Freight Sustainability Demonstration Program (FSDP)

Contribution Agreement Number 156357

Effects of Nitrogen Tire Inflation on Canadian Long Haul Trucking

Final Report

27 March 2007
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Drexan Corporation

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Executive Summary

This trial was highly successful. It set out to prove that Nitrogen minimized the effect of tire volume change with varying ambient temperature and that this would impact fuel economy and tread wear. It also set out to prove that tire pressure loss over time due to Oxygen and water vapour passing through the tire rubber would be minimized having an impact on fuel economy, tread wear, and tire casing life.

Fuel Economy

This trial proved through two independent methodologies that Nitrogen tire inflation increased the fuel economy of the fleet. We expected to see an improvement in the 2% to 4% range, in line with Transport Canada's projections attributable to correct tire inflation. We found that these projections were correct, with our results showing a 3.3% improvement in fuel efficiency when comparing a driver based tire maintenance program with a third party tire maintenance program. We found a further improvement attributable to Nitrogen tire inflation providing an impressive 6.1% when comparing Nitrogen inflation with a driver based tire maintenance program. This last result is significant since it exceeded expectations by double.

Tread Wear

This trial proved through measurement that tread wear would increase. We expected an increase in tread wear of 48% in line with previous studies. This trial proved that tread wear life was extended by over 75% which was one and a half times greater than our expectations.

Tire Casing Life

Results from the tire casing life analysis were inconclusive due to the low number of failures.

Freight Sustainability Demonstration Program (FSDP) Final Project Report[1]

Report Date: 20 February 2007
Contact: Konrad Mech
Report Name: Milestone #4 – Final Report

Project Status

Project's Key Objectives

The purpose of this activity was to demonstrate the effectiveness of Nitrogen Tire inflation in reducing fuel use, improving efficiency and decreasing the environmental impact of Canadian commercial fleet operations through maintenance of proper tire pressure over extended periods of time and wide temperature fluctuations. Drexan also comments on the added side benefits of improved safety of road transport fleet vehicles related to Nitrogen tire inflation.

Nitrogen tire inflation has been shown to increase tire life and maintain correct tire pressure over longer periods of time than compressed air. However, available data does not account for climactic changes that impact Canadian truck fleets. Two separate effects were studied:

- The first is the effect of tire volume change with varying ambient temperature. This impacts fuel economy and tread wear.
- The second is the effect of tire pressure loss over time due to Oxygen and water passing through the tire rubber. This also impacts fuel economy, wear, and tire casing life.

Description of the Project

Laboratory[2] and field tests[3] of Nitrogen tire inflation of new and retread tires point to potential longer life when compared to air inflation. Tires inflated with compressed air deflate over 4 times faster than tires inflated with Nitrogen, since

[1] This report was jointly authored by Andre Mech PEng, MECH and ASSOCIATES, and Konrad Mech PEng, Drexan Corporation.
[2] Effects of Nitrogen Inflation on Tire Aging and Performance, John M. Baldwin et. al., Ford Motor Company, Presented at a meeting of the Rubber Division, American Chemical Society, Grand Rapids, MI May 17-19, 2004.
Nitrogen Inflation for Truck Tires, Guy Walenga, Bridgestone/Firestone, Presented to the Clemson Tire Conference, March 11, 2004.
Factors in Tubeless Radial Tires, David M. Coddington, Exxon Chemical Co., 1993 Technical Yearbook of the Rubber and Plastics News
[3] Report S4-85, Million Mile Truck Tires – Available Today, Lawrence R. Sperberg, Stronger Longer Tires of El Paso, January 9, 1985.

oxygen and water vapour dissolve into and pass through the tire casing sidewall rubber.[4]* As the tire deflates, under inflation causes poor fuel economy and faster wear of tread rubber. As these gases pass through the casing, they also cause deleterious physical oxidative effects – breaking down the rubber, corroding steel belts, and causing air pockets at varying laminations in the tire rubber. Oxidation ultimately results in short casing life and premature tire replacement. Studies show that inflating tires with Nitrogen potentially decreases these problems.

Nitrogen tire inflation has been mandated in aircraft due to the intense and rapid environmental change experienced by aircraft tires. In aircraft, tires are exposed to external temperatures of minus 54 degrees Celsius and on landing in the tropics must withstand on landing temperatures of up to 50 degrees Celsius on the apron. This temperature swing can occur in as little as fifteen minutes and on landing tire pressure is critical. Nitrogen tire inflation maintains correct tire pressure over long periods of time and in extreme environments. This technology can be transferred to the transportation industry with the added benefits of improved fuel consumption, reduced waste and reduced GHG emissions.

There is much anecdotal evidence showing that Nitrogen tire inflation results in superior retention of correct tire pressure, and reduction or elimination of rubber oxidation. Eliminating oxygen inside the tire casing reduces or eliminates chemical aging of the tire rubber, which translates into longer service life and fewer tire failures. This in turn decreases safety hazards on the road and road-side litter. These benefits are documented, and are recognized by major tire manufacturers. However, the data needed to be validated with a made-in-Canada study, due to the unique operating conditions of Canadian long-haul trucking fleets, in order for mainstream trucking fleets to embrace this technology with confidence.

Project Implementation

The trial fleet, Harris Transport of Winnipeg, Manitoba, comprised 70 tractors and 117 trailers of different configurations (tandems, tridems, and Super B). For a list of all equipment in the trial see Appendix A.

Prior to the start of the trial, Harris Transport had to conduct administrative staff office training on the data collection systems. Staff were trained in Axion and SensorTRACS[5] so that they were able to collect and collate the raw data generated during the trial for subsequent analysis. Axion is a software used for

[4] O_2 = four times faster than N_2, H_2O = ten times faster than N_2
[5] SensorTRACS is a product of QUALCOMM Wireless Business Solutions, 5775 Morehouse Drive, San Diego, CA 92121-1714

tracking and reporting fuel tax credits. SensorTRACS is a system for generating reports downloaded from tractor engine Electronic Control Modules (ECM's).

Harris Transport also added hubometers to all equipment in order to have an independent check of the electronic instrumentation in order to verify data integrity. This was used during the statistical analysis of the raw data.

Approximately 65% of the fleet, less control groups of 35% of the fleet, was converted to Nitrogen inflation. The conversion was started in February 2006 and concluded in April 2006. The time was longer than anticipated due to very harsh climactic conditions in March which caused a temporary cessation in the project. The Nitrogen conversion was performed by West End Tire of Winnipeg. West End Tire is a full-service tire supplier that sells new tires, services tires, and retreads tires, and disposes of tires. West End Tire used Parker Hannifin's Tire$aver model MTS12 Mobile Nitrogen Tire Inflation System to perform the conversion. The MTS12 system is designed for winter operations. The system produces a minimum purity of Nitrogen of 95% at the outlet of the generator. The system utilized by West End Tire was audited and shown to generate Nitrogen at a higher purity than the guaranteed minimum shown on the Parker specification sheet for the equipment. This produced a purity of Nitrogen in the tires of over 95% as verified by spot audits using a handheld Oxygen Analyzer calibrated in ambient air.

The fuel savings portion of the study was validated in the aggregate, comparing fuel consumption in the trial with Harris Transport's historical fuel usage, normalized for cost fluctuations and seasonality. Fuel consumption was also compared within the trial itself between the control and the test groups. Sample records for the fuel tax credit reports are shown in Appendix B. Statistical analysis of the SensorTRACS statistical analysis is in Appendix D.

The tire life portion was validated on a continual basis, Snapshot. Tire data was collected on an ongoing basis throughout the trial by direct measurement using a handheld data acquisition and capture system developed specifically for commercial tire fleets, called Snapshot[6]. Snapshot uses automated field data collection equipment to record 4 separate tire depth gauge measurements and tire pressure for each tire. Data can be collected for an entire trailer (8 tires) or tractor (10 tires) in 10 minutes on average. Data for the entire fleet was gathered based on Harris Transport's own preventive maintenance routine so as not to cause unnecessary vehicle movement or interruption to Harris' revenue generating operations. This data is shown in Appendix C, Snapshot Tread Depth Data. Harris had been upgrading their tires in the fleet, so many of the tires had low mileage and were not oxidatively aged.

[6] Snapshot is a product of International Marketing Inc., Professional Arts Building, Suite C, P.O. Box B, Chambersburg, PA 17201 (p) 1-800-233-7086 (f) 1-717-264-5483

Final Project Timetable

No.	Activity and Goal(s)	Performance Indicator(s)	Status	Expected Completion Date
1	Training (Harris) ▪ Axion Training ▪ SensorTRACS Training	Personnel to Demonstrate Competence	Complete	20/02/06
2	Baseline Collection from Historical Records (Harris).	Develop auditable data base and credible baseline	Complete	20/02/06
3	Install Nitrogen Tire Inflation System (West End).	Nitrogen system installed.	Complete	20/02/06
4	Install Hubometers (Harris).	Hubometers installed on all trailers.	Complete	20/02/06
5	Initial Tire Conversion to Nitrogen (Harris).	All tires inflated with Nitrogen.	Complete	20/02/06
6	Vehicle Maintenance and Inspection (Harris).	Routine and failure maintenance during the project trial.	Complete	15/09/06
7	Capture and Reporting of Snapshot Field Data (West End).	Routine and failure data recording during the project trial.	Complete	15/09/06
8	Capture and Reporting of SensorTRACS Data (Harris).	Routine and failure data recording during the project trial.	Complete	15/09/06
9	Project Reports (M&A).	a. Kick Off activities b. Progress report #1 c. Progress report #2 d. Final Report	Complete Complete Complete Complete	23/02/06 28/03/06 30/06/06 29/09/06

10	Technical Support (Drexan).	Hot Line	Complete	15/09/06
11	Field Training of Harris Transport Personnel (Drexan/Harris).	Training of Maintenance Staff.	Complete	20/02/06
12	Field Audits and Data Collection	Collection of Data to formats for: a. Kick Off activities b. Progress report #1 c. Progress report #2 d. Final Report	 Complete Complete Complete Complete	 23/02/06 28/03/06 30/06/06 29/09/06
13	Data Analysis	Analysis of Data for: a. Kick Off activities b. Progress report #1 c. Progress report #3 d. Final Report	 Complete Complete Complete Complete	 23/02/06 28/03/06 30/06/06 29/09/06
14	Travel	Expense Reports	Complete	29/09/06
15	Project Management	General	Complete	29/09/06
16	Project Overheads	General	Complete	29/09/06

Project Milestones

Description of Milestone	Submission Date	Status
Milestone #1 Kick Off - Project Timetable Item No's 9a, and relevant costs of 14, 15 and 16.	23/02/06	Complete
Milestone #2 Interim Report No 1 - Project Timetable Item No's 1, 2, 3, 4, 5, 9b, 11, 12b, 13b and relevant costs of 14, 15 and 16.	28/03/06	Complete
Milestone #3 Interim Report No 2 – Two Thirds of Project Timetable Item No's 6, 7, 8, 10, all of 9c, 12c, 13c and relevant costs of 14, 15 and 16.	30/06/06	Complete
Milestone #4 Final Report No 1 – One Third of Project Timetable Item No's 6, 7, 8, 10, all of 9d, 12d, 13d and relevant costs of 14, 15 and 16.	29/09/06	Complete

Monitoring

Methodology

Method

The study was designed as a randomized, double blind study, with equipment selected at random and with a large control (35% of the fleet) operating on compressed air.

The study was to be conducted in the following phases from February (Cold) to July (Hot) 2006[7].

[7] February is the coldest month, – 12 degrees and July is the hottest month, +18 degrees, in Winnipeg according to Environment Canada www.weatheroffice.ec.gc.ca

Fuel savings validation for control and test groups:

- o Step one – collate historical data to provide the baseline fuel usage history and convert fleet to nitrogen tire inflation
- o Step two – record and report fuel usage for each vehicle over one half calendar year to provide a seasonal cycle (Cold to Hot) using two methods:
- o Axion fuel tax credit records; and
- o SensorTRACS engine data acquisition system
- o Step three – collate and analyze data – interim reports to be submitted bimonthly
- o Step four - Prepare and submit final report

Tire life validation for control and test groups:

- o Step one – collate available historical tire failure data; track all failures for tires in service.
- o Step two – inflate all tires, test group only, with Nitrogen (ongoing). Gauged tread wear data and recorded air pressure against road miles run will be captured during Preventive Maintenance routines. Failures will be documented and classified (run to destruction, curb impact, road debris etc.) for all tires run to destruction.
- o Step three – at end of tire casing life, compare Nitrogen test group with air filled tires.

Weather data was to be taken into account throughout the trial period but this proved problematic due to the volume of data points, funding and resources available. This is discussed further below.

Equipment was converted to Nitrogen on a random, FIFO system – what was in Harris Transport's yard got converted – on a stagger start basis from February to April 2006. West End Tire converted tractors and trailers from air inflation to Nitrogen inflation using a Parker Hannifin MTS12 Tire$aver Nitrogen Tire Inflation System[8]. Tires were purged to atmospheric pressure, then the tires were inflated to set point pressure using the generators. Purity of the gas in the casing was verified using a hand held Oxygen analyzer and minimum purity in the casing was 95%. Four tread depth readings were taken per tire using a hand-held data collection system called Snapshot. This tread wear data was tracked by tire by equipment. Tread wear data were recorded during the course of the trial as equipment cycled through the work yard. Equipment had closing readings taken after 6 months elapsed time, so closing data was taken between September and November 2006.

The drivers did not know which vehicles had Nitrogen and which had air. The conversion was done by West End Tire as part of normal tire maintenance at Harris' Winnipeg depot. Because the fleet conducted maintenance in a business-

[8] West End Tire occasionally performed top up maintenance using a MTS06 Tire$aver Mobile Nitrogen Tire Inflation System

as-usual mode, we controlled for any maintenance impact. The fact that West End was noting tread wear meant that Harris employees would not taint the experiment through changed behavior due to knowledge of experimental results.

Challenges, Notable Delays and Changes

Challenge – Logistics – Nitrogen Inflation

Not all tractors and trailers identified for Nitrogen inflation passed through the yard as foreseen and conversion from compressed air to Nitrogen took longer than planned particularly due to harsh weather in March. Bringing units in to the terminal just for Nitrogen filling would have interfered with normal fleet operations and revenue generation, and would have disrupted standard processes resulting in a change to “Business as Usual”. Two options were available.

a. Bring units in to get them inflated with Nitrogen and impact “Business as usual” or
b. Continue the trial with the number of units inflated with Nitrogen and not disrupt “Business as usual”.

It was decided to continue the trial without disrupting “Business as usual” and running the trial at a modified sample size. Therefore the trial group was 65%, or 44 tractors on Nitrogen vs. 75% or 53 tractors as planned.

Notable Delay – Duration of End Date

The study was extended to mid December to allow all Nitrogen inflated tires to have 6 months in service. The end date was 15 Dec 06.

Change – Weather Tracking

During the study it became clear that tracking vehicle ambient temperature using SensorTRACS position data was subject to error. Geographic location of the truck (using GPS positioning) and local ambient temperature recording (normally provided from the nearest major airport or weather station) were sometimes hundreds of kilometers apart and therefore significantly different. Early results revealed that control and test groups were showing an improvement due to Nitrogen tire inflation independent of ambient temperature. As a result the recording of temperature was moot and therefore was halted.

Data

Control and test data collected during the trial includes:

- Vehicle Number
- Latitude [*]
- Longitude [**]
- Data start date
- Data stop date
- Data extract date [***]
- Total distance
- Drive time
- Engine time [†]
- Move time [††]
- Trip time
- Short idle time[†††]
- Operating time
- Over speed time
- Cross speed time
- Fuel used
- Idle fuel
- Park fuel
- Tread depth by truck and tire position
- Tread depth measurement date and mileage
- Tread depth by trailer and tire position
- Tire failures and reason for tire failure
- Tires inflated with Nitrogen by vehicle and date
- Tires inflated with Air by vehicle and date
- Vehicle Status, Nitrogen or Air

Baseline Data includes:

- Fleet fuel consumption
- Fleet fuel consumption by quarter
- Tire program by year, (driver maintained, third party maintained, Nitrogen inflated.)

Soft baseline data such as driver observations and reports were gathered from the Control Group where possible to assist in developing the baseline.

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[*] Latitude – angular distance north or south of the equator of the tractor on the surface of the earth measured by Sensortracs.
[**] Longitude – angular distance east or west of the prime meridian of the tractor on the surface of the earth measured by Sensortracs.
[***] Data extract date – The date the data was extracted from the ESM by Sensortracs and recorded in the Sensortracs data file at Harris.
[†] Engine Time – The total time the engine was on.
[††] Move Time – The total time the vehicle was moving.
[†††] Short idle time – The time an engine was idled for a short period of time while the tractor was stationary.

Additional soft baseline data such as accounting records were gathered for use in determining the effectiveness of the best practice when an area of interest was identified.

Data in support of other considerations, such as maintenance capacity, were collected to provide business as usual baseline rationale for qualitative observations. Data were used to support common sense qualitative statements for the expected un-modeled benefits such as the deferred need to increase maintenance and other related accounting, management, general and administrative capacity due to decreased tire maintenance requirements.

Data was gathered from the sources identified in the following table.

Data element	Units	Collection Method	Explanation, Caveats, etc.
Distance traveled by vehicle, haul route and in the aggregate	Kilometers	SensorTRACS	Average fuel economy
Fuel used by vehicle, haul route and in the aggregate.	Litres	SensorTRACS, Fuel Tax Credit Reports and Submissions	Used in average fuel economy.
Weather	degree-day	Q Tracs Local airport weather station record.	Weather station data for long haul trucks will of limited value as these vehicles operate outside of local weather patterns. This data will apply to short haul routes that are replicated daily and have remained materially identical during the baseline and test period.
Tire retirement by vehicle, haul route, long or short haul.	Tires	West End Tire Disposals Activity, Snapshot	Used to determine frequency of tire disposal by haul route and in the aggregate.
New tire purchases by vehicle, long	New tires	West End Tire Disposals Activity, Snapshot	Used to determine frequency of new tire replacement by haul route

or short haul, and aggregate.			and in the aggregate.
Tire retread	Used tires	West End Tire Historical Snapshot	Used to determine frequency of used tire replacement.
Equipment failures by vehicle, long or short haul, and aggregate.	Tire failure	Driver Report	Used to determine frequency of catastrophic failure by haul route and in the aggregate.
Tread Wear	Tread wear – tread life	West End Tire Snapshot record	Used to determine air inflated tread life.
Tire Pressure	Pressure History	West End Tire Snapshot record	Used to correlate to tread life.

Data Collection

Baseline

Two baselines, a Historical Baseline and a Control Baseline, were used in this trial.

Historical Baseline

Two years of historical fuel tax credit records were made available for the study. This information was of particular interest as the first year, 2004, represented a period of time when driver tire maintenance was practiced using air inflation. The second year, 2005, represented a period of time when third party tire maintenance was incorporated to Harris' operations using air inflation.

Four months of historical SensorTRACS data for air inflated tires was available at the start of the trial. The data was for September through December 2005. This information represented a period where third party tire maintenance was practiced using air inflation and was considered in the control vs. test analysis.

Baseline information was plotted by quarter from fuel tax credit records revealing classical seasonal fuel consumption variation familiar to fleet operators. Fuel consumption increased during the winter and decreased during the summer in a sinusoidal manner.

Historical Baseline Data is presented and discussed with the results to this report.

Control Group

The control group was air filled. The control group for 2006 replicated the diversity of the fleet, routes and environment of the test group and was tracked with SensorTRACS. Control group tractors were mated with control group trailers. In addition, the control group results were expected to correlate with the 2005 baseline – third party tire maintenance program.

A list identifying Control and Test Group vehicles including the date they entered service is presented in Appendix A to this report.

Tread Wear Baseline

The Tread Wear Baseline was taken from the fleet prior to Nitrogen inflation. The Tread Wear Baseline is presented in the Results of Data Analysis.

Experimental Data

Two sets of experimental data were collected via independent means to determine the performance of Nitrogen inflated tires in comparison with air inflated tires. The first set of experimental data was collected using the Fuel Tax Credit Reports. The second set was collected using the SensorTRACS system.

Fuel Tax Credit Reports

The first set of data was collected from historical and in-trial fuel tax credit reports. It provided average fuel economy of the fleet as a whole (control and test vehicles) and was used to provide year on year comparison between the fleet practicing a driver maintained air inflated tire program (2004), the fleet using professional third party air inflated tire program (2005), and the fleet running 64% of its equipment on Nitrogen inflated tires (2006). One advantage of this data was its independence. It was collected through a completely different and independent process than SensorTRACS. Most of the data was generated before the trial was started thus could not be compromised and all data was auditable for income tax purposes therefore adding to its validity.

A series of fuel tax credit reports from which average fuel efficiency data were taken are presented in Appendix B to this report as examples.

SensorTRACS Reports - Test Group

All tractors are fitted with SensorTRACS which made data collection simple. The Nitrogen inflated test group comprised 64% of the fleet. Nitrogen inflated test group tractors were mated with Nitrogen inflated test group trailers. The advantage of the SensorTRACS process was it's independence from the Fuel Tax Credit data production system and lack of human involvement in the data collection process.

Conservativeness

Conservativeness was inherent in the test. While every effort was made to match Nitrogen equipment with Nitrogen equipment and air equipment with air equipment, it was possible that mixed sets of Nitrogen equipment and air equipment occurred. However, if, for instance, a Nitrogen tractor pulled an air trailer or an air tractor pulled a Nitrogen trailer, those situations would reduce the expected benefits of Nitrogen, thereby making the data streams converge and resulting in a more conservative differential.

Tread Wear

Tread Wear was recorded for a cross section of all tires, air and Nitrogen inflated, using Snapshot. The third party tire service provider was tasked with taking tread wear measurements.

Snapshot data is presented in Appendix C to this report.

Analysis Performed on Collected Data

Fuel Consumption

Historical Baseline Analysis

The Historical Baseline reveals a seasonal variation over two years. Fuel consumption increases dramatically in winter months and decreases in the summer months. This trend is consistent for 2004 to 2005 but shows an improvement in fuel economy attributable to the third party tire monitoring and inflation maintenance program. The fuel consumption and seasonal variation profile is classical.

Experimental Data

Because drivers drove the same equipment, driving behavior was eliminated as a factor.

Because the routes were consistent, route variances were eliminated as a factor.

The trial started in February, statistically the coldest month of the year in Canada, and incorporated July, statistically the hottest month of the year in Canada. Thus the data set incorporates climactic changes during the course of the trial as well as during the course of individual hauls. A minimum of 6 months data was captured per piece of equipment. Trials were run over 9 months spanning winter through fall and experienced all typical climactic events.

Tires were converted to Nitrogen at random without regard for tire age, new or retread, tread depth, tire brand, or retread technology. Thus, any change in the mean could only be attributed to the change in inflation gas, and nothing else. This is also reflective of how Nitrogen technology would be incorporated into a typical operating fleet.

This data set consists of 2 years history and 9 months of fleet trial usage. It comprises over 22 million tractor miles. Because the sample size was so large statistical uncertainty created by outliers is eliminated. Results are statistically valid.

Results of the Data Analysis

Expectations

Anecdotal evidence and evidence from previous trials indicated that we should see an improvement in fuel economy in the order of 2% to 4%.

Improvement in Fuel Efficiency

Year on Year Comparison - Fuel Tax Credit Reports

Fig. 1: Comparison Fleet against Historical Data

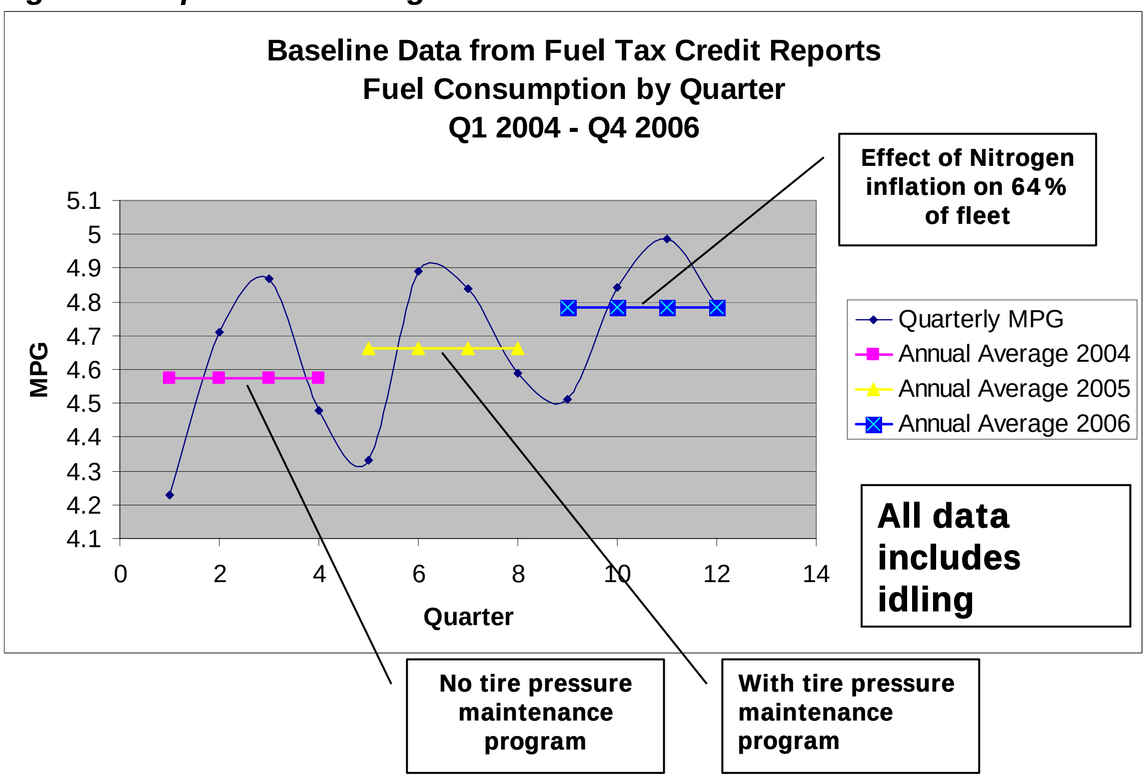


Figure 1 is produced from the fuel tax credit reports during the trial period and from historical records. The sine wave shape shows the period from winter (cold, increased idling, winter fuel and lower fuel efficiency) to summer (hot, less idling, summer fuel and higher fuel efficiency) and back to winter.

The first sine wave shows 2004 data – before a tire pressure maintenance program. The average fuel efficiency for this period is 4.58 mpg.

The second sine wave shows 2005 data with the impact of the third party tire pressure maintenance program on the fleet. The average fuel efficiency increases to 4.66 mpg.

The third sine wave shows 2006 data and includes the trial period which is very interesting. It shows the impact of Nitrogen tire inflation on the total fleet average fuel economy, which becomes a 4.37% improvement on 2004 results as average fuel efficiency increases to 4.78 mpg. But Nitrogen was only used in 64% of the tractors in the fleet. So if the entire fleet had been converted, the increase would have been greater still estimated at 6.82%.

Comparing 2006 results with 2005 results we see that the fleet had a 2.58% improvement in average fuel efficiency. We can estimate that if the entire fleet were changed to Nitrogen inflation fuel efficiency would have increased by 4.03%.

Overall, while the seasonal sine wave is consistent year on year, the trend for efficiency is up and to the right based on the introduction of each measure – pressure maintenance, then Nitrogen inflation, with Nitrogen inflated tires providing the best fuel efficiency.

Trial Comparison – Air Control Group vs. Nitrogen Test Group

Fig. 2: Comparison of Test vs. Control within the Experimental Trial

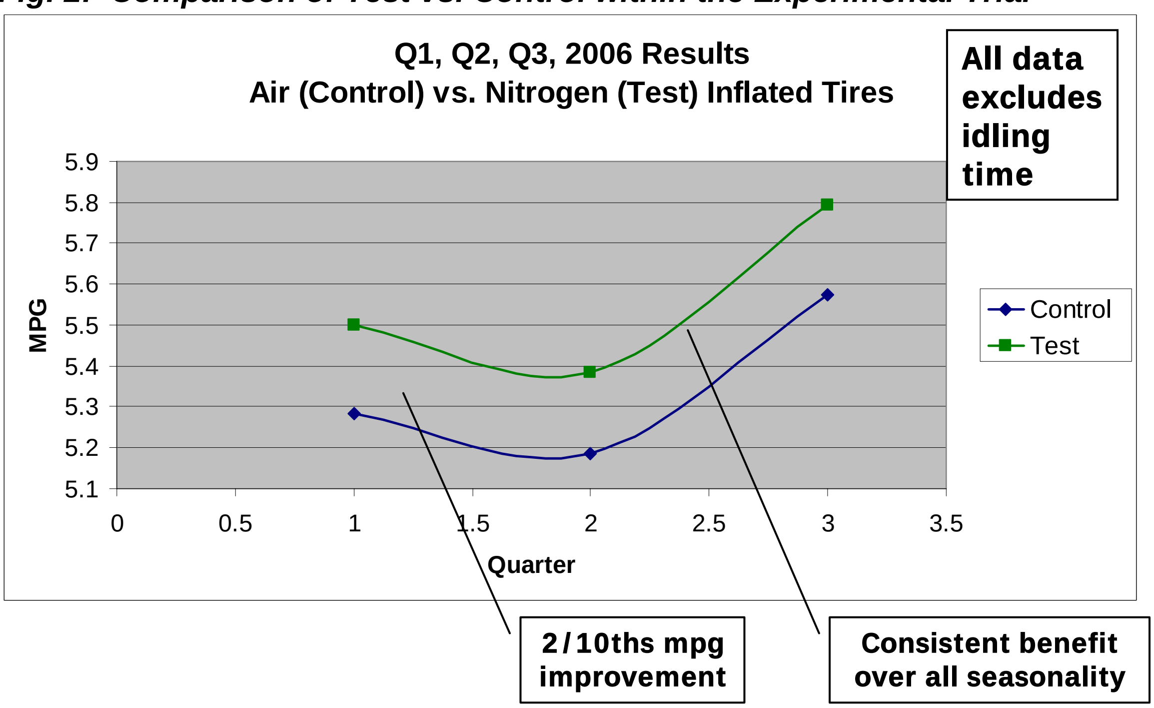


Figure 2 uses a second methodology to demonstrate significant fuel savings within the trial period between control and test populations. The average mpg calculations were derived using SPSS statistical analysis software.[9] Results were statistically significant.

SensorTRACS data for the air inflated control group showed that it had a fuel efficiency of 5.28 mpg during the first quarter, 5.19 mpg during the second quarter and 5.58 mpg during the third quarter of 2006.

SensorTRACS data of the Nitrogen inflated test group operated in parallel with the air inflated control group showed that it had a fuel efficiency of 5.50 mpg during the first quarter, 5.38 mpg during the second quarter and 5.79 mpg during the third quarter. The mpg calculations were determined using SPSS, Statistical Analysis Software. Results were statistically significant.

While Figure 1 compared fleet fuel efficiency year-on-year, Figure 2 compares fuel efficiency within the experiment itself. This data is derived from electronic data capture using SensorTRACS and is not subject to human data input error.

The lower curve shows fuel consumption for the air inflated control. The upper curve shows the fuel consumption for the Nitrogen inflated test group. We see clearly that the Nitrogen inflated vehicles were 2/10ths of a mile per gallon or 3.3% (on average) more efficient in comparison with the air inflated control vehicles running a third party tire maintenance program. We also see that the lines are parallel over the entire test period though all temperature regimes (Winter, Summer, Fall) indicating the independence of the benefit of Nitrogen tire inflation from environmental conditions in comparison with air tire inflation. It is important to note that distance traveled during the trial was over 6.1 million tractor miles. It represents fuel usage during actual driving conditions (including standing idling at stop lights). A “typical fleet” can expect the same results.

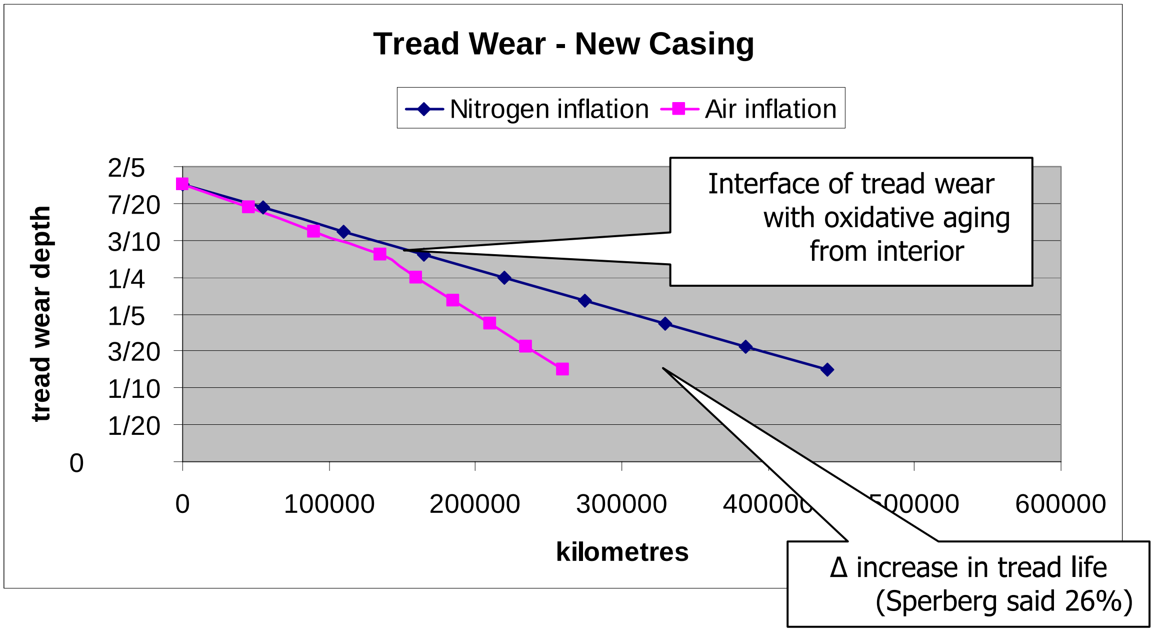
SensorTRACS statistical analysis is presented in Appendix D to this report.

[9] SPSS Statistical Analysis Software – a comprehensive and flexible statistical analysis and data management system. SPSS Federal Systems.

Tread Wear

Expectations

Figure 3: Expected tread wear – new casings



Prior to the trial, anecdotal evidence of increased tread life from existing users pointed towards tread wear of about 45,000 to 50,000 km per 32nd.

Figure 3 is a graph prepared from this anecdotal evidence. While the data used to prepare this graph is statistically insignificant due to small sample size, it explains why a Nitrogen inflated tire achieves more tread miles than an air inflated tire. The purple (lower) line shows a new trailer tire with approximately 250,000 km of tread wear. This is typical tread wear for new, air-inflated trailer tires. However, tread wear of 45,000 to 60,000 km tread wear per 32^{nd} on Nitrogen inflated tires was experienced by the same group. Extrapolating this as a straight line yielded the blue line. We expected our results to replicate these results to a great extent.

Sperberg[10], explained the mechanism for increased tread wear over the entire tread life shown in Figure 3. Sperberg's experiment showed that that for new tires, Nitrogen provided 26% longer tread life. He concluded that the increase was due to the elimination of oxidative aging of the tire rubber that occurs in air inflated tires right through to the tread face itself. The interface between the tire road surface with the oxidized tread rubber is represented at the inflection point of the purple line in this graph where it curves downward. At this point, the aged tire rubber has shorter polymers. Oxygen has broken down unsaturated bonds in

[10] Report S4-85, Million Mile Truck Tires – Available today, Lawrence R Sperberg, Stronger Longer Tires of El Paso, January 9, 1985.

the tire rubber. Shorter polymers mean weaker polymers, a softening durometer hardness of the tread rubber, and accelerated wear of the tread rubber due to road contact. And this is indeed what fleet owners and operators report as their experience in the field.

Figure 4: Expected tread wear – retreaded casings

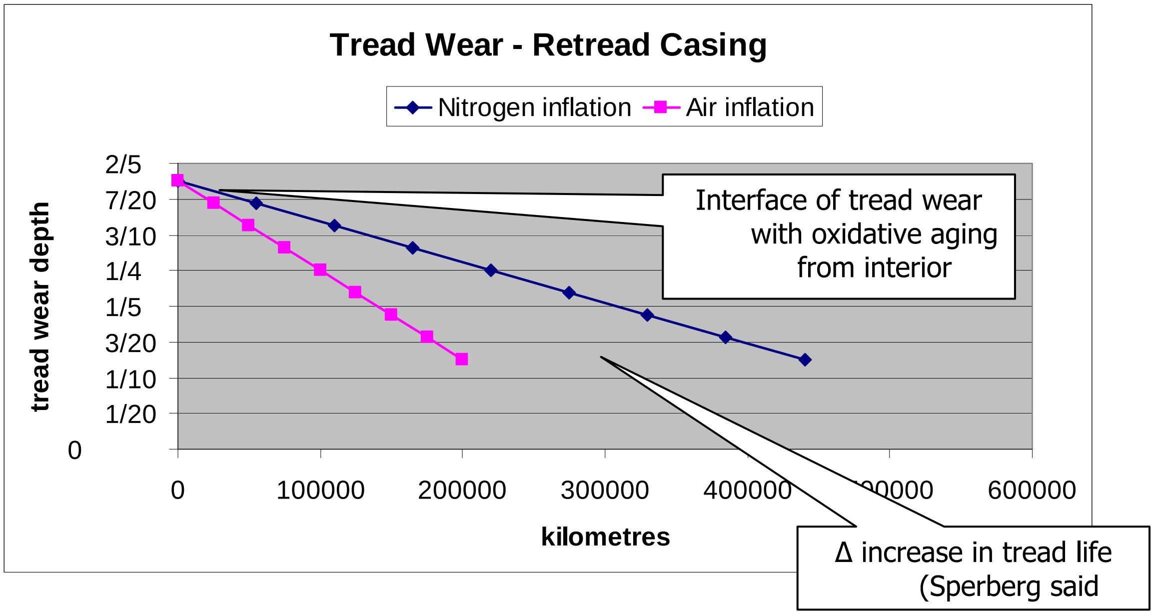


Figure 4 shows a similar treatment from anecdotal evidence for retreads. Retreads have a shorter life span. Sperberg said Nitrogen-inflated retreads lasted 54% longer than air-inflated retreads. This occurs not because the Nitrogen tires last any longer – that would be impossible. This occurs because the air inflated tire rubber breaks down faster, since the oxygen in air has no more bonds to attack in the casing. So these Oxygen molecules start to break down the tread rubber faster than in a new casing.

Trial Results

Figure 5: Actual tread wear – all trial casings

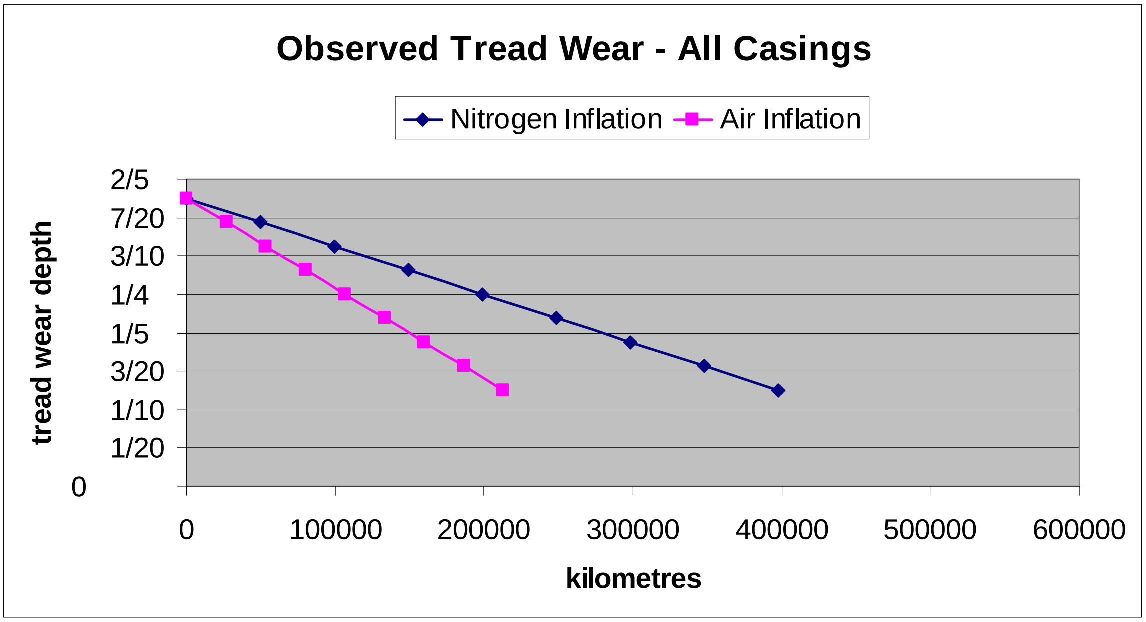
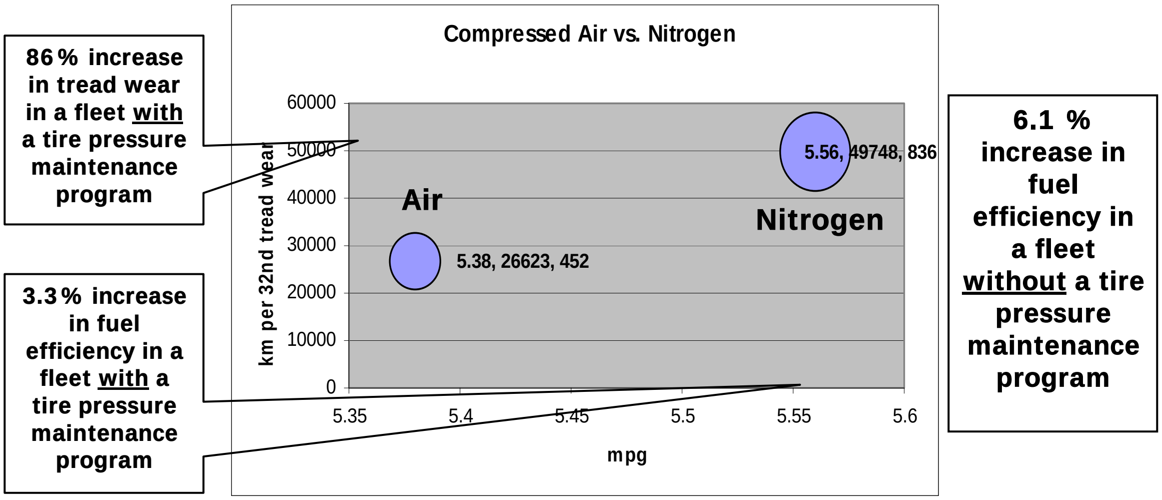


Figure 5 shows tread wear for all trial casings combined, projected for the tread life of trailer casings. It shows that during the trial the Nitrogen inflated test group casings experienced 49,738 km per 32nd tread wear while air inflated control group casings experienced 26,623 km per 32nd tread wear. Results of this trial are consistent with previous test data and anecdotal evidence. Trial data was obtained over 110 million miles of tread wear data from the actual trial, and the sample size included 1988 tire positions. We have extremely high confidence in the results.

During the trial, we were doing Business-As-Usual maintenance so as not to skew the baseline nor compromise safety. If a tire had to be replaced, it was. The replacement tire was inflated with the same gas as before – air with air, Nitrogen with Nitrogen. So during the trial, old oxidative-aged casings were replaced with new rubber that was either new casings or newly re-treaded tires. In the event that a tire was replaced, that tire was removed from the tread wear analysis.

All Results

Figure 6: Tread Wear and Fuel Efficiency – Air vs. Nitrogen Inflation



Sperberg study (1985): 7.5 million tread miles, 98 drive tires, bias ply construction
Mech and Mech study (2006): over 110 million tread miles, 1,988 drive & trailer tires, steel belt radial

Figure 6 compares the air inflated control to the Nitrogen inflated test group for the trial. This figure summarizes the results of both the fuel efficiency findings and the tread life findings on one chart.

The last major tire study into the effects of Nitrogen tire inflation was Lawrence Sperberg's study. It was conducted over 7.5 million tread miles of data with only 98 tire positions, on drive tires, with an obsolete (bias ply) tire construction. Our study comprises over 110 million tread miles of data on 1,988 tire positions, on all tire positions, using today's widely-used steel belt radial construction. Our study consists of over 22 million tractor miles of fuel efficiency data.

The left balloon shows the air inflated control with 452 tire positions. This control obtained 5.38 mpg average fuel consumption, and average tread wear of 26,623 km per 32nd.

The right balloon shows the Nitrogen test group with 836 tire positions. The Nitrogen group achieved average fuel consumption of 5.56 mpg, and average tread wear of 49,748 km per 32nd tread wear.

These results show a 3.3% increase in mean fuel efficiency for Nitrogen inflated tires over compressed air. These results show an 86% increase in mean tread life for Nitrogen inflated tires over compressed air. Both these metrics are obtained in a fleet practicing a third party tire maintenance program that has proven to increase fuel efficiency and tire life over driver or corporate tire maintenance programs. The increase in fuel efficiency for this fleet when compared to a driver or corporate tire maintenance program is truly impressive – it is 6.1%.

Results – Casing Failures

The results for casing failure were inconclusive due to the small number of failures (7 in total for the life of the trial).

All casing failures occurred in casings that were near the end of their design life (high mileage, multiple retread older casings). Three of the seven were air inflated tires and four of the seven were Nitrogen inflated tires.

Air inflated failures were due to sidewall separation, casing separation and liner cracking of old tires. Nitrogen inflated failures were due to tread lift (3) and an impact break of old tires.

Nitrogen inflation will not repair damaged rubber. It will only prevent oxidative aging of rubber. The early failures of Nitrogen inflated tires were attributed to their high mileage and the already oxidized and aged state of the tires.

It is recommended that a longer trial be conducted to address the issue of casing failures only to replicate the expected decreased failure rates expected from Nitrogen tire inflation.

Casing failure results are presented in Appendix E.

Conclusions

Relative Success of the Project

This trial was highly successful.

This trial set out to prove that Nitrogen minimized the effect of tire volume change with varying ambient temperature and that this would impact fuel economy and tread wear. It also set out to prove that tire pressure loss over time due to Oxygen and water vapour passing through the tire rubber would be minimized having an impact on fuel economy, tread wear, and tire casing life.

Fuel Economy

This trial proved through two independent methodologies that Nitrogen tire inflation increased the fuel economy of the fleet.

We expected to see an improvement in the 2% to 4% range, in line with Transport Canada's projections attributable to correct tire inflation. We found that these projections were correct, with our results showing a 3.3% improvement in fuel efficiency when comparing a driver based tire maintenance program with a third party tire maintenance program. We found a further improvement attributable to Nitrogen tire inflation of 3.8% and an impressive 6.1% when comparing Nitrogen inflation with a driver based tire maintenance program. This last result is significant since it exceeded expectations by double.

Statistical analysis of the data revealed that these results were statistically significant.

Tread Wear

We expected to see an increase in tread wear of 48%, in line with previous studies. This trial proved that tread wear life was extended by over 75% due to Nitrogen inflation, which was one and a half times greater than our expectations.

Tire Casing Life

Results from the tire casing life analysis were inconclusive due to the low number of failures.

Conclusion Recommendations

As a result of this trial it is recommended that:

1. Long haul truck fleets should convert to Nitrogen inflation immediately to save on tire and fuel costs.
2. Short haul truck fleets should consider converting to Nitrogen inflation to save on tire and fuel costs.
3. Additional study should be conducted to determine with more accuracy the amount of tire life extension beyond 48%.
4. Additional study should be conducted to quantify the benefit for cars and light trucks.
5. Transport Canada should consider adding Nitrogen tire inflation to its ecoFreight program under ecoEnergy for fleets and Freight Technology Incentives Program.