Left Outside		Left Inside		Right Inside		Right Outside	
TPMS Dash Display								
Tire Pressure	81	Psi	81	Psi	81	Psi	78	Psi
Tire Temperature	35	°C	27	°C	26	°C	25	°C
Tire Pressure Gauge								
Tire Pressure	82	Psi	81	Psi	81	Psi	78	Psi
Tire Thread Gauge (center)								
12 o'clock position	20	/32	20	/32	21	/32	21	/32
Infrared thermometer								
Tire Temperature	42	°C	45	°C	46	°C	46	°C

	Left Outside		Left Inside		Right Inside		Right Outside	
TPMS Dash Display								
Tire Pressure	83	Psi	82	Psi	82	Psi	81	Psi
Tire Temperature	32	°C	26	°C	40	°C	29	°C
Tire Pressure Gauge								
Tire Pressure	83	Psi	81	Psi	81	Psi	82	Psi
Tire Thread Gauge (center)								
12 o'clock position	20	/32	21	/32	21	/32	21	/32
Infrared thermometer								
Tire Temperature	47	°C	47	°C	47	°C	51	°C

Figure 10: Sample checklist completed by FPI at Trans-West garage

4.3 Commencement of data collection

An initial shakedown period of 4-6 weeks was deemed necessary to allow adequate time for TPMS sensor and system issues to be properly identified and rectified. The unofficial recording of vehicle network and TPMS sensor data began in November 2020, and the drivers and mechanics began completing checklists in January 2021. However, the official data collection start date was delayed beyond the initial 4-6 week timeframe for several reasons:

- the scheduled 2020 Christmas holiday period;
- a Quebec provincial COVID-19 lockdown which took effect on December 25, 2020, and restricted FPI personnel access to the Trans-West facilities;
- the sudden death of the maintenance manager at Trans-West fleet headquarters; and
- a telematics data collection issue noted in mid-February 2021, where it was discovered that the TPMS data channels were not being properly recorded to the Isaac telematics units.

As a result the official data collection start date was February 24, 2021, and the test campaign was extended such that data collection ended around end-November 2021.

4.4 Data collection methodology

Telematics data, which included vehicle network data for all trucks and TPMS sensor data for the seven test trucks, were downloaded on a regular basis from the trucks to a Trans-West server. FPI accessed and downloaded the raw telematics data using an FTP client, and subsequently advised the NRC that new data were available for download from FPI. The NRC downloaded the data and organized them into subfolders by month and truck number; however, due to reporting limitations of the commercially available Isaac Instruments InDetail software, it was not possible to analyze one month of telemetry data for an individual truck. The data were subsequently uploaded to an Isaac Instruments cloud server and an Isaac Instruments technical representative re-organized all recorded segments of data into one file for each truck for each month. These constructed data files were then downloaded by the NRC and stored on a secure NRC network drive.

The logbook checklists completed by the drivers and mechanics were scanned by a Trans-West employee after the trucks returned to the Trans-West garage. They were provided to FPI who forwarded them on a bi-weekly basis to the NRC. The NRC transposed the hand written checklist entries and driver/mechanic comments to a Microsoft Excel spreadsheet, which facilitated analysis of the manually recorded data.

5 Data Analysis

The Microsoft Excel spreadsheet that was created from the logbook checklists permitted some basic data analysis to assess the accuracy of the TPMS sensors. It also enabled a comparison of tire wear between the test and control trucks, and provided some insight into the quality of data. The specific analyses and findings are presented in Section 6.

The telematics data were used to investigate specific events, to determine if the TPMS provided the appropriate warnings and to assess whether or not the driver responded to the warnings. The data files were analyzed by the NRC using Isaac Instruments InDetail V9.2 software.

6 Results

6.1 Truck mileage

The mileage on each of the test and control trucks at the time the test tires were installed is noted in Section 3.1. The mileage at the end of the test campaign was read from the last telematics data file that contained TPMS data (for the test trucks), and the last available telematics data file near the end of November 2021 for the control trucks. The initial and final odometer readings, the date of the final odometer reading, and the accumulated mileage on the trucks during the test campaign are presented in Table 8.

Truck	Initial mileage (km)	Final mileage (km)	Test Campaign end date	Accumulated mileage (km)
165711	716,659	1,176,350	30-Nov-21	459,691
165712	675,870	1,022,238	16-Nov-21	346,368
165713	652,960	982,658	02-Dec-21	329,698
165714	637,409	1,003,125	24-Nov-21	365,716
165715	697,846	1,048,927	15-Nov-21	351,081
165716	634,138	1,004,688	01-Nov-21	370,550
165717	704,501	1,058,708	07-Nov-21	354,207
165718	624,471	1,032,533	22-Nov-21	408,062
165719	703,551	1,080,923	04-Dec-21	377,372
165720	616,905	962,200	30-Nov-21	345,295
			Lowest accumulated mileage:	329,698
			Highest accumulated mileage:	459,691
			Average accumulated mileage:	370,804

Table 8: Accumulated mileage on trucks during test campaign

6.2 Tire maintenance

To minimize and balance tire wear, the test tires were rotated and a front wheel alignment was performed as required. It was apparent during the data analysis that tire wear was consistent for both front tires, and for all eight drive tires, so the average tire wear for the front tires and the drive tires was used.

6.2.1 Tire rotation

The truck drive tires were rotated once they accumulated approximately 250,000 km, or if there was a delta in treadwear of more than 2/32 in. Trans-West's drive axle tire rotation pattern is shown in Figure 11. When the tires were rotated the TPMS sensors were reprogrammed to report the correct tire position.

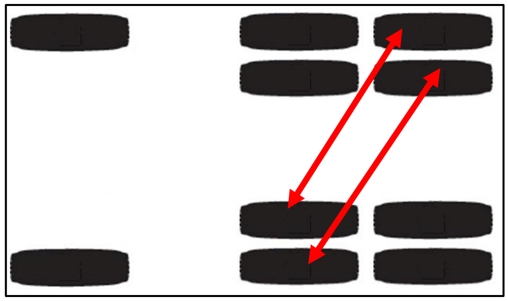


Figure 11: Drive tire rotation pattern

6.2.2 Front wheel alignment

The typical life span of a steer tire is approximately 250,000 km, and many of the steer tires used in this test program significantly exceeded this mileage. Factors such as weather, maintenance (including tire pressure and alignment) and load can impact steer tire life span. It was necessary to replace the steer tires on some trucks during the test campaign due to alignment issues which caused uneven wear. The NRC was advised that as part of the Trans-West preventive maintenance program, all trucks received at least one wheel alignment (however, details were not received for two of the trucks). A summary of the front wheel alignments that were performed is presented in Table 9. It was noted that there was only one mention of an alignment on a submitted checklist, and the dates of all other alignments do not correspond to checklists. Such challenges with data collection are further discussed in Section 7.

Truck	Date of wheel alignment	Mileage on test tires at time of wheel alignment (km)
165711	No wheel alignment data provided by Trans-West	
165712	14-Apr-21	193,404
	05-Oct-21	335,219
165713	16-Sep-21	460,176
165714	04-Aug-21	268,568
165715	21-Apr-21	165,785
	27-Sep-21	315,654
165716	30-Sep-21	332,102
	18-May-21	226,397
	06-Apr-21	184,201
165717	03-May-21	172,701
	17-Nov-21	362,813
165718	04-Aug-21	312,455
165719	22-Apr-21	203,882
	16-Nov-21	358,320
165720	No wheel alignment data provided by Trans-West	

Table 9: Summary of front wheel alignments performed during test campaign

6.3 Submission of checklists

Completion of logbook checklists was initially scheduled to begin the week of November 15, 2020, but due to project delays the first checklist was completed by a Trans-West mechanic on January 6, 2021. The first driver checklist was received on January 19, 2021.

Unfortunately, not all of the driver checklists were completed. In fact, one driver refused to participate so no driver checklists were received for that truck. Furthermore, some of the checklists that were submitted were not 100% complete. At the conclusion of the test campaign a total of 85 test truck checklists and 76 control truck checklists were received from the drivers. This represents a return rate of 30% and 63% of the expected checklists for the test and control trucks, respectively. The total quantity of driver and mechanic checklists received for each truck is summarized in Table 10, and the date of the last driver and mechanic checklist received for each truck is summarized in Table 11.

Test truck	Quantity of checklists received	
	Driver	Mechanic
165712	0	6
165713	7	5
165714	20	9
165715	21	7
165716	11	5
165717	13	8
165719	13	6
Total	**85**	**46**

Control truck	Quantity of checklists received	
	Driver	Mechanic
165711	26	6
165718	26	7
165720	24	6
Total	**76**	**19**

Table 10: Quantity of completed driver and mechanic checklists received for each truck

Test truck	Date of last checklist received	
	Driver	Mechanic
165712	-	15 Jun 21
165713	23 Jul 21	5 Aug 21
165714	7 Sep 21	5 Aug 21
165715	29 Sep 21	14 Jun 21
165716	5 Oct 21	7 Jun 21
165717	8 Oct 21	5 Aug 21
165719	14 Oct 21	14 May 21

Control truck	Date of last checklist received	
	Driver	Mechanic
165711	22 Dec 21	6 Jul 21
165718	19 Oct 21	14 Jul 21
165720	17 Dec 21	5 Aug 21

Table 11: Date of last completed driver and mechanic checklist received for each truck

6.4 Low pressure warning functionality spot check

The Trans-West mechanic and FPI representative conducted a low pressure warning functionality spot check at the Trans-West garage on September 9, 2021. For this test the truck was parked in the garage and the tires were cold. One front tire and two rear tires on truck 165715 were rapidly deflated by removing the valve core, and the tire pressures and warnings presented on the display unit were noted. The results are presented in Table 12.

	Tire position		
	Left front	Second axle left outer	Second axle left inner
Initial tire pressure shown on TPMS display unit (psi)	104	84	83
Tire pressure when TPMS low pressure warning triggered (psi)	85	61	63

Table 12: TPMS low pressure warning functionality spot check

For this test the truck was stationary and the engine was off. As detailed in Section 2.3.1, the sensor data update rate at the start of the test would have been every 16 s until a fast pressure loss was detected, and then the update rate would have been every 4 s. Since the tires were deflated very quickly, the warning was triggered at a lower pressure than that programmed into the TPMS. As detailed in Section 3.1, a warning should have been triggered at a tire pressure of 94 psi for the front tire and 72 psi for the rear tires. It is expected that a slower deflation rate would have resulted in an earlier warning (closer to the programmed warning threshold). Nevertheless the TPMS accurately detected the fast pressure loss in each of the tires, and presented the appropriate high-level warning.

Trans-West's implementation of the Isaac Instruments telematics programming was such that telematics data were recorded only when the truck was driving or idling. Unfortunately this spot check test was performed while the truck engine was off so no TPMS telematics data were recorded.

6.5 TPMS accuracy and reliability

The pressure and temperature data collected from the logbook checklists was examined to assess the accuracy, consistency and reliability of the TPMS. The data were entered by one or several drivers who operated each truck, one mechanic at the Trans-West garage, and one FPI representative. Identical high-quality pressure and temperature gauges were used, and it is assumed that they provided accurate results.

A version of the spreadsheet dated August 23, 2021, was used for the following analysis. Although the test campaign ended in November 2021, the last driver checklist for each of the test trucks was received between July 23 and October 14, 2021 (as noted in Section 6.3). It is also suspected that the quality of the data may have deteriorated as the drivers became tired of taking manual measurements, so the data collected in the early portion of the test campaign may be of a higher quality.

6.5.1 Comparison of tire pressure measurements

To conduct this analysis it was desirable to eliminate as many variables as possible, but include as much available data as possible. It is expected that the data collected by the Trans-West mechanic and FPI personnel were carefully obtained and are therefore accurate and reliable. Where there were several drivers, it was sometimes obvious which drivers took the time to collect high-quality data, and which drivers were less committed to the test objectives. For example, in some cases the same tire pressure was reported for all drive tires, which is highly unlikely. The data used for analysis were carefully selected to exclude data which were incomplete or appeared to be unreliable. The data for those few trucks with the highest number of completed checklists were examined.

Truck 165714 had six checklists from the mechanic, nine checklists from one driver, and one checklist from FPI, spanning a period from January 6 to July 6, 2021. The average delta between the TPMS and manual tire pressure measurements for all tires was 0.3 psi, and the standard deviation was 1.7 psi. Note that the tire pressure gauge displayed the tire pressure in 2-psi increments. It was noted that the driver twice reported a discrepancy between the TPMS and manual tire pressure measurements for one specific tire, where the TPMS was displaying a pressure 7-12 psi lower than the manual measurement. When the truck returned to the garage a metal object was discovered in the tire, and the tire was replaced. The tire was apparently leaking, so the accuracy of the manual tire pressure measurement is questionable. There was no available telematics data at this time so it is not possible to review the data.

Truck 165715 had one driver during the period January 6 to August 9, 2021. However, it was noted that there were some large discrepancies between the manual gauge reading and the TPMS sensor reading – up to 34 psi. This raised some doubt as to the accuracy of the manual measurements or the recording of the manual and TPMS readings. So the first analysis was performed using six checklists from the mechanic and one checklist from FPI. The average delta between the TPMS and manual tire pressure measurements for all tires was 0.3 psi, and the standard deviation was 1.1 psi. Note that these findings are very consistent with those for truck 165714. A subsequent analysis was performed using only the 17 checklists completed by the driver. In this case the average delta between the TPMS and manual tire pressure measurements for all tires was 1.0 psi, but the standard deviation was 5.6 psi. This shows significantly more variation than the data provided by the mechanic.

Truck 165719 had two drivers during the period January 15 to August 4, 2021. The data appeared to be complete and consistent, so 13 checklists from the drivers, five checklists from the mechanic and one checklist from FPI were included in the analysis. The average delta between the TPMS and manual tire pressure measurements for all tires was 0.7 psi, and the standard deviation was 1.9 psi.

The findings described above are summarized in Table 13.

Truck	Checklists		Average Delta (psi)	Standard Deviation (psi)
	Source	Quantity		
165714	mechanic driver FPI	6 9 1	0.3	1.7
165715	mechanic FPI	6 1	0.3	1.1
	driver	17	1.0	5.6
165719	mechanic driver driver FPI	5 2 11 1	0.7	1.9

Table 13: Comparison of tire pressure measurements – summary of findings

From this analysis it can be concluded that the TPMS sensors provide an accurate tire pressure measurement. Under the most controlled conditions, where only the manual tire pressure measurements obtained by the same mechanic and FPI representative were considered, the average delta between the

TPMS and manual tire pressure measurements for all tires was 0.3 psi, with a standard deviation of 1.1 psi.

6.5.2 Comparison of temperature measurements

Although the ambient temperature at the truck was recorded, it is difficult to assess the accuracy of the TPMS sensor by comparing to the ambient temperature. If the truck tires are hot (i.e., any time after the truck has been moving), there would be little correlation between tire temperature and ambient temperature. The only time this comparison could be made is after the truck has been parked for an extended period (such as overnight), and it is not exposed to sun or wind. There were instances where the truck was parked inside the garage at Trans-West (as noted on the checklist), and in each of these cases the tire temperature reported by the TPMS and the temperature measured with the infrared thermometer were in close agreement (within 1-2°C).

Since the tire temperatures were measured using an infrared thermometer, it is possible to compare that measurement with the TPMS sensor temperature measurement. It must be noted, however, that the TPMS sensor is affixed to the tire liner, so it measures the internal temperature of the tire at that specific location of the tire liner. The infrared thermometer was aimed at the exposed outer surface of the tread or sidewall, so it would not be surprising if there was a significant delta between the two temperature measurements. Furthermore, the actual spot on the tire where the tire temperature was obtained likely varied considerably between all of the drivers and the mechanic. Therefore only the measurements obtained by the mechanic were considered for this analysis.

Again, a version of the spreadsheet dated August 23, 2021, was used for this analysis. Considering only 100% complete checklists completed by the mechanic, a total of 19 checklists were analyzed. The average delta between the TPMS and manual tire temperature measurements for all tires was 1.0°C, and the standard deviation was 3.2°C. The maximum delta was 16°C. Considering the stated assumptions and sources of error, it appears that the TPMS sensor provides a reasonably accurate measurement of the tire temperature.

The same analysis was performed using checklists completed by the drivers (again, considering only those checklists that were 100% complete). In this case the average delta between the TPMS and manual tire temperature measurements for all tires was 0.0°C (this is a coincidental average value since there was significant variation in the data), and the standard deviation was 9.4°C. The maximum delta was 50°C. This analysis is not considered a reliable assessment of the accuracy of the TPMS sensor temperature measurement.

6.5.3 TPMS reliability

No issues with the TPMS sensor functionality were encountered, and no sensor error messages were reported by the TPMS (other than detached sensors detailed below). The CCU and display unit did not experience any functional issues.

One sensor became detached on truck 165717 on June 12, 2021. The appropriate warning was presented to the driver, and the sensor was reinstalled at the Trans-West garage on June 22, 2021. It subsequently became detached again on July 31, 2021, and was reinstalled again on August 4, 2021.

One sensor became detached on truck 165713 on July 24, 2021. The appropriate warning was presented to the driver, and the sensor was reinstalled at the Trans-West garage on August 5, 2021.

Given that two sensors did not adhere properly when the sensors were first installed in October, 2020, and there were three more instances of sensors becoming unglued, it appears that sensor adhesion could be a problem. Since the sensors are installed inside the tire, reinstalling sensors is a labour-intensive process.

6.6 Comparison of treadwear

Tread depth was measured at the Trans-West garage on all test and control trucks by the same mechanic every month, to the closest 1/32 in. Based on Michelin tire specifications, the new steer tires had a tread depth of 19/32 in., and the new drive tires had a tread depth of 23/32 in. Treadwear, the data of interest, is calculated as the new tire tread depth minus the remaining tread depth. When a tire was replaced (due to alignment issues or damage), no further data points for those steer or drive tires were included in the analysis.

The average tread depth measurements of the two steer tires of each truck, plotted against the accumulated mileage on the tires, is shown in Figure 12. The analysis included 38 data points for the test trucks and 17 data points for the control trucks. There does not appear to be any significant difference in the rate of tread wear between the test and control trucks. As discussed in Section 7, this is the expected finding since the TPMS was not used to initiate any unscheduled tire maintenance during the test campaign, the test and control trucks were operated in a similar manner, and the trucks were well maintained every month at the Trans-West garage.

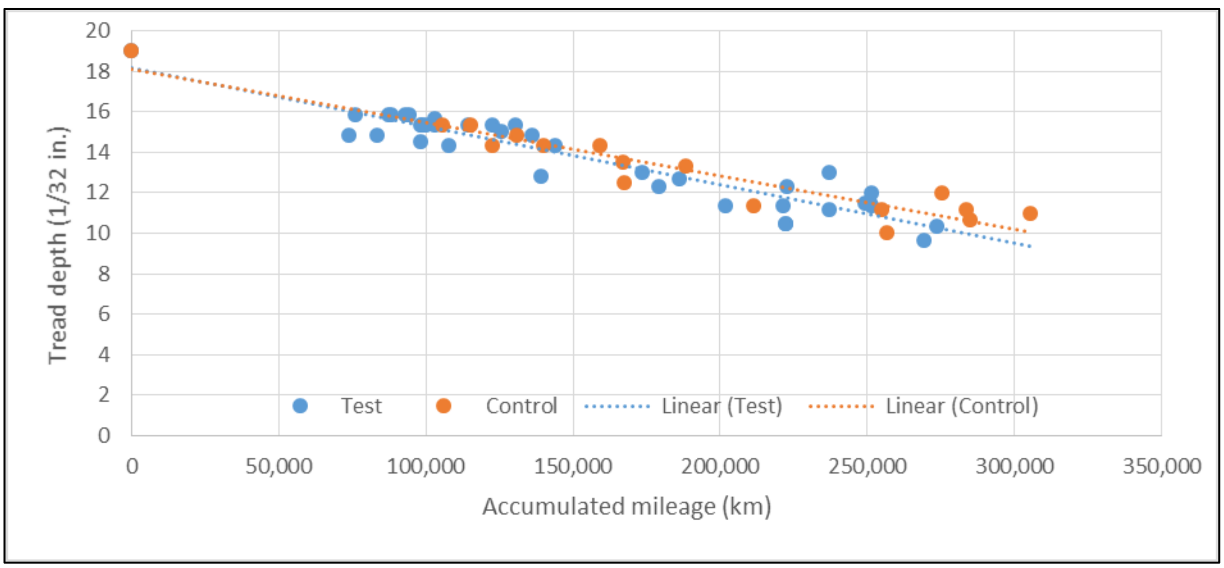


Figure 12: Comparison of remaining tread depth versus accumulated mileage on front tires

A similar comparison of the average tread depth measurements of the eight drive tires of each truck, plotted against the accumulated mileage on the tires, is shown in Figure 13. The analysis included 53 data points for the test trucks and 21 data points for the control trucks. Again, there does not appear to be any significant difference in the rate of tread wear between the test and control trucks.

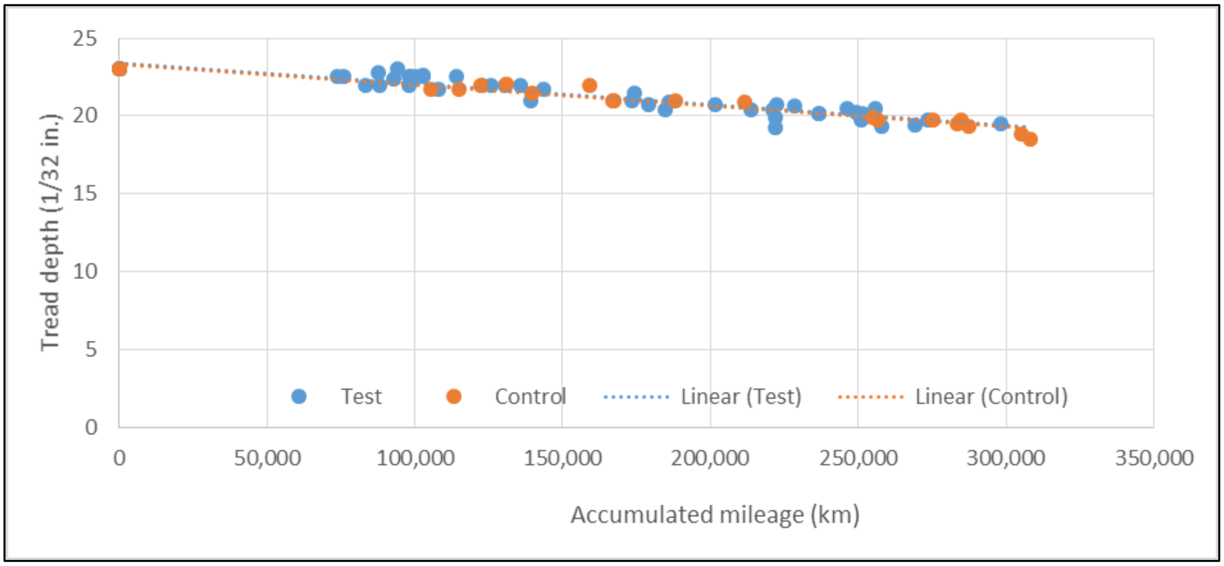


Figure 13: Comparison of remaining tread depth versus accumulated mileage on drive tires

6.7 Analysis of events

Considering the high accumulated mileage on the test fleet during the test campaign, there were very few incidents or events. As discussed in Section 7, Trans-West has a very thorough and proactive maintenance program which significantly reduces the likelihood of breakdowns. The experienced professional drivers did not incur any accidents. The only driving incident involved test truck 165717, where a jackknife incident removed the truck from service for a short period of time while the truck was repaired.

There were two tire events which are detailed below.

6.7.1 Event #1 – metal object embedded in tire

Event #1 occurred early in the test campaign during the period when no telematics data were being collected (as detailed in Section 4.3); therefore, the only available information is extracted from driver and mechanic checklists. The checklist completed by the driver on January 22, 2021, noted that the third axle right outside tire pressure displayed on the TPMS display was only 88 psi, while the other drive tires had pressures ranging from 94 to 99 psi. The driver recorded a manual tire pressure of 95 psi for that same tire, and did not comment on the discrepancy.

The checklist completed by the Trans-West mechanic on January 29, 2021, noted that the third axle right outside tire had been replaced by roadside service due to a metal object in the tire. There was no additional information. A new TPMS sensor was installed by the mechanic and reprogrammed by a Continental technical representative.

It is unknown whether or not the TPMS detected the pressure loss and triggered a warning when the tire pressure dropped below the set threshold. The discrepancy between the tire pressure displayed by the TPMS display and that measured by the driver using a manual gauge is discussed in Section 7.

6.7.2 Event #2 – pressure loss while in motion

On August 30, 2021, at approximately 8:03 pm EDT (5:03 pm PDT), truck 165714 began losing air pressure on the second axle left inner tire. The available telematics data were examined and it was noted that the tire pressure dropped in a linear manner from 98 psi to 2 psi in just over 5 min. The truck was travelling North on Highway I-15 in San Bernardino, California at a speed of 29 km/h when the pressure loss began, apparently because of a “rip” in the tire. Approximately 60 s later, at a tire pressure of 71 psi, the TPMS sensor triggered parameter ID2B_CTITireStatus and displayed a warning that a leak was detected. Approximately 30 s later, at a tire pressure of 63 psi, the TPMS sensor triggered parameter ID2B_CTIPresThresholdDetection and displayed an under-inflation warning.

The driver responded to the warnings and stopped the vehicle at the next rest area, which was less than 3 min away. The maximum speed during this timeframe was 53 km/h. During this period there was no significant change in the temperature of the deflated tire or the adjacent tire. The total mileage on the tire at the time of the event was 293,801 km.

The truck was stopped for less than 2 min at the rest area before the driver re-entered the highway and travelled at an average speed of 89 km/h for 2 hrs 33 min before arriving at the repair facility where the tire was changed. The maximum speed during the journey was 106 km/h. The truck arrived at the repair facility at 10:44 pm EDT (7:44 pm PDT). The temperature of the deflated tire did not rise during the trip, but the temperature of the adjacent tire rose throughout the trip from 57 to 73°C. Note that in the previous trip segment prior to the tire damage, the maximum temperature of the adjacent tire during a 3 hr trip was 58°C.

The tire was replaced and the truck resumed its journey at 1:18 am EDT (10:18 pm PDT). Since there was no tire sensor installed there was no data available for the replaced tire. A new sensor was installed at the Trans-West garage on September 2, 2021.

Plots of the telematics data around the time of this event are shown in Figure 14. The speed plot shows that the driver stopped the truck approximately 2 min after the warning was presented on the display. The pressure plot shows the consistent pressure of two tires leading up to the event, and then the steady pressure loss following the event until the tire was completely deflated.

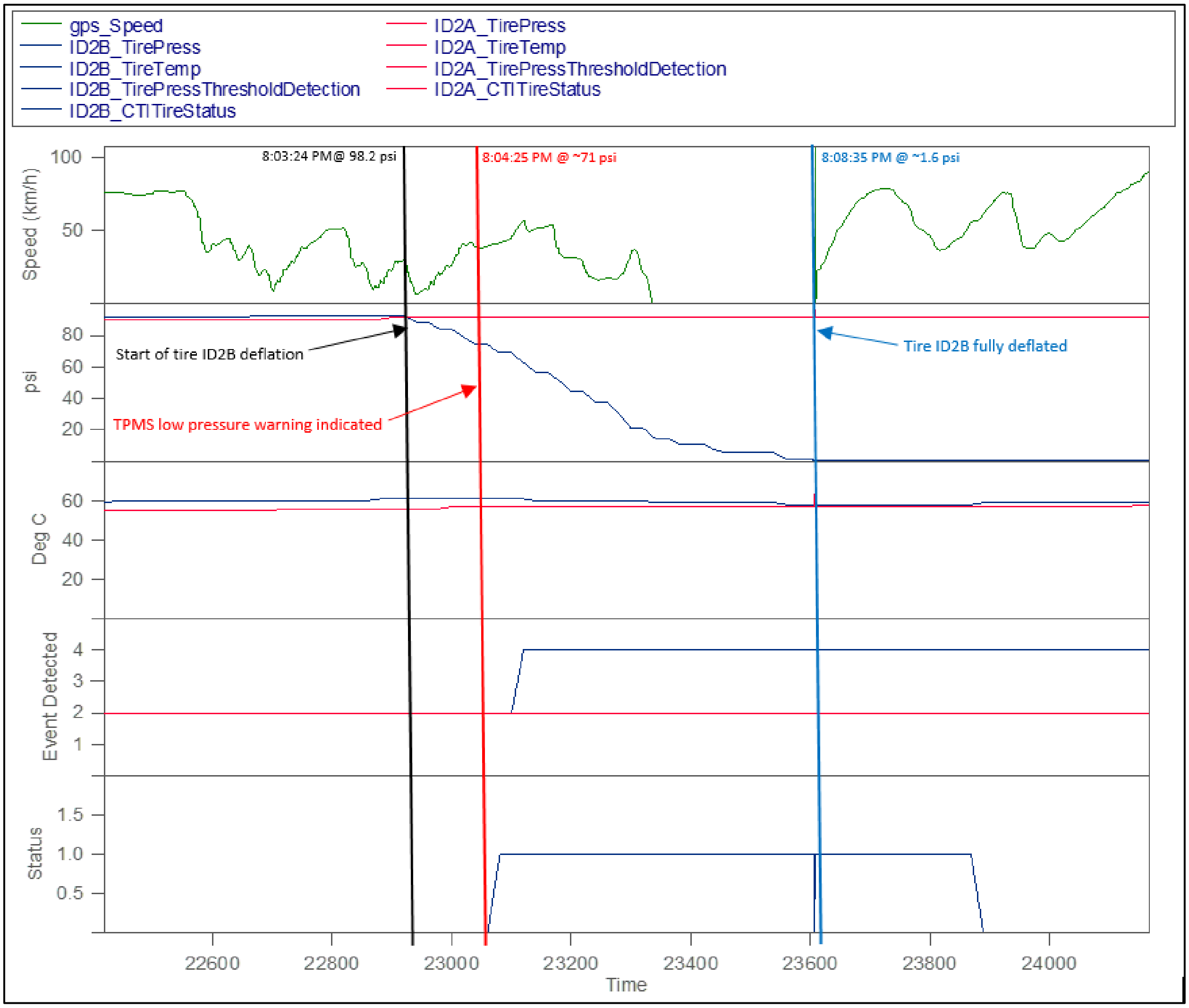


Figure 14: Plots of telematics data during pressure loss event #2

6.8 Surveys

6.8.1 Driver surveys

Upon completion of the test campaign, FPI interviewed the drivers of the test trucks to complete driver surveys. The comments were very consistent, and included the following responses:

- the system was accurate, very reliable, and easy to use;
- the drivers looked at the display often;
- the system was very useful for checking the tire pressure of the inside dual tires;
- using the TPMS was easier and more reliable than striking the tires with a hammer to check for proper inflation;
- the drivers would recommend the use of the system, and would install it on their own trucks;
- a TPMS would be very useful on a trailer as well as a tractor; and
- the screen was somewhat difficult to read in bright sunlight.

The one driver who refused to complete checklists provided positive feedback regarding the usefulness of the system (consistent with the responses of the other drivers).

6.8.2 Fleet management survey

FPI conducted a survey on September 9, 2021, with the following Trans-West employees: Andre Boisvert, Technological Development Vice President; Yannick Beaudry, Tire Specialist; and Greg Castillo, Head Mechanic. The completed survey is provided in Appendix C. The following is a summary of the fleet management survey responses:

- a positive recommendation for the purchase and installation of the Continental TPMS was indicated and that ~80% of fleet tire issues experienced during the test campaign were related to trailers, which did not contain TPMS sensors;
- technical support and training prior to TPMS installation was considered extremely complex and long;
- TPMS installation, programming and activation was demanding with medium difficulty;
- telematics connectivity was complex and long;
- TPMS did not increase tire life but was useful in minimizing irregular tire wear due to early detection of slow air leak events;
- an estimated fuel saving of 2-3% was noted by survey respondents but was not quantified with data at the time of the survey;
- labor and maintenance costs were reduced, but implementation of TPMS on the entire fleet would be necessary to know for sure;
- roadside issues/outages were reduced;
- truck safety was considered to be improved, potentially avoiding a tire blowout due to a slow air leak or an overheated tire (possibly due to a seized wheel bearing);
- accidents may be avoided by the driver being warned of a tire issue with sufficient time to stop the truck to investigate;
- disadvantages were initial cost, management of the system, labour related to tire rotation (necessary reprogramming of sensor location using Continental hand held unit), and tire replacement (application of sensor to new inner tire and necessary reprogramming on sensor location using Continental hand held unit);
- return on investment was considered strong, but would be dependent on fleet age and maintenance practices;
- visual and auditory warnings presented to drivers were at a proper level;
- low pressure, very low pressure and rapid pressure loss warnings were justified and valid;
- high temperature warnings were not justified;
- sporadic service interruptions or system defects were noted, specifically loose sensors;
- no permanent system failures were noted for either the tire sensors, control module, in-cab display screens or system electrical connections;
- no TPMS equipment maintenance was required after initial system installation;
- telematics issues were experienced but were not related to Continental TPMS but rather the telematics manufacturer (Isaac Instruments);
- TPMS reporting quality was perfect and reliable, and easy to understand;
- the Continental TPMS was not designed to interface with the Isaac telematics system;

- Trans-West did not have a yard reader implemented during the testing campaign which would have been useful for reporting to management;
- Trans-West performed an inspection of each truck at the end of each trip – adjustments to tire pressure minimized potential tire failures, improved fuel economy and extended tire life; and
- a typical fleet would likely benefit more from the use of TPMS.

7 Discussion

The test campaign collected data from three primary sources: driver checklists, telematics data, and surveys. It proved to be challenging to collect reliable data from all of the drivers. One driver refused to complete checklists, and it was only after the test campaign was well underway that this was discovered. Unfortunately it was not possible to swap drivers or trucks in order to engage a different driver. Some of the drivers appeared to complete the checklists neatly, and presumably accurately, while other drivers submitted hastily completed checklists that were difficult to decipher and were sometimes incomplete. There were instances where the manual tire pressure measurements appeared to be inaccurate since they were not in close agreement with the TPMS values, or they were the same values for all tires. It is acknowledged that manual tire pressure measurements are time consuming, and may not be the highest priority for a tired driver at the end of a long trip. As a result the quality of the checklist data supplied by the drivers was questionable. The checklists also became more sporadic as the test campaign progressed. The checklists submitted by the Trans-West mechanic appeared to be of a high quality; however, not all of the expected checklists were received. COVID-19, which led to Quebec provincial lockdowns and NRC travel bans, made it difficult to obtain data first-hand, or liaise directly with both FPI and Trans-West personnel.

The telematics data, on the other hand, was complete and of excellent quality. It was challenging to obtain the data and process it for further analysis, especially since the NRC did not have direct access to the data, but it was available to explore trends and examine specific incidents like the event detailed in Section 6.7.2 (event #2 – pressure loss while in motion). The dataset could be useful for future data analysis regarding truck use and driver behaviour, and it could possibly support studies regarding the feasibility of predicting tire issues.

Trans-West follows a very through and proactive fleet maintenance schedule involving a mechanical inspection and any necessary repairs and adjustments each time a truck returns from a cross-country trip. Any issues related to suspension, wheel alignment, tire condition and tire pressure are addressed in a timely manner. Unless a specific tire issue was encountered on the road, the drivers were not required to adjust tire pressures or perform any maintenance. As a result there was no difference in the rate of tire wear on the test trucks versus the control trucks. The only real benefit of the TPMS was to provide a warning in the event of a tire pressure loss, so that the driver could take immediate action. A trucking fleet with a less proactive maintenance schedule may have experienced more frequent tire related issues due to a longer interval between maintenance inspections. The ROI for a TPMS solution would likely be considerably longer for a fleet such as Trans-West, compared to a fleet with a less proactive maintenance and inspection schedule. However, Trans-West would still benefit from potentially fewer breakdowns due to tire issues, and improved highway safety.

The Continental ContiPressureCheck™ TPMS appeared to be very effective and reliable. Given Trans-West's proactive maintenance schedule, there were only two tire incidents during the test campaign. The second incident, detailed in Section 6.7.2, illustrated the effectiveness of the system – the driver received a warning of a rapid tire pressure loss and then immediately stopped the truck to investigate the issue. The driver then drove to a repair facility 2-1/2 hours away, with the ability to monitor the temperature of the deflated tire and both the pressure and temperature of the adjacent tire which was now supporting an increased load. A roadside assistance call was avoided, and there were no issues driving to the repair facility. Replacing the tire in a timely manner may have prevented a tire blowout and perhaps an accident on the highway.

The only significant issue experienced with the Continental TPMS involved some sensors becoming unglued. This problem would likely be avoided if Continental's intelligent tires, instead of the Michelin tires used during this testing campaign, were installed on the trucks. Continental's intelligent tires come complete with a pre-mounted TPMS sensor. There were also challenges integrating the Continental TPMS with the Isaac Instruments telematics system, since the Continental system was not specifically designed to interface with it. The TPMS was designed to interface seamlessly with certain other telematics systems.

In the literature it was noted that trailers tend to experience more tire related issues than tractors. This was confirmed in the fleet management survey, where Trans-West indicated that approximately 80% of tire related issues or failures have been experienced on trailers. Implementation of TPMS sensors on trailers was not considered during this test campaign, mainly because the trailers are not married to specific trucks. Continental offers a feature of the ContiPressureCheck™ system called Automatic Trailer Learning (ATL), where the TPMS can automatically detect a trailer equipped with the system and program the truck display to show the trailer tires. This could be very useful for fleets that exclusively haul their own trailers.

There was no noticeable difference in treadwear between the test and control trucks, but this would likely have been affected by the proactive maintenance and inspection schedule followed by the fleet.

This project did not conduct a comparative analysis of fuel economy, however other studies have shown a 0.5-1.0% increase in fuel consumption (degradation in fuel economy) for a vehicle running with all tires underinflated by 10 psi [2] .

8 Conclusions

During the test campaign approximately 370,000 km were accumulated on each of the ten Trans-West trucks over a period of approximately 13 months. The Continental ContiPressureCheck™ TPMS was installed on seven of the trucks, and a total of 85 checklists (of the expected 280) were completed by the drivers of those trucks. Telematics data for all ten trucks were collected for approximately nine months. Surveys were completed by the truck drivers and management staff at Trans-West upon completion of the test campaign.

Some challenges were encountered integrating the Continental TPMS with the Isaac Instruments telematics system, requiring the assistance of Continental and Isaac technical representatives. Once the technical issues were overcome the collection of telematics data was reliable, generating a rich dataset pertaining to truck use and TPMS performance. There were three instances of a TPMS sensor becoming unglued during the test campaign. Otherwise the TPMS provided accurate and reliable data in all weather conditions, ranging from cold Quebec temperatures in February to warm desert temperatures in the summer. The telematics data appeared to be more accurate and reliable than the checklist data.

Given the proactive maintenance schedule followed by Trans-West, there were only two tire events during the test campaign. The first event occurred early in the campaign when there was no telematics data being collected, so details are limited. The second event provided an excellent example of the potential of a TPMS to alert the driver to a tire pressure loss, and potentially avoid a highway incident. For a fleet such as Trans-West, the ROI for a TPMS is likely longer than for a fleet with a less proactive maintenance and inspection schedule since the TPMS is not used to maintain tires at their optimal tire pressure – the tire pressures are adjusted at the garage on a regular basis, and the TPMS is only used to alert the driver of a tire pressure or temperature issue.

The driver surveys unanimously indicated a positive response to the use of the TPMS, since it provided the driver with very useful information. The drivers recommended that the system be installed on all trucks and trailers. The Trans-West fleet management survey also provided positive feedback, noting the challenges with implementing the system that was used for the test campaign.

Project team

The project team consisted of the following personnel:

- project manager: David Poisson
- lead researcher: Mark Croken
- report editor: Bruce Gaudet
- FPI liaison: Marc Trudeau

The NRC would also like to express appreciation for the participation and cooperation of Trans-West – its managers, drivers and mechanics – without whom this project would not have been possible. Similarly, the assistance from Continental and Isaac Instruments technical representatives was greatly appreciated.

Acronyms and abbreviations

ATIS	automatic tire inflation system
ATL	automatic trailer learning
CAN	controller area network
CCU	central control unit
CTIS	central tire inflation system
DOT	Department of Transportation
EDT	eastern daylight time
FMCSA	Federal Motor Carrier Safety Administration
FPI	FP Innovations
FTP	file transfer protocol
NRC	National Research Council of Canada
PDT	pacific daylight time
ROI	return on investment
SAE	Society of Automotive Engineers
SWB	single wide-based
TC	Transport Canada
TMC	American Trucking Association's Technology and Maintenance Council
TPMS	tire pressure monitoring system

References

[1] S. Brady, D. Van Order and A. Sharp, "Advanced Sensors and Applications: Commercial Motor Vehicle Tire Pressure Monitoring and Maintenance," U.S. Department of Transportation, Federal Motor Carrier Safety Administration, Washington, DC, February, 2014.

[2] "CONFIDENCE REPORT: Tire Pressure Systems," North American Council for Freight Efficiency, May 15, 2020.

[3] "ContiPressureCheck," Continental, [Online]. Available: https://www.continental-tires.com/transport/products/overview-product-lines/contipressurecheck. [Accessed 21 March 2022].

Appendix A: Vehicle logbook – test truck

TPMS TELEMATIC STUDY 2020-21

Booklet for fleet inspections & monthly checkups.

Package 1/10

Test Truck

2020-11-06

Overview

The scope of the test plan is limited to a total of 10 tractors, 7 of which are equipped with Tire Pressure Monitoring Systems (TPMS), 3 of which are the control group. The test plan will focus on how Gen 2 TPMS systems impact the following in real world usage:

- Tread wear
- Maintenance & downtime
- Long-term performance
- Long-term durability (cold, salt, etc.)
- Expected return on investment (control trucks)
- Usability factors (via surveys)

Included in this document are the required data logs for the tested trucks. Measurements from the TPMS dash display will be applicable to those equipped with the systems.

A trial length of 9 months was agreed upon with trip inspections mid and post trip. This would include 10 trucks checked at the Montreal hub and at mid route (west coast routes).

9 months x 10 trucks x 4 routes per month x 2 for mid trip reports = 720 total trip reports.

Included in the report package will also be 90 (9 months x 10 trucks) end of the month trip reports conducted by the PIT group to gather more detailed tread wear data, inspect the systems and collect all data from the fleet. An additional measurement will also be taken at project closeout.

The following items will be provided to the trucks:

	Test Truck	Control Truck
Fluke 59MAX Infrared Thermometer	✓	✗
Milton Model S-506 pressure gauge	✓	✓

***Also included in this package is a process checklist to be placed at the front of the binder, in case of repairs please note the service / repair performed, the reason, the odometer reading at time of repair, and circle the position repair on the weekly/monthly checklist.**

Questions?

Please contact:

Marc Trudeau, Senior Member Relation & Business Development Specialist

Phone: 514-782-4711, Cell: 514-952-0474, Email: marc.trudeau@fpinnovations.ca

Calendar Week Reference

Test Week	Dates			Form A (Pre-Trip Completed by	Form B (Mid trip) Completed by
1	15-Nov	to	21-Nov	PIT Group	Driver
2	22-Nov	to	28-Nov	Driver	Driver
3	29-Nov	to	05-Dec	Driver	Driver
4	06-Dec	to	12-Dec	Driver	Driver
5	13-Dec	to	19-Dec	PIT Group	Driver
6	20-Dec	to	26-Dec	Driver	Driver
7	27-Dec	to	02-Jan	Driver	Driver
8	03-Jan	to	09-Jan	Driver	Driver
9	10-Jan	to	16-Jan	PIT Group	Driver
10	17-Jan	to	23-Jan	Driver	Driver
11	24-Jan	to	30-Jan	Driver	Driver
12	31-Jan	to	06-Feb	Driver	Driver
13	07-Feb	to	13-Feb	PIT Group	Driver
14	14-Feb	to	20-Feb	Driver	Driver
15	21-Feb	to	27-Feb	Driver	Driver
16	28-Feb	to	06-Mar	Driver	Driver
17	07-Mar	to	13-Mar	PIT Group	Driver
18	14-Mar	to	20-Mar	Driver	Driver
19	21-Mar	to	27-Mar	Driver	Driver
20	28-Mar	to	03-Apr	Driver	Driver
21	04-Apr	to	10-Apr	PIT Group	Driver
22	11-Apr	to	17-Apr	Driver	Driver
23	18-Apr	to	24-Apr	Driver	Driver
24	25-Apr	to	01-May	Driver	Driver
25	02-May	to	08-May	PIT Group	Driver
26	09-May	to	15-May	Driver	Driver
27	16-May	to	22-May	Driver	Driver
28	23-May	to	29-May	Driver	Driver
29	30-May	to	05-Jun	PIT Group	Driver
30	06-Jun	to	12-Jun	Driver	Driver
31	13-Jun	to	19-Jun	Driver	Driver
32	20-Jun	to	26-Jun	Driver	Driver
33	27-Jun	to	03-Jul	PIT Group	Driver
34	04-Jul	to	10-Jul	Driver	Driver
35	11-Jul	to	17-Jul	Driver	Driver
36	18-Jul	to	24-Jul	Driver	Driver
37	25-Jul	to	31-Jul	PIT Group	n/a

Instructions

How am I to measure tire pressures?

- Please use the supplied Milton Model S-506 pressure gauge to measure tire pressures.

What am I to do if a single or multiple tire pressures are measured as below recommended pressures?

- Record the tire pressure displayed on the TMPS in-cab display and the manually measured tire pressure using the Milton gauge on the appropriate weekly spreadsheet.
- Follow normal Trans-West fleet manager instruction on how to correct tire pressure.

How am I to measure tire temperatures?

- Please use the supplied Fluke 59MAX Infrared Thermometer to measure tire temperatures.

Do I need to measure tire tread depths?

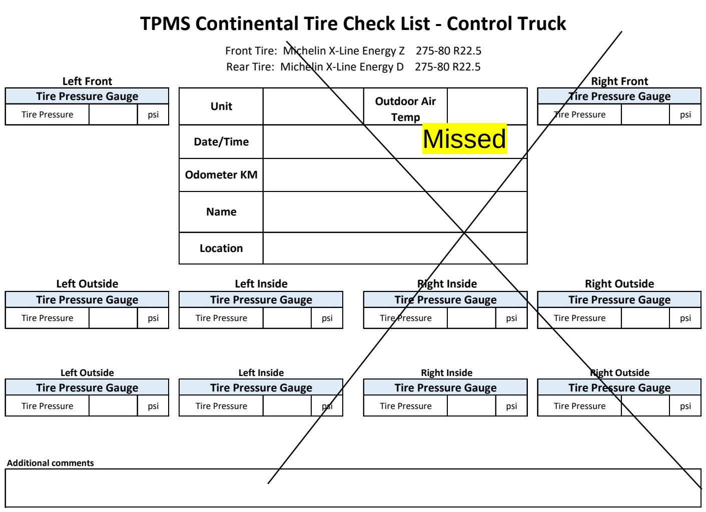
- No. These measurements will be completed by a mechanic during routine servicing at the fleet garage.

What do I do if a tire flat tire or damaged tire is noted or experienced?

- Follow the normal fleet procedures when a flat or damaged tire is experienced.

What do I do if I forget to fill in a form?

- If you have forgotten or missed filling in a form please draw an ‘X’ across the form and write “Missed” in the Date/Time box as shown below.



TPMS Continental Tire Check List - Control Truck

Front Tire: Michelin X-Line Energy Z 275-80 R22.5
Rear Tire: Michelin X-Line Energy D 275-80 R22.5

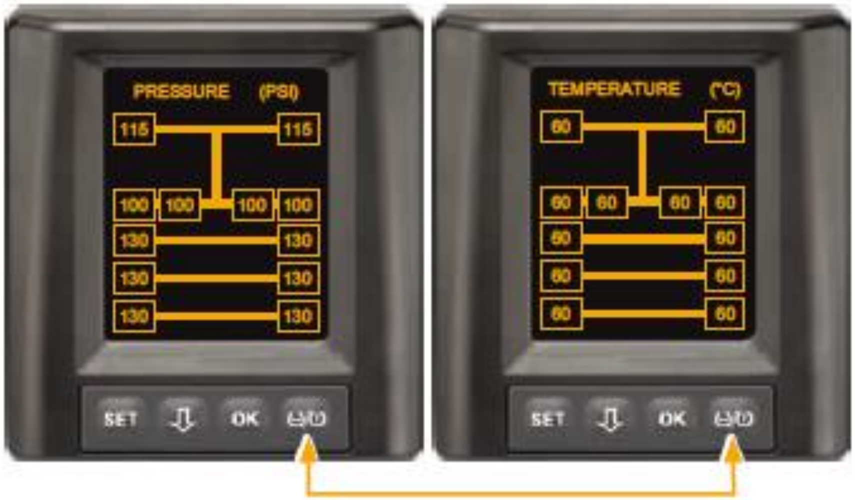
Unit	
Outdoor Air Temp	
Date/Time	Missed
Odometer KM	
Name	
Location	

Left Front — Tire Pressure Gauge — Tire Pressure ___ psi
Right Front — Tire Pressure Gauge — Tire Pressure ___ psi
Left Outside — Tire Pressure Gauge — Tire Pressure ___ psi
Left Inside — Tire Pressure Gauge — Tire Pressure ___ psi
Right Inside — Tire Pressure Gauge — Tire Pressure ___ psi
Right Outside — Tire Pressure Gauge — Tire Pressure ___ psi
Left Outside — Tire Pressure Gauge — Tire Pressure ___ psi
Left Inside — Tire Pressure Gauge — Tire Pressure ___ psi
Right Inside — Tire Pressure Gauge — Tire Pressure ___ psi
Right Outside — Tire Pressure Gauge — Tire Pressure ___ psi

Additional comments

TPMS Display Operation Keys and Warning Symbol Description

Switching between pressure and temperature display



- Press the button to change between the temperature display and the pressure display.

Priority:	Level	Symbol	Warning message	Reason
High	High	72 2*)	FAST PRESS. LOSS	Continuous, fast pressure loss. Tire damage and tire destruction will occur.
	High	77 1*), 2*)	VERY LOW PRESSURE	The tire pressure falls below the recommended alarm threshold value. Tire damage or even tire destruction is possible.
	High	2*)	CHECK SENSOR	The Tire Sensor is no longer properly affixed.
	Low	86 1*)	LOW PRESSURE	The tire pressure falls below the recommended warning threshold value. Tire damage or even tire destruction is possible.
	Low	116	TEMPERATURE	The measured temperature in the tire exceeds 115 °C (239 °F). The Tire Sensor no longer functions at 120 °C (248 °F).
	Low		NO SIGNAL	Due to insufficient signal strength, it is not possible to display a sensor protocol.
Low	Low		SENSOR DEFECT	Tire Sensor is defective

System Error – Low Priority Messages

Tire Sensor defect

Warning type: Low-level warning

Warning message: Sensor defect

Error: The Tire Sensor is defective.

Action: Ask the garage to remove the tire as soon as possible and replace the Sensor. (In the case of a defective Tire Sensor, no pressure/ temperature warning is possible).

No signal

Warning type: Low-level warning

Warning message: No signal

Error: Due to insufficient signal strength, it is not possible to display a Sensor Protocol.

Action: The authorized garage must clarify the cause for insufficient signal strength. If no signal is received, no pressure/temperature warning is possible.

Temperature

Warning type: Low-level warning

Warning message: Temperature

Error: The measured temperature in the tire exceeds 115 °C (239 °F). The Tire Sensor no longer functions from 120 °C (248 °F).

Action: Stop the truck immediately at a suitable location. Allow the tire concerned to cool down and then check it.

Low pressure

Warning type: Low-level warning

Warning message: Low pressure

Error: The tire pressure falls below the recommended warning threshold value. Tire damage or even tire destruction is possible.

Action: At the next opportunity (e.g., tire service, gas station, etc.) investigate the cause of low pressure and set the correct pressure. If the tire is damaged by a nail for example, arrange a repair or replacement by a specialist as soon as possible.

System Error – High Priority Messages

Check Sensor

Both displays appear alternately at intervals of 1.5 seconds.

Warning type: High-level warning

Warning message: Check Sensor

Error: The Tire Sensor is not properly affixed.

Action: Get the tire removed as quickly as possible by specialist staff at a tire dealer and allow the Tire Sensor and Tire Sensor Container to be replaced by a specialist.

Very low pressure

Both displays appear alternately at intervals of 1.5 seconds.

Warning type: High-level warning

Warning message: Very low pressure

Error: The tire pressure falls below the recommended alarm threshold value. Tire damage or even tire destruction is possible.

Action: Stop the truck at a suitable location as soon as possible and investigate the cause of the low pressure.
Top up the tire pressure and make sure that the tire is checked by a specialist as quickly as possible.

Fast pressure loss

Both displays appear alternately at intervals of 1.5 seconds.

Warning type: High-level warning

Warning message: Fast press. loss

Error: Continuous, fast pressure loss. Tire damage and tire destruction will occur.

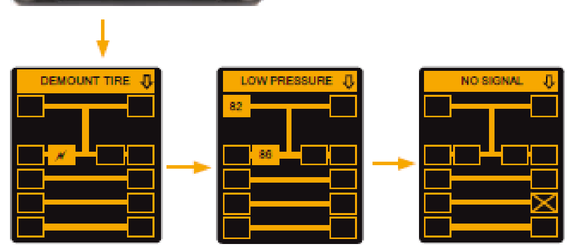
Action: Stop the truck immediately at a suitable location and investigate the cause of fast loss of pressure and ensure that the tire is checked by a specialist as soon as possible.

Multiple warnings

If various problems occur simultaneously, a multiple warning screen is displayed. Press the ⇩ -button to call up different warning messages.

Example of a triple warning message:

- In the header, the number of different warning messages or the individual warning screens is shown. Press the ⇩ -button to call up the individual warning screens.



Individual warning screens show the symbols of the individual warnings.

Process Checklist

TPMS Continental Tire Maintenance Log

Unit	
Date/Time	
Odometer KM	
Name	
Location	

Front Tire: Michelin X-Line Energy Z, 275-80 R22.5
Rear Tire: Michelin X-Line Energy D, 275-80 R22.5

Completed?

1. Steer and both drive axle tire pressures reading displayed on Continental TPMS in-cab display noted and recorded on weekly checklist.
2. Steer and both drive axle tire pressures measured with portable tire pressure gauge and values noted on weekly checklist.
3. Vehicle identification number recorded on weekly checklist.
4. Vehicle odometer reading noted and recorded on weekly checklist.
5. Date and time of weekly inspection recorded on weekly checklist.
6. Weekly tire maintenance log (copy) for each truck provided to PIT/NRC.
7. If tire service performed in past week please provide the following details:
   a. Replacement/repair service performed
   ____
   b. Reason for tire service
   ____
   c. Odometer reading at time of service
   ____
   d. Axle and tire position of repair
   ____

Initial Measurements & Monthly Report 1 (PIT Group) Week 1A

MONTHLY - TPMS Continental Tire Check List: Test Truck

Front Tire: Michelin X-Line Energy Z 275-80 R22.5
Rear Tire: Michelin X-Line Energy D 275-80 R22.5

Left Front

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Unit		**Outdoor Air Temp**	
Date/Time			
Odometer KM			
Name			
Location			

Right Front

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Left Outside

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Left Inside

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Right Inside

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Right Outside

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Left Outside

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Left Inside

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Right Inside

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Right Outside

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Did the TPMS system report any anomolies during the trip? (circle) Yes No

If so, what was the event?

Was the event real or a false alarm? (circle) Real False Alarm

What was the difference between the TPMS monitor screen and your measurement?

Additional comments

Mid-Trip Report Week 1B

WEEKLY - TPMS Continental Tire Check List: Test Truck

Front Tire: Michelin X-Line Energy Z 275-80 R22.5
Rear Tire: Michelin X-Line Energy D 275-80 R22.5

Left Front

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		°C
Tire Thread Gauge (center)		
Tread Depth		/32
Temperature Gun		
Tire Temperature		°C

Unit		Outdoor Air Temp	
Date/Time			
Odometer KM			
Name			
Location			

Right Front

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		°C
Tire Thread Gauge (center)		
Tread Depth		/32
Temperature Gun		
Tire Temperature		°C

Left Outside

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		°C
Tire Thread Gauge (center)		
Tread Depth		/32
Temperature Gun		
Tire Temperature		°C

Left Inside

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		°C
Tire Thread Gauge (center)		
Tread Depth		/32
Temperature Gun		
Tire Temperature		°C

Right Inside

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		°C
Tire Thread Gauge (center)		
Tread Depth		/32
Temperature Gun		
Tire Temperature		°C

Right Outside

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		°C
Tire Thread Gauge (center)		
Tread Depth		/32
Temperature Gun		
Tire Temperature		°C

Left Outside

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		°C
Tire Thread Gauge (center)		
Tread Depth		/32
Temperature Gun		
Tire Temperature		°C

Left Inside

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		°C
Tire Thread Gauge (center)		
Tread Depth		/32
Temperature Gun		
Tire Temperature		°C

Right Inside

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		°C
Tire Thread Gauge (center)		
Tread Depth		/32
Temperature Gun		
Tire Temperature		°C

Right Outside

TPMS Dash Display		
Tire Pressure		Psi
Tire Temperature		°C
Tire Pressure Gauge		
Tire Pressure		°C
Tire Thread Gauge (center)		
Tread Depth		/32
Temperature Gun		
Tire Temperature		°C

Did the TPMS system report any anomolies during the trip? (circle) Yes No

If so, what was the event?

Was the event real or a false alarm? (circle) Real False Alarm

What was the difference between the TPMS monitor screen and your measurement?

Additional comments

NOTE:

Mid-trips Reports continue until week 36B.

Monthly Reports repeat for a total of 10 inspections

Appendix B: Vehicle logbook – control truck

TPMS TELEMATIC STUDY 2020-2021 Project Logbook

Booklet for fleet inspections & monthly checkups.

Package 1/10

Control Truck

2020-11-06

Overview

The scope of the test plan is limited to a total of 10 tractors, 7 of which are equipped with Tire Pressure Monitoring Systems (TPMS), 3 of which are the control group. The test plan will focus on how Gen 2 TPMS systems impact the following in real world usage:

- Treadwear
- Maintenance & downtime
- Long-term performance
- Long-term durability (cold, salt, etc.)
- Expected return on investment (control trucks)
- Usability factors (via surveys)

Included in this document are the required data logs for the tested trucks. Measurements from the TPMS dash display will be applicable to those equipped with the systems.

A trial length of 9 months was agreed upon with trip inspections mid and post trip. This would include 10 trucks checked at the Montreal hub and at mid route (west coast routes).

9 months x 10 trucks x 4 routes per month x 2 for mid trip reports = 720 total trip reports.

Included in the report package will also be 90 (9 months x 10 trucks) end of the month trip reports conducted by the PIT group to gather more detailed tread wear data, inspect the systems and collect all data from the fleet. An additional measurement will also be taken at project closeout.

The following items will be provided to the trucks:

	Test Truck	Control Truck
Fluke 59MAX Infrared Thermometer	✔	✘
Milton Model S-506 pressure gauge	✔	✔

***Also included in this package is a process checklist to be placed at the front of the binder, in case of repairs please note the service / repair performed, the reason, the odometer reading at time of repair, and circle the position repair on the weekly/monthly checklist.**

Questions?

Please contact:

Marc Trudeau, Senior Member Relation & Business Development Specialist

Phone: 514-782-4711, Cell: 514-952-0474, Email: marc.trudeau@fpinnovations.ca

Calendar Week Reference

Test Week	Dates			Form A (Pre-Trip Completed by	Form B (Mid trip) Completed by
1	15-Nov	to	21-Nov	PIT Group	Driver
2	22-Nov	to	28-Nov	Driver	Driver
3	29-Nov	to	05-Dec	Driver	Driver
4	06-Dec	to	12-Dec	Driver	Driver
5	13-Dec	to	19-Dec	PIT Group	Driver
6	20-Dec	to	26-Dec	Driver	Driver
7	27-Dec	to	02-Jan	Driver	Driver
8	03-Jan	to	09-Jan	Driver	Driver
9	10-Jan	to	16-Jan	PIT Group	Driver
10	17-Jan	to	23-Jan	Driver	Driver
11	24-Jan	to	30-Jan	Driver	Driver
12	31-Jan	to	06-Feb	Driver	Driver
13	07-Feb	to	13-Feb	PIT Group	Driver
14	14-Feb	to	20-Feb	Driver	Driver
15	21-Feb	to	27-Feb	Driver	Driver
16	28-Feb	to	06-Mar	Driver	Driver
17	07-Mar	to	13-Mar	PIT Group	Driver
18	14-Mar	to	20-Mar	Driver	Driver
19	21-Mar	to	27-Mar	Driver	Driver
20	28-Mar	to	03-Apr	Driver	Driver
21	04-Apr	to	10-Apr	PIT Group	Driver
22	11-Apr	to	17-Apr	Driver	Driver
23	18-Apr	to	24-Apr	Driver	Driver
24	25-Apr	to	01-May	Driver	Driver
25	02-May	to	08-May	PIT Group	Driver
26	09-May	to	15-May	Driver	Driver
27	16-May	to	22-May	Driver	Driver
28	23-May	to	29-May	Driver	Driver
29	30-May	to	05-Jun	PIT Group	Driver
30	06-Jun	to	12-Jun	Driver	Driver
31	13-Jun	to	19-Jun	Driver	Driver
32	20-Jun	to	26-Jun	Driver	Driver
33	27-Jun	to	03-Jul	PIT Group	Driver
34	04-Jul	to	10-Jul	Driver	Driver
35	11-Jul	to	17-Jul	Driver	Driver
36	18-Jul	to	24-Jul	Driver	Driver
37	25-Jul	to	31-Jul	PIT Group	n/a

Instructions

How am I to measure tire pressures?

- Please use the supplied Milton Model S-506 pressure gauge to measure tire pressures.

Do I need to measure tire tread depths?

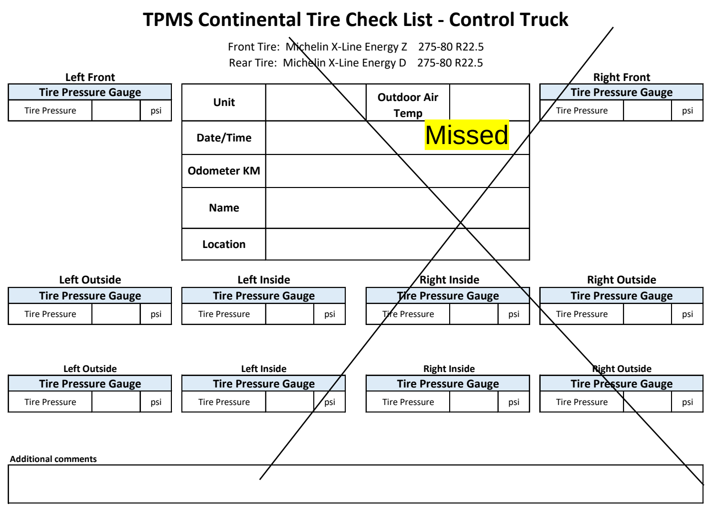
- No. These measurements will be completed by a mechanic during routine servicing at the fleet garage.

What do I do if a tire flat tire or damaged tire is noted or experienced?

- Follow the normal fleet procedures when a flat or damaged tire is experienced.

What do I do if I forget to fill in a form?

- If you have forgotten or missed filling in a form please draw an 'X' across the form and write "Missed" in the Date/Time box as shown below.



TPMS Continental Tire Check List - Control Truck

Front Tire: Michelin X-Line Energy Z 275-80 R22.5
Rear Tire: Michelin X-Line Energy D 275-80 R22.5

Left Front — Tire Pressure Gauge — Tire Pressure ___ psi

Right Front — Tire Pressure Gauge — Tire Pressure ___ psi

Unit		Outdoor Air Temp	
Date/Time	Missed		
Odometer KM			
Name			
Location			

Left Outside — Tire Pressure Gauge — Tire Pressure ___ psi
Left Inside — Tire Pressure Gauge — Tire Pressure ___ psi
Right Inside — Tire Pressure Gauge — Tire Pressure ___ psi
Right Outside — Tire Pressure Gauge — Tire Pressure ___ psi

Left Outside — Tire Pressure Gauge — Tire Pressure ___ psi
Left Inside — Tire Pressure Gauge — Tire Pressure ___ psi
Right Inside — Tire Pressure Gauge — Tire Pressure ___ psi
Right Outside — Tire Pressure Gauge — Tire Pressure ___ psi

Additional comments

Initial Measurements & Monthly Report 1 (PIT Group) Week 1A

MONTHLY - TPMS Continental Tire Check List: Control Truck

Front Tire: Michelin X-Line Energy Z 275-80 R22.5
Rear Tire: Michelin X-Line Energy D 275-80 R22.5

Left Front

Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Unit		**Outdoor Air Temp**	
Date/Time			
Odometer KM			
Name			
Location			

Right Front

Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Left Outside

Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Left Inside

Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Right Inside

Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Right Outside

Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Left Outside

Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Left Inside

Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Right Inside

Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Right Outside

Tire Pressure Gauge		
Tire Pressure		Psi
Tire Thread Gauge (center)		
12 o'clock position		/32
4 o'clock position		/32
8 o'clock position		/32

Additional comments

Mid-Trip Report Week 1B

TPMS Continental Tire Check List - Control Truck

Front Tire: Michelin X-Line Energy Z 275-80 R22.5
Rear Tire: Michelin X-Line Energy D 275-80 R22.5

Left Front

Tire Pressure Gauge		
Tire Pressure		psi

Unit		**Outdoor Air Temp**	
Date/Time			
Odometer KM			
Name			
Location			

Right Front

Tire Pressure Gauge		
Tire Pressure		psi

Left Outside

Tire Pressure Gauge		
Tire Pressure		psi

Left Inside

Tire Pressure Gauge		
Tire Pressure		psi

Right Inside

Tire Pressure Gauge		
Tire Pressure		psi

Right Outside

Tire Pressure Gauge		
Tire Pressure		psi

Left Outside

Tire Pressure Gauge		
Tire Pressure		psi

Left Inside

Tire Pressure Gauge		
Tire Pressure		psi

Right Inside

Tire Pressure Gauge		
Tire Pressure		psi

Right Outside

Tire Pressure Gauge		
Tire Pressure		psi

Additional comments

NOTE:

Mid-trips Reports continue until week 36B.

Monthly Reports repeat for a total of 10 inspections.

Appendix C: Trans-West management survey

Groupe PIT
FPInnovations

TPMS SURVEY, TRANSPORT CANADA

TRANS-WEST

100, 1900 52e Avenue
Lachine, Qc
H8T 2X9
514 345-1090

September 10, 2021

Dear/Dear participants

Thank you for taking the time to share your experience as a user of Continental's Conti-Check system

Please respond as accurately as possible so that we can know exactly your level of appreciation.

Please contact us if you have any questions or need clarification.

Kind regards,

Marc Trudeau, 514 782-4711
TPMS Survey, Transport Canada

Vehicle No: **<u>All TransWest trucks</u>**

Name of participants: **<u>André Boivert, Yannick Beaudry, Greg Castillo</u>**

Role/Duty: **<u>VP Tech, Tire Specialist, Head Mechanic</u>**

Date: **<u>September 9th, 2021</u>**

General administrative and mechanical issues:

Purchase: Choice of components and ease of purchase:

Is it possible to have the system installed in the factory?

Yes/No

With which truck manufacturer: ___________________________________
With which trailer manufacturer: __________________________________

Technical support and training before installation:

a) Simple and effective
b) Demanding with medium difficulty
c) Complex & long
d) Extremely complex and long

Ease of installation in the truck:

a) Easy and fast
b) Demanding with medium difficulty
c) Complex and long

Programming and commissioning:

a) Easy and fast
b) Demanding with medium difficulty
c) Complex and long

Telematics connectivity:

a) Easy and fast
b) Demanding with medium difficulty
c) Complex and long

Do you find that the system has?

Increased tire life (Steer and Drive separate)

Yes/No
How many percent and miles? ____

Minimizes irregular tire wear

Yes/No
How many percent? Difficult to evaluate but it will save irregular wear in a slow leak event.

Saved fuel

Yes/No
How many percent? 2-3%

Saved labour and maintenance costs

Yes/No
How many percent? Would have to implement the whole system to know.

Reducing road outages

Yes/No
How many percent? Depends on the problem and location.

Improved safety

Yes/No
How many percent? 100% in the case of a seized wheel bearing.
Example: Driver will avoid wheel lost and blow out on slow leaks.

3

Detect overheating

Yes/No
How? Alarm will trigger and send a specific message.

Avoiding accidents

Yes/No
How would it do that? Driver would stop the truck before it's too late.

Have Disadvantages:

Yes/No
Which? Initial cost and management, labour intensive when rotating and replacing tires.

Has a Business case for a Return on investment

Yes/No
How many percent? Depends on the fleet age, maintenance habits.

Drivers' comments on Warnings:

Proper sound level?

Yes/No

Proper visual?

Yes/No

Emails?

Yes/No

Alerts:

Were the low pressure tire alerts justified?

Low Pressure (10%)

Yes/No

Number of events: Not sure

4

Very low pressure (20% and more)

Yes/No

Number of events: Not sure

Rapid pressure loss

Yes/No

Number of events: Not sure

High temperature

Yes/No

Number of events: ___________________________________

Have you experienced sporadic service interruptions or system defects?

If so, how many: Yes

Which? Some sensors loosen up

System failure

Have you experienced permanent failures that require a part replacement?

Number of times:

Sensors: No

Screen: No

Module: No

Connection: No

Telematics: Yes, but not on the Continental side (Isaac)

5

Reports

Quality of information:

a) Perfect and 100% reliable
b) Very good and over 90% true
c) Okay, 80-90% true
d) Medium, 70-80% true
e) Wrong, less than 70% true

Easy understanding

a) Easy and fast
b) Demanding with medium difficulty
c) Complex and long

Maintenance

What kind of maintenance is required by the system?

a) None
b) Weekly
c) Monthly
d) Other:_______________

Do you recommend purchasing and using this system?

Yes/No
What for? Mostly the trailers since 80% of the problems occur on them.

Appendix D: Isaac telemetry system data channels

The following table summarizes the data channels that were recorded by the Isaac telemetry system, noting which channels were recorded when the truck was idling and which channels were recorded when the truck was driving.

	Data parameter	Idling	Driving
1	Acc_Lat	*	*
2	Acc_Long	*	*
3	Acc_Vert	*	*
4	Acc_X	*	*
5	Acc_Y	*	*
6	Acc_Z	*	*
7	ACCDistanceAlertSignal		*
8	AccelPedalPos1	*	*
9	AccLong_WBVS		*
10	ACCTargetDetected		*
11	ActualEnginePower	*	*
12	ActualEngPercentTorque	*	*
13	ActualEngTorque	*	*
14	ActualLimit	*	*
15	ActualPercentLimit	*	*
16	ActualRetarderPercentTorque	*	*
17	AdvancdEmgencyBrakingSystemState		*
18	Aftrtr1SCRCatalystTankLevel	*	*
19	AmbientAir	*	*
20	AmbientAirTemp_F	*	*
21	BoxT	*	*
22	BoxV	*	*
23	BrakeSwitch_1	*	*
24	Bsfc	*	*
25	CoachIsaac	*	*
26	CruiseCtrlActive	*	*
27	CruiseCtrlHighSetLimitSpeed	*	*
28	CruiseCtrlLowSetLimitSpeed	*	*
29	CruiseCtrlStates	*	*
30	DistanceToForwardVehicle		*
31	EcoMode	*	*
32	EnableSwitchTransInputShaftPTO1	*	*
33	EngCoolantTemp	*	*
34	EngFuelRate	*	*
35	EnginePTOGovonorEnableSwitch	*	*
36	EngPercentLoadAtCurrentSpeed	*	*
37	EngPercentLoadAtCurrentSpeed_1	*	*

	Data parameter	Idling	Driving
38	EngReferenceTorque	*	*
39	EngSpeed	*	*
40	EngTurboBoostPress_PSI	*	*
41	EstEngPrsticLossesPercentTorque	*	*
42	FanSpeed	*	*
43	ForwardColisionWarning		*
44	FuelEconomy	*	*
45	FuelLevel_1	*	*
46	GPS_Altitude	*	*
47	GPS_Course	*	*
48	GPS_Lat	*	*
49	GPS_Long	*	*
50	GPS_mode	*	*
51	GPS_NbSatellite	*	*
52	GPS_Speed	*	*
53	LaneDepartureImminentLefttSide		*
54	LaneDepartureImminentRightSide		*
55	LaneDepartureLeft		*
56	LaneDepartureRight		*
57	MaxVehicleSpeedLimit	*	*
58	NominalFrictionPercentTorque	*	*
59	ParkingBrakeSwitch	*	*
60	ParkingBrakeSwitch_1	*	*
61	ParkingBrakeSwitch_2	*	*
62	PTOGovonorState	*	*
63	PTOState_Volvo	*	*
64	PTOState_Volvo1	*	*
65	Retarder	*	*
66	RlvntObjctDectFrAdvancdEmrgncyBr		*
67	RoadCurvature		*
68	ROPBrakeCtrlActive		*
69	ROPEngCtrlActive		*
70	Safety	*	*
71	Shdwn_state	*	*
72	SpeedOfForwardVehicle		*
73	TEH1708	*	*
74	TEH1939	*	*
75	Time	*	*
76	TimeToCollisionwithRelevantObject		*
77	Top_Gear_State		*
78	TotalEngineHours	*	*
79	TotalVehicleDistance	*	*
80	TVD128	*	*
81	TVD142	*	*
82	VD	*	*

	Data parameter	Idling	Driving
83	VDHR	*	*
84	WheelBasedVehicleSpeed	*	*
85	WheelBasedVehicleSpeed_mph	*	*
86	YCBrakeCtrlActive		*
87	YCEngCtrlActive		*

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