Final Report

for

Duty Cycle Performance Test of Retread Tires

Submitted to

North Carolina Department of Transportation

by the

NCAT Pavement Test Track at
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16. Abstract

The Fleet and Material Management Unit (FMMU) manages the Retread Program for the North Carolina Department of Transportation (NCDOT). Over the past several years, questions have been raised as to the performance of the various types of retreads, and how their respective performance stacks up against each other, as well as against new tires. In order to determine the cost effectiveness of the Retread Program, the FMMU has commissioned comparative evaluation performance studies of major brands of recaps and new tires in "real world duty cycle" environments.

The overall objective of this study was to generate data on the cost effectiveness of using retreads (1100R 22.5) versus new tires and compare the cost effectiveness of different types of retreads (i.e., (i) Top Cap - Pre-cure, (ii) Top Cap - Mold-cure, (iii) Wing Tread, and (iv) Bead to Bead) using the methodology described in Recommended Practice (RP) 203A entitled Test Tire Procedures for Tread Wear, Serviceability and Fuel Economy published by the American Trucking Association's (ATA's) Technology and Maintenance Council (TMC).

This final report has been prepared to describe all tasks and results of the overall research effort at the conclusion of this project. Details on the testing, analyses, and findings are included. The study provides the NCDOT with an objective assessment of the performance of select tires within real world duty cycles.

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1. Background

The Fleet and Material Management Unit (FMMU) manages the Retread Program for the North Carolina Department of Transportation (NCDOT, referred to occasional hereafter as the Department). Over the past several years, questions have been raised as to the performance of the various types of retreads, and how their respective performance stacks up against each other, as well as against new tires. In order to determine the cost effectiveness of the current program, the FMMU has performed experiments for comparative evaluation of performance of major brands of recaps and new tires in “real world duty cycle” environments.

No experiments have been identified where all the major types of recaps available to NCDOT were evaluated against each other in a “real world duty cycle” environment. Each tire type has by itself been tested, but has been tested using dynamometers.

2. Objectives and Methodology

The overall objective of this study was to generate data on the cost effectiveness of using retreads (1100R 22.5) versus new tires and compare the cost effectiveness of different types of retreads (i.e., (i) Top Cap - Pre-cure, (ii) Top Cap - Mold-cure, (iii) Wing Tread, and (iv) Bead to Bead) using the following methodology:

- A comprehensive experimental design and an effective RP 230A-complaint test protocol to be used by NCDOT employees was provided to the Department by researchers at the National Center for Asphalt Technology’s (NCAT) Pavement Test Track to facilitate the experiment;
- Test sites and test trucks were selected by the Department to include the major geographical regions of North Carolina;
- NCDOT employees collected test data per experimental design and test protocol, which was transmitted electronically to the NCAT Pavement Test Track in a blind manner on a schedule using the provided test protocol;
- Mr. Mark Walker, the NCDOT Fleet Support Manager, submitted updated test data to NCAT researchers on a continuous basis; and
- NCAT personnel visited the North Carolina test sites, as well as the Raleigh Headquarters office, during the course of the experiment, to ensure that proper procedures were established and followed.

3. Project Deliverables

This effort was intended to produce the following deliverables over the course of the multiyear experiment:

- Quarterly progress reports;
- A draft final report at the completion of the study; and
- A final report, based on review of the draft final report by a Project Steering & Implementation Committee.

4. Product Utilization

- Research product(s) of this study are expected to help the FMMU determine the effectiveness of its current retread program;
- NCDOT is expected to utilize the product(s) of this study to review its current program and implement changes that may be necessary to reflect the experimental outcome; and
- The information gathered is expected to equip the Department to increase operational efficiency, provide a safe product to field forces, continue to recycle usable casings, and save money.

5. Benefit to Research Sponsor

Other than the financial benefits, the Department will be able to answer concerns that all types of available retreads have been tested and verified to perform as advertised in a safe and effective manner.

6. Implementation

Fully implementable findings from this work will enable Department management to continue to support the field forces with products that are safe, that perform well, and that can be serviced by the vendor community involved.

7. Experimental Plan

All the physical work in this study was conducted in the State of North Carolina by DOT forces, while data management and analysis of results occurred at the NCAT Pavement Test Track. The research can be described in terms of the following five tasks:

Task 1: Development of a RP 203A Compliant Test Protocol that Satisfies Objectives

The primary goal of Task 1 was to develop a formal plan of study that would yield significant results. The final plan of study was developed to be in compliance with Recommended Practice (RP) 203A entitled *Test Tire Procedures for Tread Wear, Serviceability and Fuel Economy*. This document, with the tread wear section included as Appendix A, is published by the American Trucking Association's (ATA's) Technology and Maintenance Council (TMC) to define the industry standard recommended practice for tire wear experiments in heavy duty applications.

A draft procedure was independently developed by personnel at the NCAT Pavement Test Track to ensure compliance with RP 203A. Subsequent meetings with NCDOT personnel served to fine tune the process so that it was properly aligned with the Department's standard practices (e.g., measuring tread depth when trucks were in for standard service intervals every 5,000 miles, rather than waiting for the specified 30,000 miles). The final procedure is included as Appendix B. Data collection forms are included as Appendix C.

In order to achieve a statistically significant outcome, RP 203A recommends a test population per study tire consisting of at least 30 tires that have survived until the end of the experiment. Fifty tires were selected for this study based on the assumption that some unknown number of tires would not survive. The Department identified 22 trucks spread across 5 different Divisions to serve as test vehicles. Five test trucks were based in Division 2, three were based in Division 5, five were based in Division 8, five were based in Division 10, and four were based in Division 11.

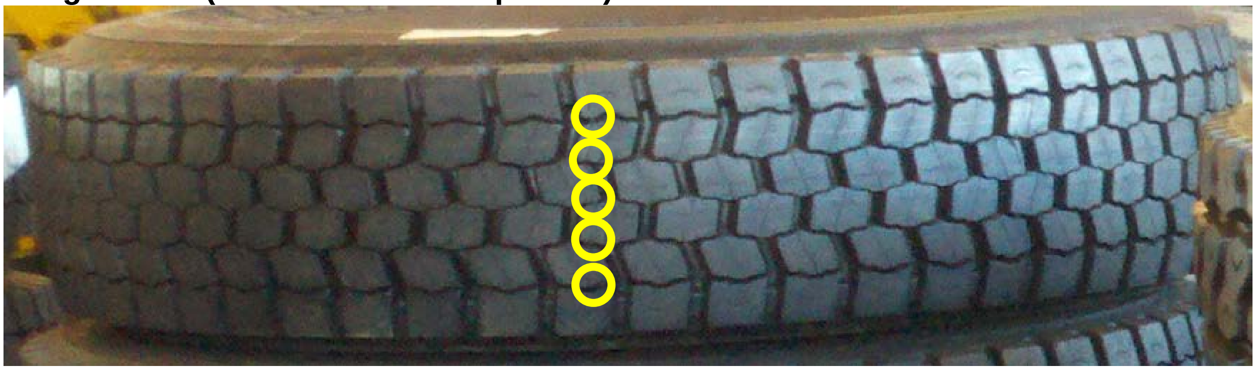
Trucks were randomized in order to avoid bias in tire assignments. Tires were branded with unique tracking numbers in numerical order between 1 and 200. Referring to the tire number diagram on the bottom of Appendix B, test tires were then randomly assigned to locations 3 through 10 on the randomized trucks, taking care to only install matched pairs in each dual tire assembly in order to avoid confounding wear rates with potentially mismatched circumferences. Stratified randomization was used to ensure that pairs of tires were randomly distributed throughout the test truck population to avoid the potentially confounding effects of position and truck assignment on measured performance.

Multiple levels of randomization served several purposes. Most importantly, it ensured that the outcome of the experiment would not be unintentionally biased. It also made it possible to potentially report statistically significant differences related to tire location, truck number, etc.

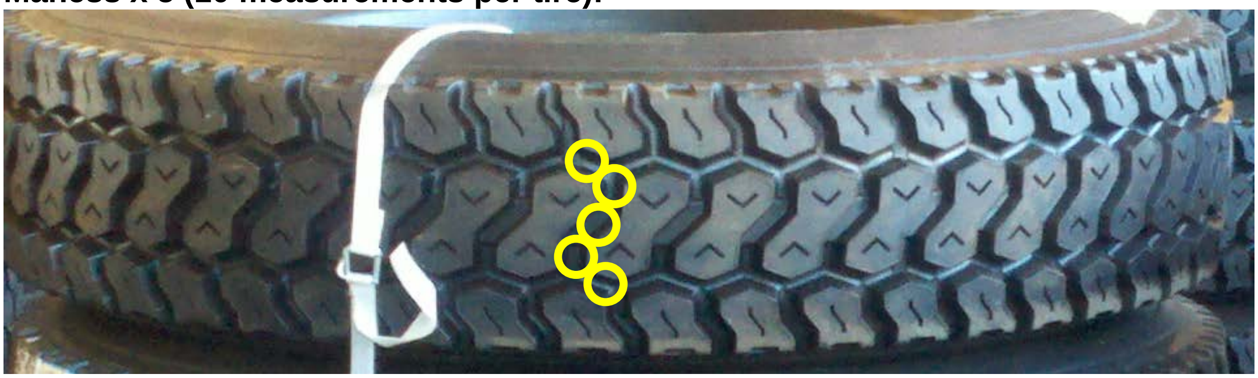
Task 2: Document Test Tire Installation and Train Service Technicians

The primary goal of Task 2 was to ensure all test tires were mounted in a similar manner and that anyone who would be collecting and recording tread depth data was well trained. Branded tires were inspected by personnel from the NCAT Pavement Test Track prior to randomization and installation. All tires were balanced and subjected to standard NCDOT maintenance practices regarding deployment. Service personnel were trained to measure tread depths for the four study tires using the methodology shown in Figure 1 that was established by personnel from the NCAT Pavement Test Track. This was important because the tread patterns in the four study tires were very dissimilar and different technicians may have otherwise measured tread depths in confounding locations. Five Tread depth measurements were taken at the location of the valve stem and 5 were taken at a 180 degree offset (i.e., halfway around the circumference on the opposite side of the tire). As seen in Appendix C, all 10 measurements were reported to personnel at the NCAT Pavement Test Track.

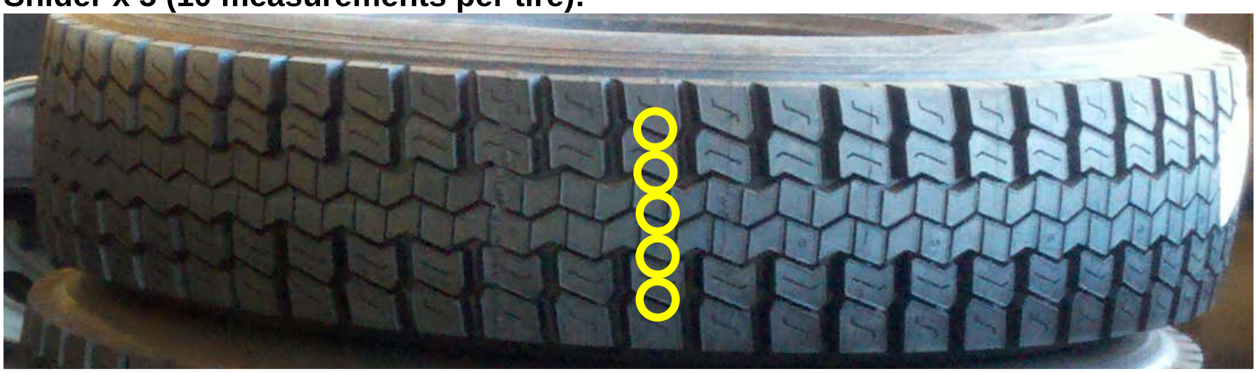
Wingfoot x 5 (10 measurements per tire):



Maness x 5 (10 measurements per tire):



Snider x 5 (10 measurements per tire):



White x 5 (10 measurements per tire):

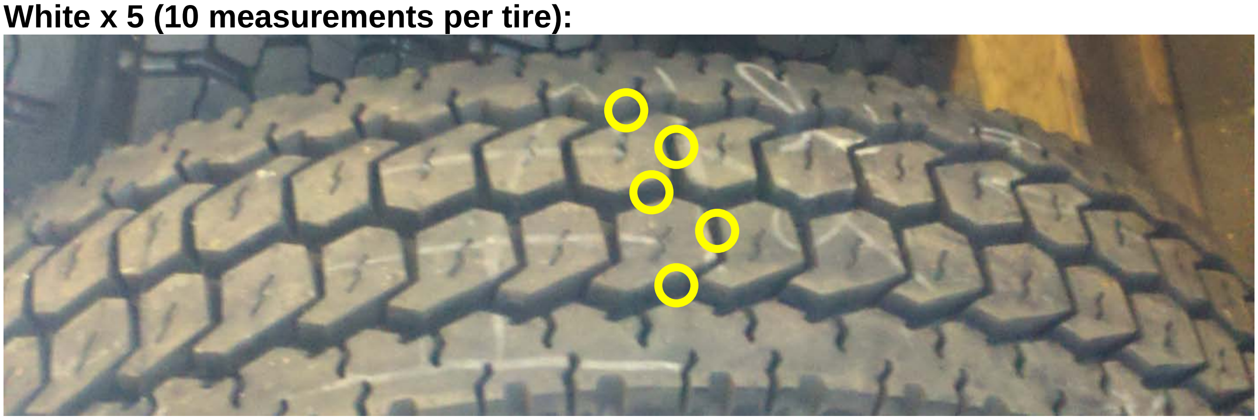


Figure 1 – Tread Depth Measurement Plan Used to Train Onsite Technicians

Task 3: Process Periodic Tire Wear Data Supplied by NCDOT

The primary goal of Task 3 was to manage tire wear performance data in a completely objective and blind manner in an offsite location. As seen in Appendix B, measurements were made by Department technicians and transmitted electronically to the NCAT Pavement Test Track for processing. Tread wear data plots, shown in Figure 2, were used as a data validation tool and were provided to the Department on a quarterly basis for review. Each data point represents the average of 10 tread depth measurements made on every test tire when trucks came in for routine maintenance.

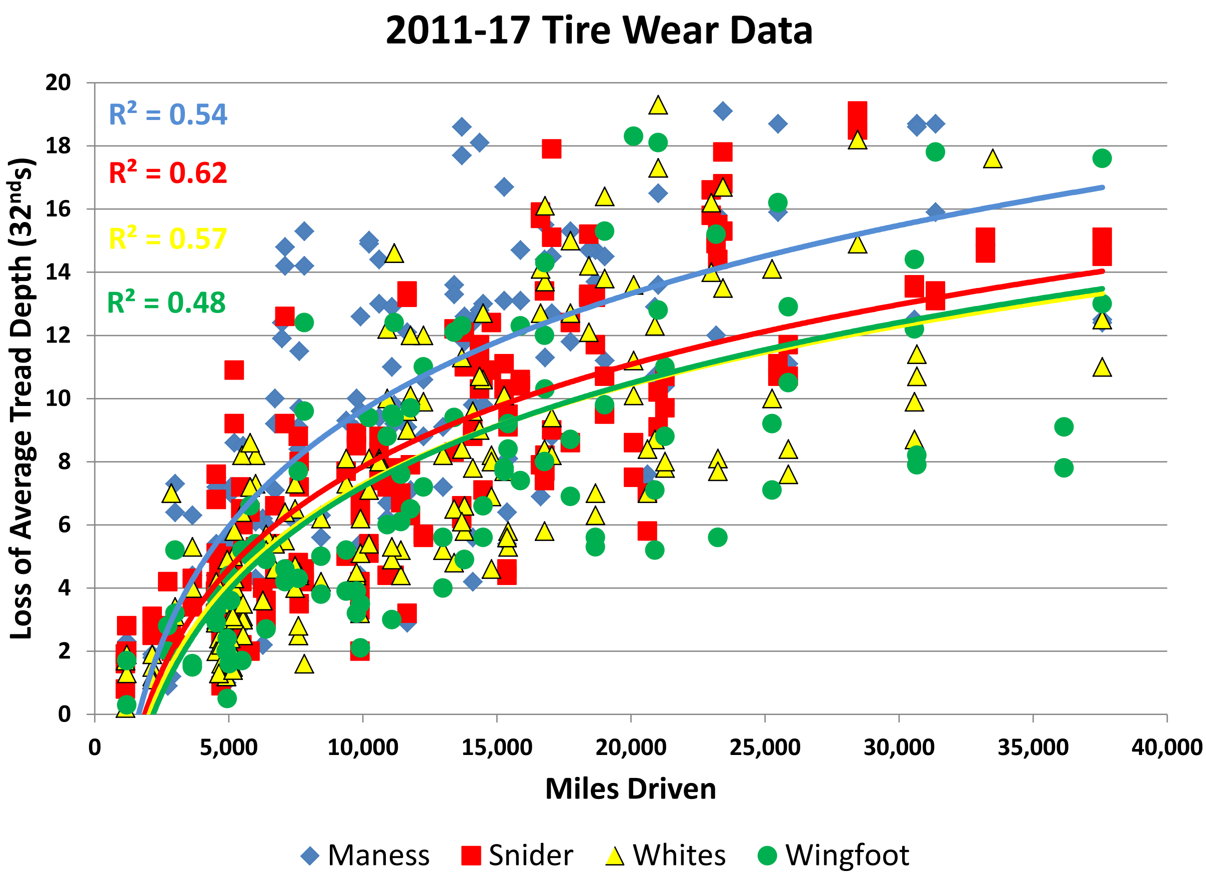


Figure 2 – General Wear Rate Plot Developed for Quarterly Progress Reports

Task 4: Periodically Inspect Test Tires to Ensure Data Quality

The primary goal of Task 4 was to provide an assurance of quality and objectivity for the overall testing program. Every tire was visually inspected by NCAT researchers to ensure that branded tires were in the proper position on the assigned test truck in the correct Division (all randomly assigned). Aside from a few pairs of tires needing to be swapped because they were installed inside out (verified corrected at a later time), all 200 tires were found to be in the proper position. During testing, pictures were provided of failed tires in order to support the documentation process in a cost effective manner. An example picture of a tire removed as a result of failure is shown in Figure 3, and an example picture of a tire removed as a result of damage is shown in Figure 4.

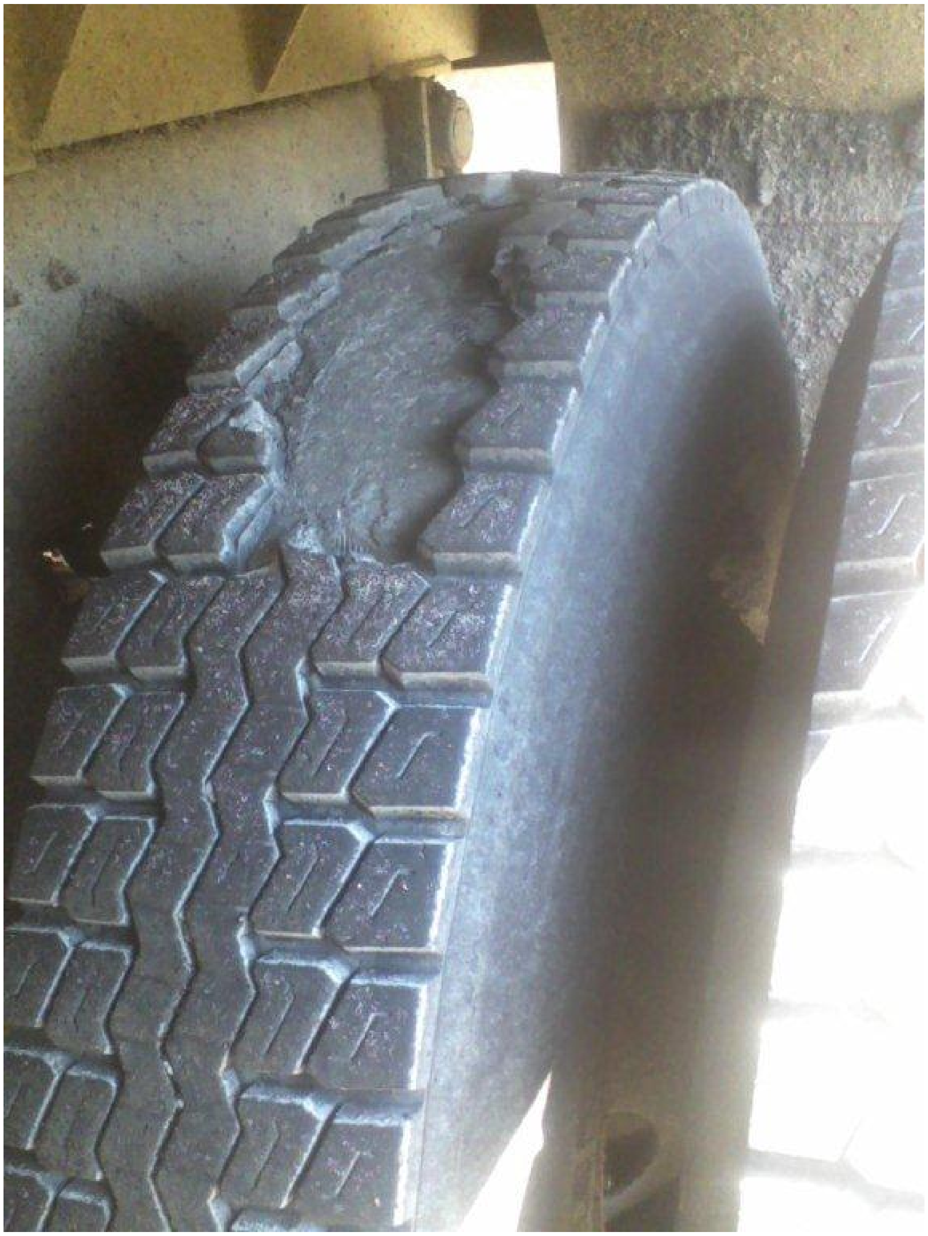


Figure 3 – Picture of Failed Tire Number 107 Removed from Service 9/10/2012

Figure 4 –Picture of Damaged Tire Number 56 Removed from Service 12/5/2012

Task 5: Prepare Final Report

This final report has been prepared to describe all planned tasks and results of the overall research effort at the conclusion of this project. Details on the testing, analyses, and findings are included. The study is expected to provide the NCDOT with an objective assessment of the performance of select tires within real world duty cycles.

The database used to create Figure 2 was mined to generate the data tables that served as the basis of the balance of this report. Table 1 is provided to illustrate how many tires were taken out of service for all reasons. Tire removals were coded in one of four ways. Tires could be removed due to excessive wear. They could be removed because of damage (e.g., tire number 56 shown in Figure 4). They could be removed because of a non-damage related failure (e.g., tire number 107 shown in Figure 3). Or, they could be removed because the other tire in the dual tire pair was removed for one of the first four reasons. Replacing a tire when the other tire in the dual tire pair was replaced was necessary to avoid the confounding effect of mismatched circumferences on wear rates.

	Maness	Snider	Whites	Wingfoot
2	8	6	6	1
5	2	0	0	0
8	10	8	8	8
10	4	2	4	0
11	2	3	4	2
Totals	26	19	22	11

Table 1 – Study Tire Removal for All Reasons by Manufacturer and Division

Only 3 tires were coded as being removed for non-damage related failures. They were all Sniders, with one reported in Division 2, one in Division 8, and one in Division 11. All other removed tires were treated as if they were either at or near the $4/32^{nd}$ inch safety threshold, they were damaged (e.g., nail puncture), or they were removed because the paired tire needed to be removed for one of the aforementioned reasons.

Tread wear data for each of the 200 test tires was individually scrutinized to use the trend in the measurements to correct mileage to precisely 4/32 inch. This was necessary because many of the test tires had not yet been removed as a result of excessive tread wear. Further, tires taken out of service were not necessarily removed at exactly 4/32 inch. The process of identifying a best fit equation to serve as the basis of this correction to precisely 4/32 inch for tire number 6 is shown in Figure 5. The consistency in the measurements apparent in Figure 5 for tire number 6, which resulted in a very high coefficient of determination in the fitted equation, is representative of the level of consistency seen for the entire population of test tires. Coefficients of determination averaged 0.94 for Maness, 0.97 for Snider, 0.98 for Whites, and 0.96 for Wingfoot tires using only those curve fits where 3 or more data points were utilized (resulting in 38, 36, 40, and 39 coefficients of determination to average for each of the four study manufacturers, respectively). The overall high quality of the curve fit process is evidence of uniform adherence to the study methodology by Department personnel.

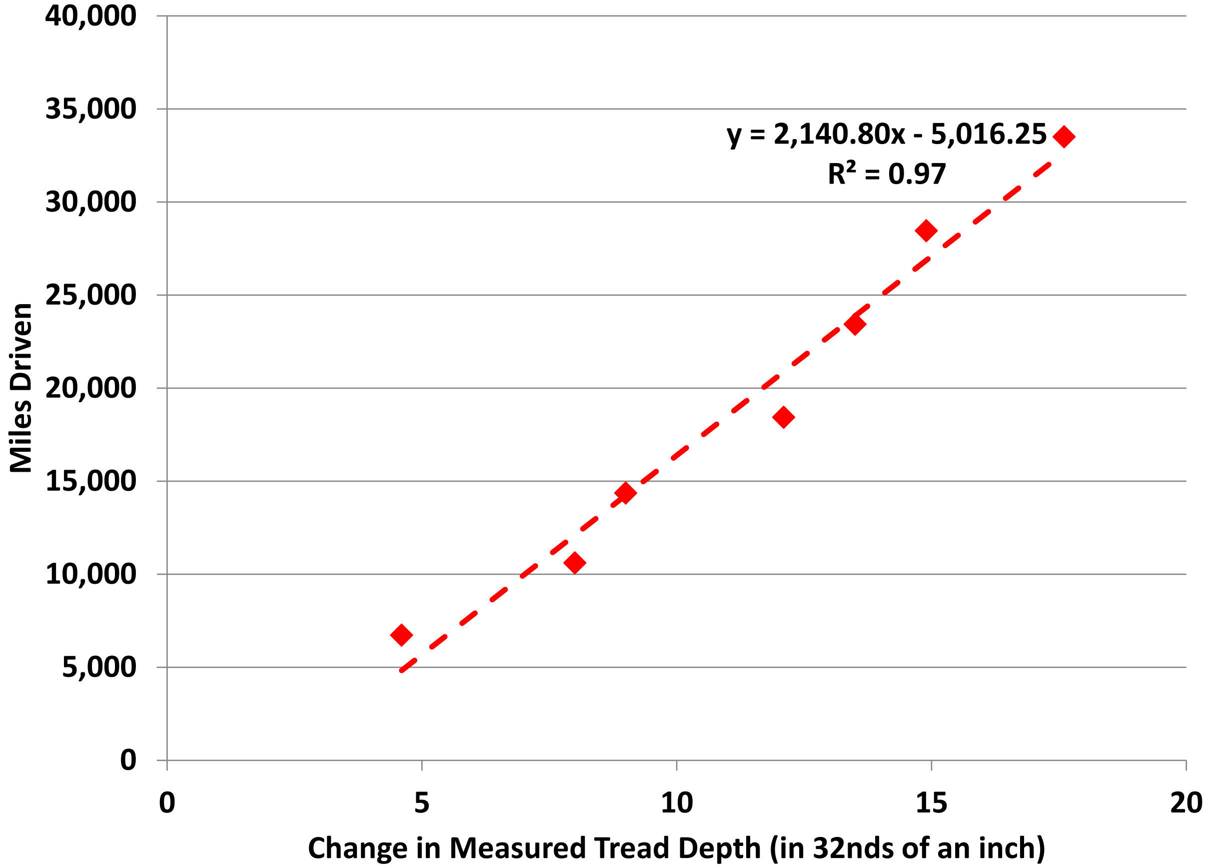


Figure 5 – Tire #6 Plot Showing Data Fit Used to Correct Mileage to Precisely 4/32 inch

Twenty-five tires were excluded from the data analysis as a result of either irreconcilable measurements or mileage that was too low to provide at least two data points through which an equation could be fitted. This exclusion resulted in a slightly unbalanced experiment design. Fortunately, and presumably the result of the multilevel randomization process, excluded tires were very evenly distributed amongst the four manufacturers (6 for Maness, 7 for Snider, 6 for Whites, and 6 for Wingfoot). As a result, they were not viewed to significantly impact the outcome of the study.

It should be noted that RP 230A stresses tires should be run completely out to 4/32 inches of tread depth before final conclusions are drawn. It also states that projections of tire life should be made when at least 50 percent of tread wear life has occurred. At the time when data inclusion ended to facilitate the writing of this report, the average percent tread wear in reported data was 67 percent for Maness, 50 percent for Snider, 55 percent for Whites, and 44 percent for Wingfoot.

The high coefficients of determination reported in the previous paragraph gave researchers confidence to make reliable tire life comparisons using mileage projections based on the dataset available at the time of writing. The low number of excluded tires produced a final dataset that easily exceeded the surviving tire minimum requirement of 30 specified in RP 230A (44 for Maness, 43 for Snider, 44 for Whites, and 44 for Wingfoot). Because the fitted equations described in the previous paragraphs were based on measured change in tread depth from the time the study began, it was necessary to use the actual beginning (zero mile) tread depth measurement for each tire as the basis of the correction for mileage to precisely 4/32 inch in tread depth. With this final step completed, Table 2 was developed to compare the average miles to 4/32 inch for each tire manufacturer.

Manufacturer	Avg Tread	Avg Miles	Failed	Tot Miles
Maness	22.0	24,924	0	1,246,219
Snider	22.3	34,970	3	1,683,737
Whites	22.7	38,673	0	1,933,669
Wingfoot	28.1	51,572	0	2,578,592

Table 2 – Average and Total Miles to Precisely 4/32 inch for Each Tire Manufacturer

The last column in Table 2 was computed by multiplying the average miles for each manufacturer by 50, which was the original total number of tires, discounted by the reduced mileages for failed tires. This calculation corrects the population for tires that were removed as a result of damage and can be divided into the total cost to purchase the fifty tires from each manufacturer to produce an average cost per mile of use for all tires. Results from Table 2 appear to be substantially different; however, it is important to investigate further to verify statistical significance in the observed outcomes.

A general factorial regression and analysis of variance (ANOVA) were run using Minitab 17 in order to relate manufacturer and truck number (factors) to projected miles run to reach 4/32 inches of tread depth (response). As seen in Table 3, this effort produced a model with a very good coefficient of determination ($R^2 > 0.93$) and a pooled standard deviation (S) of 7,739.9.

General Factorial Regression: Miles versus Manufacturer, Truck

Factor Information

Factor	Levels	Values
M	4	Maness, Snider, Whites, Wingfoot
T	22	1220-0620, 1475-0108, 1475-0110, 1475-0111, 1475-0126, 1475-0256, 1475-0300, 1475-0364, 220-0527, 220-0707, 475-0026, 475-0197, 475-0200, 475-0201, 475-0204, 475-0206, 475-0279, 475-0297, 475-0395, 490-0043, 490-0044, 490-0048

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	87	71649128059	823553196	13.75	0.000
Linear	24	41591950654	1732997944	28.93	0.000
M	3	15814795506	5271598502	88.00	0.000
T	21	25544803138	1216419197	20.31	0.000
2-Way Interactions	63	30144460012	478483492	7.99	0.000
M*T	63	30144460012	478483492	7.99	0.000
Error	87	5211833039	59906127		
Total	174	76860961098			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
7739.90	93.22%	86.44%	*

Table 3 - General Factorial Regression and ANOVA Run Using Minitab 17

Results from this process were used to compute 95 percent confidence intervals ($\alpha = 0.05$) for projected miles to 4/32 inches of tread depth grouped by both manufacturers (Figure 6) and truck numbers (Figure 7). In Figure 6, it is seen that the apparent difference between tires supplied by Whites and Snider are not statistically significant (because the ranges of the 95 percent confidence intervals overlap); however, Maness tires were projected to run significantly fewer miles to reach 4/32 inches of tread depth and Wingfoot tires were projected to run significantly more miles to reach 4/32 inches of tread depth (because their confidence intervals do not overlap with either those for Whites or Snider).

Similar observations can be made about Figure 7, where statistical significance is apparent in all cases where the 95 percent confidence intervals do not overlay. Tires from all manufacturers on most trucks projected to average running between 20,000 and 45,000 miles before reaching 4/32 inches of tread depth. Tires from all manufacturers on trucks numbered 1475-0110 (in Division 2), 1475-0256 (in Division 5), 475-0200 (in Division 8), and 475-0201 (in Division 8) were all projected to run average miles that were statistically greater than the average for most of the other trucks ($\alpha = 0.05$), presumably the result of differences in duty cycles (e.g., a larger number of relatively low scrub highway miles).

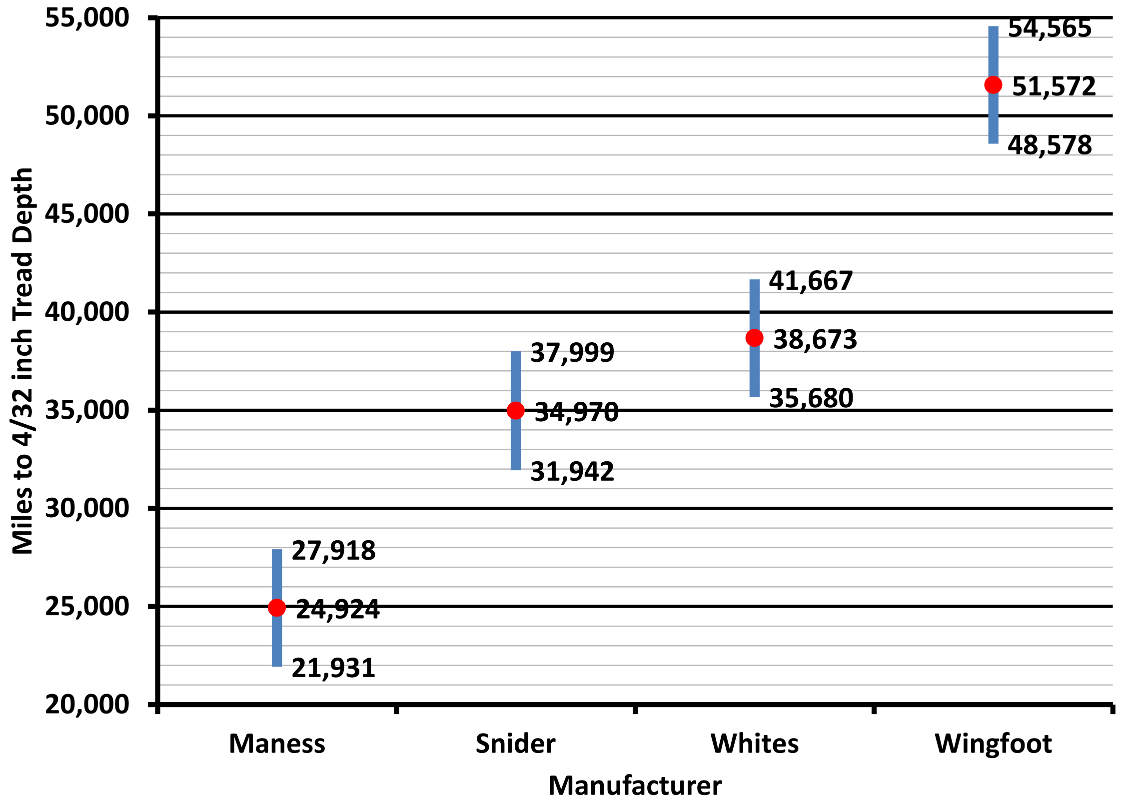


Figure 6 – Interval Plot of Miles to 4/32 inch Tread Depth by Manufacturer (α=0.05)

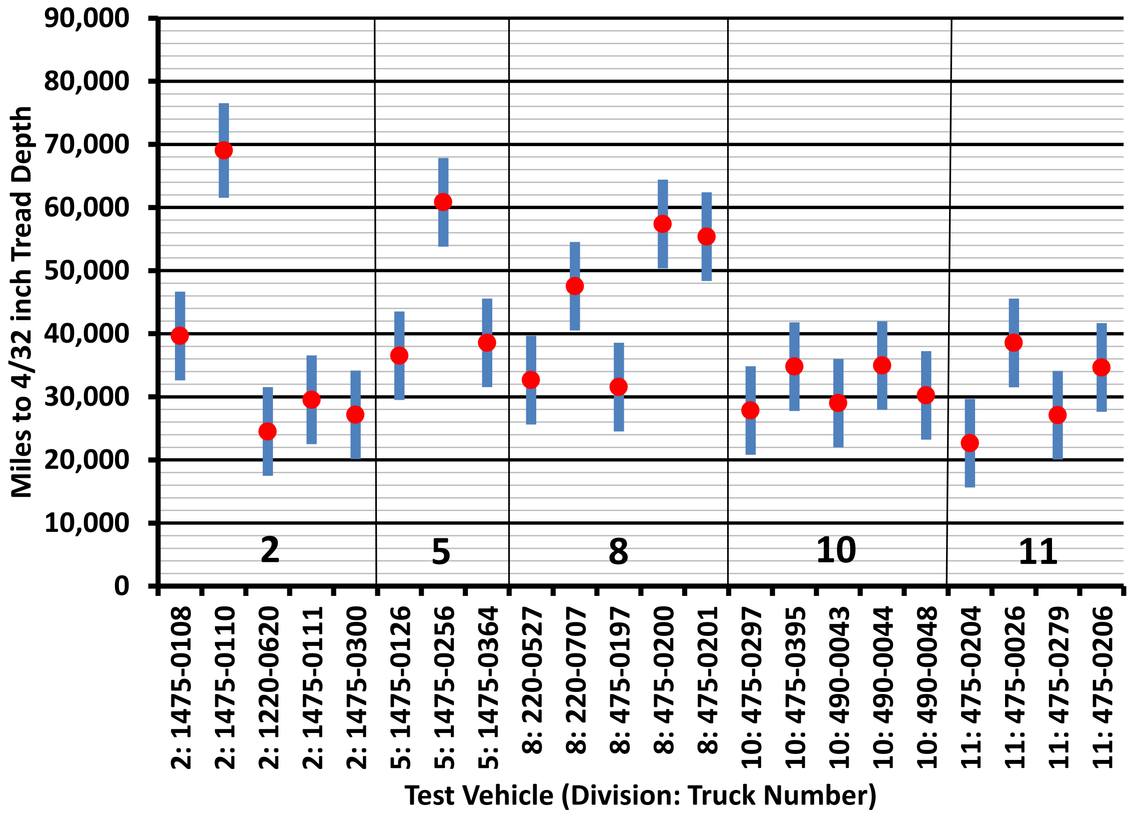


Figure 7 – Interval Plot of Miles to 4/32 inch Tread Depth by Truck (α=0.05)

Task 6: Communicate Findings to Management

Personnel from the NCAT Pavement Test Track will be available to travel to NCDOT and present the findings described above to management on an as-needed basis. Three trips were assumed for budgeting purposes.

8. Conclusions and Recommendations

At the 5 percent level of significance ($\alpha = 0.05$), there is no statistical difference in projected miles run to reach a tread depth of 4/32 inches between tires supplied by Whites and Snider. Wingfoot tires were projected to run significantly more miles, and Maness tires were projected to run significantly fewer miles. The observed difference between tires supplied by Whites and Snider are not statistically significant because the ranges of the 95 percent confidence intervals overlap; however, the lower mileage projection to reach 4/32 inches of tread depth for Maness is statistically significant because the ranges of the 95 percent confidence intervals do not overlap. Likewise, the higher mileage projection to reach 4/32 inches of tread depth for Wingfoot is statistically significant for the same reason.

Total projected miles run to reach precisely 4/32 inches in tread depth (shown in Table 2) can be divided into the total cost to purchase the fifty tire populations from each statistically different manufacturer to produce an average cost per mile of use. Alternatively, projected miles on the extreme points in the respective 95 percent confidence intervals (shown in Figure 6) for each manufacturer can be used for more conservative direct comparisons. Comparing the economy of 2,428,900 (48,578 x 50) projected miles for Wingfoot (the lowest value in the 95 percent confidence interval) to 1,395,900 (27,918 x 50) projected miles for Maness (the highest value in the 95 percent confidence interval) is an example of this more statistically conservative approach.

9. Appendices

Appendix A – RP 203A Test Procedure

TMC Recommended Practice

RP 230A **VMRS 017**

TIRE TEST PROCEDURES FOR TREAD WEAR, SERVICEABILITY AND FUEL ECONOMY

PREFACE

The following Recommended Practice is subject to the Disclaimer at the front of TMC's *Recommended Maintenance Practices Manual.* Users are urged to read the Disclaimer before considering adoption of any portion of this Recommended Practice.

PURPOSE AND SCOPE

The purpose of this Recommended Practice (RP) is to provide fleets guidelines on tire testing procedures. The RP is organized in three parts:

- Tire Testing Procedures—Tread Wear
- Tire Testing Procedures—Serviceability
- Tire Testing Procedures—Fuel Economy

The Tread Wear section provides information to help fleets evaluate tires through one complete tread life cycle (either new or retreaded) from initial placement on a vehicle to removal at wear out or for any other reason.

The Serviceability section provides information to help fleets evaluate tires through a complete casing life cycle—from initial placement on a vehicle as a new tire through multiple retreads and ending when casings are disposed, sold or placed on sold or traded vehicles.

The Fuel Economy section is a supplement to TMC Recommended Practices RP 1102, *TMC/SAE In-Service Fuel Consumption Test Procedure—Type II,* and RP 1103, *TMC/SAE In-Service Fuel Consumption Test Procedure—Type III.* It provides specific information to help fleets evaluate the effects of tire variables (brands, types, etc.) on vehicle fuel consumption.

SECTION I
TREAD WEAR TIRE TEST PROCEDURES

The objective of this section is to help fleets reduce the number of variables that can influence test result quality. Procedures for calculating tire cost per mile are provided in the **Appendix**.

A tread wear test can be combined with a tire serviceability test. A recommended test procedure for serviceability appears in **Section II**.

TREADWEAR TERMINOLOGY

Tire treadwear can be analyzed in terms of wear rate, irregular wear, resistance-to-irregular wear, and/or removal mileage.

Wear rate is usually expressed in terms of miles-per-32nd inch of worn tread depth. Wear rate can be tracked during tire life and used to calculate projected tire removal mileage. Projected mileage should only be used as a tire performance indicator. Final analysis of performance should be made using actual removal mileage.

Irregular wear is defined as non-uniform wear of individual tread elements or elements around the tire. Some examples include heel/toe wear, diagonal wipes, high/low wear, etc. **NOTE:** See TMC RP 219B,*Radial Tire Wear Conditions and Causes.*

Removal mileage is the number of miles a tire has accumulated when removed. This is often the most important tire performance consideration. Take care to document reasons for removal (i.e., road hazards, irregular wear, pull point, etc.) and separate tire-related removal causes from other removal causes when analyzing data.

TIRE TEST EXAMPLES

Many factors affect tire treadwear. The following are examples of different treadwear tests that can be run. It is important to test only one variable at a time to ensure data quality and avoid confusion.

<u>Examples</u>

Tire brand (new tires):	Brand A 123 vs. Brand B 456
Tread type within brand:	Traction Tread vs. Rib-Type Drive Tires
Retread brand:	Brand C ABC vs. Brand C DEF

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Revised 12/2004

Retread process:	Pre-cure vs. Mold Cure
Tire size:	Conventional vs. Low-Profile
Wheel or rim size:	22.5" vs. 19.5"
Inflation pressure:	Minimum Required for Load vs. Increased Pressure
Tire rotation procedure:	No Rotation vs. Left-Right
Vehicle Type:	COE vs. Conv. or Std. vs. Set-back Axle
Vehicle Brand:	Brand AB vs. Brand CD
Alignment:	Positive vs. Negative Camber or Toe Setting

TREAD WEAR TEST CONSIDERATIONS

A. Number Of Tires Required
For steer, drive and trailer tire tests, TMC recommends that fleets have a sample of 30 tires for each individual test type or test group at the ***end*** of each test. This allows fleets to obtain statistically significant and repeatable data. Smaller sample sizes may provide useful data that indicate differences between tire groups in the test, but the results may not be statistically significant or repeatable. Refer to **"Test Group Sample Size Table"** in the **Appendix** for an indication of the value of smaller sample sizes.

B. Vehicle Specification
Tire wear rate and wear uniformity can vary with vehicle type, make, year and major components. The fewer the variables, the better the data. To account for major vehicle effects, follow these guidelines during test setup:

- Use identical vehicles for all test groups unless vehicle type is the test variable.
- If vehicles of different specification must be used, make sure they're equally represented in each test group.
- Make sure the test vehicles are representative of the fleet's equipment.
- Use new vehicles (highly recommended).

C. Gross Vehicle Weight
Make sure the load weights of all test vehicles are similar to ensure fair evaluation between test groups.

D. Wheels
Follow these guidelines:

- Make sure all wheels in the test are of the same width (unless different tire sizes require different width).
- Inspect all wheels for damage, excessive runout and wobble.
- Use new valve stems and grommets when tires are mounted.
- Be consistent regarding the use of aluminum and steel wheels on test vehicles.

E. Wheel Position
Tire wear rates, irregular wear, wear uniformity, and removal mileage also vary with axle and wheel position.

F. Steer Tire Wear Testing Variables
Wear rates for left-side and right-side steer axle tires are seldom equal. Reasons for different tire wear rates from right side to left side are normally combinations of the following:

- Road Crown
- Vehicle Steering Geometry
- Frequency and Angle of Left and Right Turns
- Total Vehicle Alignment

Typically, the right front tires on commercial trucks wear more slowly than do the left front tires on the same vehicle. However, right-side tires are more susceptible to irregular wear conditions that can cause early removal—despite acceptable remaining tread depth.

G. Drive and Trailer Tire Wear Testing Variables
On multiple axle configurations, wear rates will vary from axle to axle.

H. Tire Position Rotation
Due to the typical differences in treadwear for various wheel positions, fleets often rotate tires by position to even out wear. For testing purposes, this procedure should only be used if it is normal fleet policy. If position rotation is desired, tires must be rotated in the same manner and at the same test mileage interval on all vehicles in the test.

I. Total Vehicle Alignment
Axle alignment is a particularly critical variable. Follow these guidelines:

- Align all vehicles at the start of the test.
- Align steer and drive axles to fleet specifications. See TMC RP 642A, *Guidelines for Total Vehicle Alignment.*
- Check vehicle alignment if unusual wear develops during the test.
- Keep all alignment records.

J. Vehicle Maintenance
Make every effort to replace worn steering system and suspension system components that are likely to

need replacement before testing begins, then align the vehicle. Minimize any changes to test vehicles during the test.

K. Tire Maintenance
During the test, remove any nails (that do not cause air leakage) found embedded in the tread of any tires.

Tires with objects that have penetrated the casings should be repaired and returned to their test position with the same direction of rotation if possible. If this is not possible, the damaged tire is considered "lost." For proper repair procedures, refer to TMC RP 206A, *Tire Repair Procedures.*

L. Tires Removed Before Test Completion
Tires damaged beyond repair must be dropped from the test. If the damaged tire is mated with another tire of a dual assembly, the mate must also be dropped from the test as differences in tire diameter will affect the test outcome. Note the specific reason for tire removal, tread depth and the accumulated mileage. Separate removal causes into two categories: tread wear related and non-tread wear related (such as vandalism or vehicle accident). Do not discard data collected on the removed tire or tires as it may be beneficial during data analysis.

M. Air Pressure
Follow these guidelines:

- Follow fleet practices (unless air pressure is the test variable).
- Be sure that inflation pressure is adequate to carry vehicle load.
- Check/correct cold inflation pressures at least monthly (preferably weekly) with a calibrated gauge.
- Keep records showing "pre-correction" inflation pressures.
- Use positive seal metal valve caps.

N. Weather
Follow these guidelines:

- Install all test tire groups within 30 days.
- Make every effort to ensure that the vehicle routes for each test group experience the same weather. If the test vehicles are exposed to large variations in weather, make every effort to ensure that each test group is equally exposed to these variations.

O. Geography
Follow these guidelines:

- Make sure truck routes for each test group share the same geographic area.
- Make sure route geography is representative of fleet operation.
- Use a domiciled fleet if possible. Experience has shown using a domiciled fleet (or portion of a fleet) reduces geographic variations.

P. Drivers
Follow these guidelines:

- Screen out drivers with known unusual driving habits.
- Make sure drivers are representative of fleet personnel.

Q. Casing Manufacturer
When testing retreaded tires, be sure comparisons are made with casings made by the same manufacturer (if casings are not the test variable). A retread wear test with "mixed" casings, mixed tread designs or tread widths may invalidate test results.

R. Tire Age
All new tires and retreaded casings in a tread wear test must be manufactured within one year of each other as designated by the last three or four digits of the DOT number on each tire sidewall. See TMC RP 218C, *DOT Tire Identification Codes* for information on reading DOT tire codes.

UNIQUE TIRE IDENTIFICATION
It is very difficult to document tire wear data confidently without unique identification of individual tires, since tires are often removed from service or moved to another wheel position or vehicle without formal documentation. Unique tire identification may not help locate a lost tire, but it will indicate if tires have been lost or moved from their intended positions as data is collected throughout the test duration.

Labeling all test wheels and vehicles with a visual identification mark may help alert maintenance personnel and drivers that the wheels and vehicles are part of a test.

STATISTICAL METHODOLOGY FOR TIRE TREAD WEAR TESTING
At least two products must run concurrently during testing. All parameters for the test and control vehicles, except for the test variable, must be consistent. See **Fig. 1** for tread wear evaluation positions.

For tire mileage testing, measure remaining tread depth at specific intervals. The recommended mileage intervals in line-haul operations for all wheel

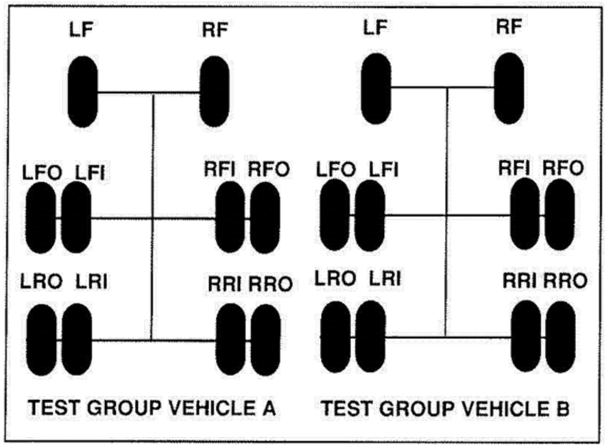


Fig. 1: Positions for Tread Wear Evaluation

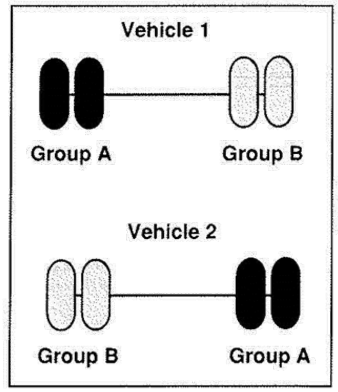


Fig. 2: Right-side, Left-side Installation Method

positions are at least every 30,000 miles or at scheduled preventive maintenance intervals. Measurements are not significant prior to 30,000 miles since most tires wear more quickly in their early tread life than their remaining tread life.

Tire mileage projections should not be based on early tire mileage wear, but projections can be made when at least 50 percent tread wear has occurred. Such projections should be used only as indicators of tire performance.

For high wear conditions such as pick-up and delivery, construction, mining and refuse operations, use percentages of "expected removal"— such as 25 percent, 50 percent, 75 percent—and "at removal" as measuring intervals. The percentages may be based on mileage or time, depending on the fleet's normal means for determining tire life.

For smaller test samples, tire test groups can be mixed on the same vehicle to equalize exposure to random variables. The following are test tire installation methods for single and tandem axles.

Single Axles
For single axles with dual tire assemblies, a left-side, right side installation method can be used for test groups, as shown in **Fig. 2**.

Tandem Axles
The X-pattern method for tandem axle vehicles is shown in **Fig. 3**.

NOTE: Mixing sample groups on vehicles is less important as sample size increases.

TIRE LOSSES
During the course of the test, it is expected that several tires will be unserviceable due to road hazards or other conditions. When a tire fails, note the cause and the mileage at the time of failure. When one tire of a dual assembly fails, drop the companion tire from the test.

TEST DATA COLLECTION AND RECORDING
The simplest means of recording test data is by using paper forms. (See **Appendix** for sample tire installation and inspection data forms.) Hand-held computers can also be used to gather tire performance data.

Tire tread condition must be noted and a tread condition coding system makes recording, filing and

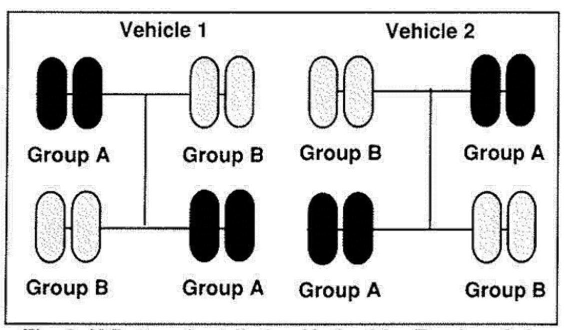


Fig. 3: X-Pattern Installation Method for Tandem Axles

analyzing test data easier. See the **Appendix** for a complete list of codes with suggested abbreviations.

NOTE: Refer to TMC RP 219B, *Radial Tire Conditions Analysis Guide* for detailed photographs and descriptions of all tire conditions/failures.

RECOMMENDED TOOLS FOR TEST

The following tools are recommended for tire treadwear testing:

- Air gauge
- Tread depth or "non-skid" gauge
- Pliers
- Awl/Probe
- Small mirror (to aid reading brand numbers between duels)
- Tire crayon or chalk
- Flashlight
- Clipboard
- Appropriate forms
- Digital camera

TIRE TREADWEAR MEASUREMENT

Tread depth measurements are typically taken with a simple tread depth or "non-skid" gauge. Units of measurement are typically 32nds of an inch or millimeters. Electronic depth gauges with digital readout are also available and are acceptable for treadwear measurements. However, periodic calibration of the gauge is critical.

The minimum number of tread depth measurements needed is one measurement per "major groove" in two "representative" locations about 180° apart. Be sure to take tread depth measurements at the lowest part of a major tread groove. The valve stem can be used as a reference to ensure tread depth measurements are taken at the same locations.

TIRE INSPECTION PROCEDURE

Follow these guidelines:

- Tires must be available for periodic inspection at predefined intervals.
- Only one person should take measurements (for data consistency).
- Measure or check the following items:
  1. Inflation pressure.
  2. Tread depth measurement as described previously.
  3. Treadwear uniformity (irregular wear).
  4. Sidewall appearance (cuts, snags, etc.).
  5. Other evaluation points (stone holding, for example).
- Note driver comments on tire performance (such as ride and wet traction).

DATA ANALYSIS

Although it is best to complete a test before drawing any conclusions, indications of tire performance may be made when tires are at least 50 percent worn. Use the same analysis procedures for preliminary analysis (detailed in the following paragraphs) but, remember, the data must be interpreted as projections *not* as a final test result based on removal mileage. Data acquisition for all test and control tires should end at the same mileage or a wear rate should be used for wear out.

When the test is complete and data has been gathered, final analysis of results can begin. The test variable can be evaluated for wear rate, irregular wear and removal mileage.

1. For Steer Tires:

List removal mileages for all tires that complete the test. Exclude tires that are removed for non-wear related reasons (vehicle accidents, vandalism, etc.) Include tires that were removed due to manufacturing defects. Compute the average (Avg.) left steer tire mileage for each test group by adding the total removal mileage of all left steer tires and dividing by the number of tires that completed the test from that group.

Group A (Steer Axle Tires)

$$\text{Average Steer Mileage (Avg. Steer)} = \frac{\text{Total Miles Traveled by Steer Tires (A)}}{\text{Total Number of Steer Tires (A)}}$$

Repeat this procedure for each test group of tires.

2. For Drive And Trailer Tires:

List removal mileages for all tires that complete the test. Exclude tires (and the corresponding dual mate tire) if they are removed for non-wear related reasons. Include tires that were removed due to manufacturing defects.

Average the removal mileage for all drive or trailer wheel positions. See **Fig. 4** for positions.

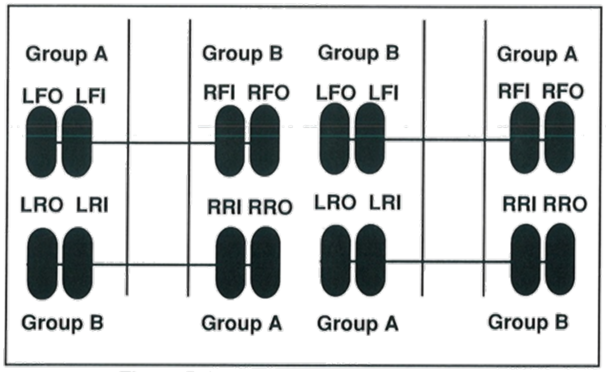


Fig. 4: Drive and Trailer Tire Positions

For example:
Group A (Drive Axle Tires)

Average Drive Group A Mileage =

$$\frac{\text{Total Miles Traveled by Drive Tires Group(A)}}{\text{Total Number of Drive Tires Remaining in Group (A)}}$$

Repeat this procedure for each test group of tires.

Determining average removal mileage is important because most choices involving tire tests focus on "cost per mile" considerations. Cost per mile (in the simplest form) is determined by dividing the original cost of the tire by removal mileage.

$$\text{Cost per Mile (CPM)} = \frac{\text{Original Total Tire Cost}}{\text{Total Number of Miles}}$$

Over the entire life of the tire, cost per mile is also impacted by factors such as casing value, repairability, retreadability, number of retreads per casing and miles per retread. Analysis of test results is often clearer if data is plotted or graphed. Pie charts and bar graphs communicate results more clearly. (See **Fig. 5.**)

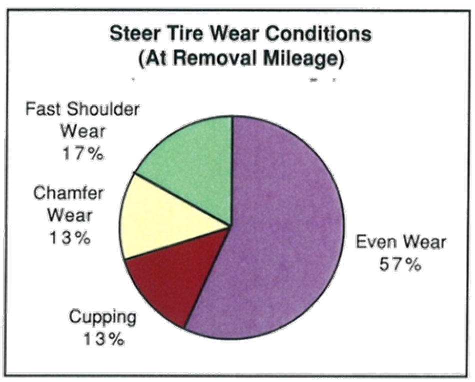


Fig. 5: Sample Data Analysis Chart

SECTION II
TIRE SERVICEABILITY TEST PROCEDURES

Radial truck tires have the potential for long initial tread life, excellent repairability and multiple retreadability before casings are scrapped. This means that many miles and several years may pass between initial installation and casing disposal. This section outlines procedures that can help fleets document truck tire casing costs and performance during this potentially long period of time. A tire tread wear test can be run concurrently with a serviceability test. (See **Section I** of this RP.)

PERFORMANCE PARAMETERS
Tire serviceability can be evaluated in terms of:

1. Total Life Cycle Costs—consisting of the following:
   - New tire costs
   - Repair costs
   - Retread costs
   - Casing value
   - Tire disposal costs
2. Casing Durability—total number of miles delivered by a casing.

It is important to define a test objective before the test begins. In particular, a clearly defined "end point" of the useful life of a tire is needed. This end point may be when the tire can no longer be used or retreaded or after a specified number of retreads, etc.

TEST EXAMPLES
Many variables can affect casing life. By minimizing other variables, a test variable can be evaluated for its impact on casing life. Examples:

Test Type	**Example**
Tire Brand (new tires):	Brand A vs. Brand B
Retread System:	Process C vs. Process D
Repair Procedures	Repaired Tires vs. Non-Repaired Tires (Repair cost effectiveness)

Appendix B – Specific Test Procedure for North Carolina Tires

03/19/2012

Tire Test Procedures

1-Install test tires in assigned positions on test vehicles;

2-Mount tires using new valve stems with metal valve caps;

3-Measure tread depths at valve stem & 180 degree offset as specified;

4-Install test tires decals on vehicle above pairs;

5-All measurements will be taken every 5000 miles at scheduled service intervals;

6-Pre-correction cold air pressures will be noted for all study tires;

7-Air pressures will thereafter be corrected to 100 psi throughout the length of test;

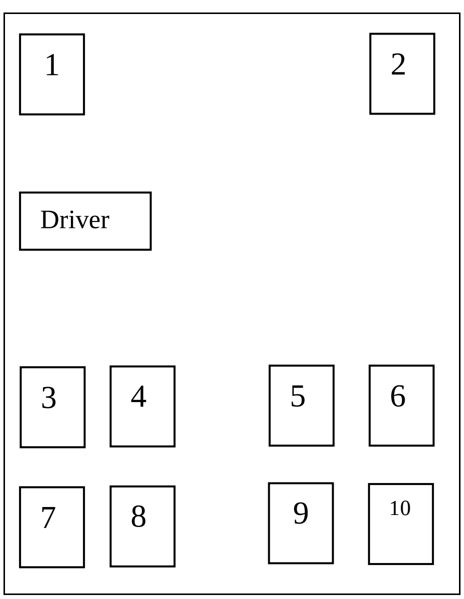
8-Note wear uniformity, sidewall appearance, and repairs (where applicable);

9-Take pictures with date stamp of all tires removed because of non-wear reasons;

10-Submit all pictures and data sheets (via email or Fax 252-830-3149) to Buddy Dixon as they are taken/prepared; and

11-Buddy Dixon will compile all information and send to the NCAT Pavement Test Track.

Tire Positions



Appendix C – North Carolina Tire Study Data Collection Forms

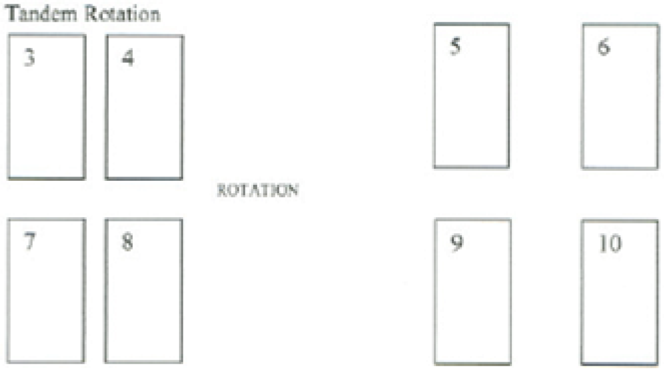
PROCEDURE FOR EVALUATING MILEAGE COMPARISON FOR NCDOT TIRES

- Use the attached "NCDOT Tire Mileage Evaluation Form" to document all required data When evaluating tires.
- This form may be used for mileage comparisons between any two different tires on a single Equipment number.
- Each tire will be branded with an identification number for tracking purposes.
- Tires will normally be tested on the rear axles in positions 3 thru 10 on tandems, and 3 thru 6 on single axle trucks.
- Four tires of one type will be installed on one side in positions 3,4,9,10 while the second type will be on the opposite side in positions 5,6,7,8 on tandems. Two tires of one type will be installed on one side in positions 3 and 4 while the second type will be in the opposite side in positions 5 and 6 on single axle trucks.

* One tread depth measurement will be made per "major groove" in 2 locations 180 degrees apart using the location of the valve stem as one of the locations (i.e., either 6 or 10 measurements will be taken per tire).

- Tread depth readings should be taken at each tire rotation.
- When rotating tires, all tries will move to the opposite side of the vehicle, to the other axle, and from the outside position to the inside position or inside to outside. (i.e. 3 to 9, 4 to 10, 9 to 3, 10 to 4, 5 to 7, 6 to 8, 7 to 5, and 8 to 6) on tandems. When rotating tires on single axle trucks, move tires to opposite side of the vehicle and from outside position to inside position or inside to outside.

Tandem Rotation



- In addition to normal rotation and tread depth measurements, all other tire maintenance activities such as flats, repairs, blowouts, and changes should be recorded under the attached "inspection/rotation data." This will provide repair data for tires being evaluated.

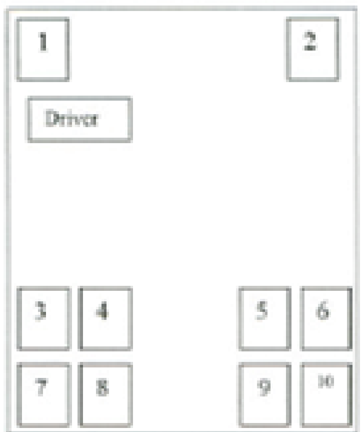
- If a tire requires replacing prior to the end of the test, it must be replaced with an identical tire and a new identification number.

- Each test will continue until all test tires have been replaced under normal tire maintenance policies.

* After each tire rotation, a copy of the attached form with complete data to that point will be faxed to Buzz Powell at 334-844-6853. The original copy of the forms should remain in the vehicle.

* Should you have questions, call Buzz Powell at 334-750-6293

NCDOT TIRE MILEAGE EVALUATION FORM



EQUIPMENT NO______________ TIRE-SIZE________________

VEHICLE -LOCATION_________ CONTACT______________

TIRES TO BE EVALUATED

DOT-NUMBER __________	DOT-NUMBER __________
DESCRIPTION __________	DESCRIPTION __________
BRAND NUMBERS	BRAND NUMBERS
______________	______________
______________	______________
______________	______________
______________	______________

* A copy of this completed form should be faxed to Buzz Powell at 334-844-6853.
The original copy of the forms should remain in the vehicle.

INITIAL INSTALLATION DATA

VEHICLE MILEAGE____________ DATE__________

TIRE POSITION	BRAND NO	TREAD DEPTH (1/32") STEM	OFFSET	REMARKS
3	______	______	______	______
		______	______	
		______	______	
		______	______	
		______	______	
4	______	______	______	______
		______	______	
		______	______	
		______	______	
		______	______	
5	______	______	______	______
		______	______	
		______	______	
		______	______	
		______	______	
6	______	______	______	______
		______	______	
		______	______	
		______	______	
		______	______	
7	______	______	______	______
		______	______	
		______	______	
		______	______	
		______	______	
8	______	______	______	______
		______	______	
		______	______	
		______	______	
		______	______	
9	______	______	______	______
		______	______	
		______	______	
		______	______	
		______	______	
10	______	______	______	______
		______	______	
		______	______	
		______	______	
		______	______	

* A copy of this completed form should be faxed to Buzz Powell at 334-844-6853. The original copy of the form should remain in the vehicle.

INSPECTION / ROTATION DATA

VEHICLE MILEAGE ____________ DATE ________________

TIRE POSITION	BRAND NO	TREAD DEPTH (1/32") STEM	OFFSET	PRECORRECTION AIR PRESSURE	REMARKS (REPAIRS, ETC.)
3	______	______	______	______	______
		______	______		
		______	______		
		______	______		
		______	______		
4	______	______	______	______	______
		______	______		
		______	______		
		______	______		
		______	______		
5	______	______	______	______	______
		______	______		
		______	______		
		______	______		
		______	______		
6	______	______	______	______	______
		______	______		
		______	______		
		______	______		
		______	______		
7	______	______	______	______	______
		______	______		
		______	______		
		______	______		
		______	______		
8	______	______	______	______	______
		______	______		
		______	______		
		______	______		
		______	______		
9	______	______	______	______	______
		______	______		
		______	______		
		______	______		
		______	______		
10	______	______	______	______	______
		______	______		
		______	______		
		______	______		
		______	______		

* After each tire rotation, a copy of this completed form will be faxed to Buzz Powell at 334-844-6853. The original copy should remain in the vehicle.