DOT-HS-806-743
DOT-TSC-NHTSA-85-2

Statistical Analysis of Tire Treadwear Data

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May 1985
Final Report

U.S. Department of Transportation
National Highway Traffic Safety Administration

Office of Research and Development
Office of Vehicle Research
Washington DC 20590

Technical Report Documentation Page

1. Report No. DOT-HS-806-743	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle STATISTICAL ANALYSIS OF TIRE TREADWEAR DATA		5. Report Date May 1985
		6. Performing Organization Code DTS-45
7. Author(s) Joseph Yarmus, Robert Walter, and Peter Mengert		8. Performing Organization Report No. DOT-TSC-NHTSA-85-2
9. Performing Organization Name and Address U.S. Department of Transportation Research and Special Programs Administration Transportation Systems Center Cambridge, MA 02142		10. Work Unit No. (TRAIS) HS402/R4426
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation National Highway Traffic Safety Administration Office of Research and Development Washington, DC 20590		13. Type of Report and Period Covered FINAL REPORT August 1982 - April 1984
		14. Sponsoring Agency Code NRD-11
15. Supplementary Notes		

16. Abstract

This report describes the results of a statistical analysis of the treadwear variability of radial tires subjected to the Uniform Tire Quality Grading (UTQG) standard. Because unexplained variability in the treadwear portion of the standard could lead to the misgrading of tires and provide false information to the consumer, the National Highway Traffic Safety Administration (NHTSA) had temporarily suspended the treadwear test. This report documents NHTSA's efforts to determine and eliminate sources of this variability.

Data analyzed in this report were obtained from UTQG compliance tests performed at the San Angelo, TX test track, and from various tire manufacturers. Both aggregate and disaggregate regression analyses, as well as an analysis of variance, were performed. From these analyses, it is concluded that NHTSA should standardize the tire grade assignment procedure to ensure the true precision of the UTQG test. It is proposed that such standardization be accomplished either by assigning numerical grades with a given error range, or by assigning letter grades reflecting a range of grades.

17. Key Words Tires, Treadwear, Surrogate Variables, Regression Analysis, Analysis of Variance, ANOVA Analysis	18. Distribution Statement DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	88	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

This report describes the results of a statistical analysis of the treadwear variability of radial tires subjected to the Uniform Tire Quality Grading (UTQG) standard. Because unexplained variability in the treadwear portion of the standard could lead to the misgrading of tires and provide false information to the consumer, the National Highway Traffic Safety Administration (NHTSA) at the time of this report had temporarily suspended the treadwear test. This report documents NHTSA's efforts to determine and eliminate sources of this variability.

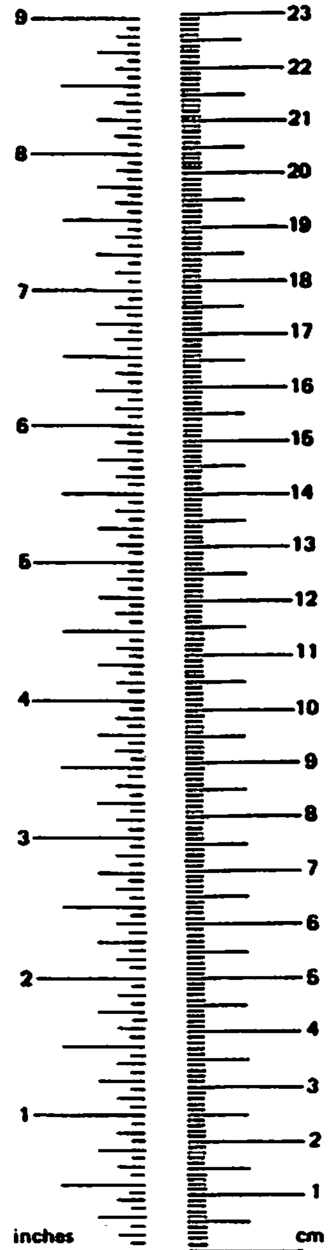
This report was sponsored by the U.S. Department of Transportation, National Highway Traffic Safety Administration, Office of Research and Development. Data analyzed in this report were obtained from UTQG compliance tests performed at the San Angelo, TX test track, and from various tire manufacturers.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

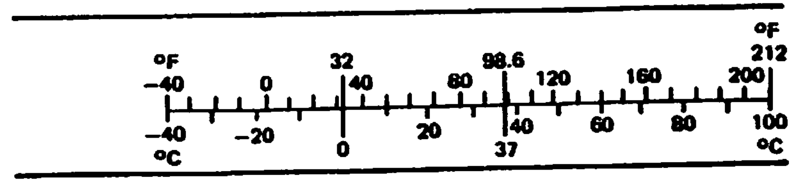
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

This summary describes the results of a statistical analysis of the treadwear variability of radial tires subjected to the Uniform Tire Quality Grading (UTQG) standard. Both the Government and industry expressed concern that any unexplained variability in the test could lead to the misgrading of tires and could actually provide false information to the consumer. With these concerns in mind, the National Highway Traffic Safety Administration (NHTSA) at the time of this analysis, temporarily suspended the treadwear portion of the standard and accelerated their efforts to determine and eliminate the sources of this variability.

NHTSA made available to the Transportation Systems Center (TSC) the results of UTQG compliance tests from the San Angelo, TX test track. The tests discussed in this report were performed on radial tires during FY'80-81. Other data for this analysis were supplied by tire manufacturers.

The NHTSA compliance tests included approximately 800 candidate (i.e., under test) tires and 300 course monitoring tires (CMT). These results were supplied to TSC in machine-readable format and merged into a computerized data base for statistical analysis. The data base also included pertinent weather data from San Angelo, TX, and other important test-related variables. The statistical analyses initially were performed on the TSC PDP-10 computer using the Statistical Program for the Social Sciences (SPSS). The data then were transferred to the National Institutes of Health (NIH) IBM System 370 computer for use with the Statistical Analysis System (SAS). All of the manufacturers' data also were entered into the NIH computer.

The major objectives of the statistical analyses were to identify the sources of variability in the UTQG treadwear test and to quantify the effectiveness of the grading procedure. The primary statistical techniques used to accomplish these objectives are multivariate regression analysis and one-way analysis of variance (ANOVA).

Two regression analyses were performed. The first analysis, called disaggregate level regression, used data obtained during each 800-mile segment of the test. The second analysis, called aggregate level regression, used data averaged for each tire over the entire 6400 miles of each test. Separate regression analyses were performed for the candidate and CMT tires.

ANOVA tests were performed to determine the precision of the UTQG treadwear test. For each candidate tire, the NHTSA data base contained at least eight tires of the same tire type (same manufacturer, line, and size) tested in two separate convoys of four tires each. These two convoys generally were run approximately two weeks apart. The results of these two tests then could be compared using ANOVA techniques. The manufacturers' data contained the results of both candidate and CMT tire tests, in which tires of the same type were in some instances tested over a longer time interval.

In this report, regression results obtained by Uniroyal from tire tests and entered into the public docket also are addressed.*

From regression analyses using the FY'80-81 compliance test data on radial tires, the following conclusions may be drawn:

- <u>Explanatory Capability of Regression Analyses Performed</u>

  1. The analyses of candidate tires did not account for all of the variance in the tests. At the disaggregate level, only 20 to 30 percent of the variance could be accounted for in these analyses. Accountability was improved to 40 percent at the aggregate level. Analyses of CMT tires at the aggregate level produced accountability of up to 60 percent. Through the use of a different technique, accountability was improved to 80 percent (see regression on differences, Section 6.4.3). It must be added, however, that none of the regression models used here has been validated by cross-validation techniques.

*Uniroyal Docket Submission To 49 CFR Part 575, Docket No. 25; Notice Petition, January 21, 1983.

2. The same group of non-surrogate variables appeared consistently in the regression results with approximately the same rank-order, and their signs and relationships were physically explainable. (Note: non-surrogate variables are exclusive of driver, car, and season.)

3. Low accountability was attributed to random minor variations (noise) in the treadwear measurement, the failure of the model to reflect the actual physical relationships, and the unavailability of data on other variables that may have correlated with treadwear, such as the horsepower-inertial values of the vehicles.

- <u>Variables Found to be Significant in Regression Analyses</u>

1. The variables that were the most highly-correlated with candidate tire treadwear included the base wear factor (CMT correction), environmental effects (temperature, humidity, wet miles and season), driver, car, wheel position, tire load, and inflation pressure. Surrogate variable (driver, car, and season) effects may have been confounded.

2. The most-highly correlated variables for the CMT tire were environmental effects, indicating that the CMT tire reflected changing conditions.

- <u>Comparison With Uniroyal Results</u>

1. A comparison of TSC's regression analysis results with those obtained by Uniroyal indicated agreement on some correlating variables such as temperature and wet miles. However, Uniroyal's claimed accountability was much higher than that found in TSC regressions.

2. The high accountability of Uniroyal's regression equation (95 percent) was attributed to the non-standard "R" used to calculate accountability and the control on Uniroyal test procedures. When Uniroyal's coefficient of determination (R^2) was recalculated using standard techniques, their regression accounted for 40 percent of the variability using the standard UTQG depth-gauge technique for treadwear measurement.

3. Using Uniroyal's data, the regression analysis using the weight measurement for treadwear loss was recalculated. The R^2 obtained was 76 percent, indicating that this improvement would aid test precision. This result also substantiated the theory that some of the low accountability in the TSC regression results was due to the noise in the treadwear measurement.

Various conclusions can be drawn from the ANOVA:

- Test Precision Analysis Results

1. Within a 95 percent confidence level, the average test grade of four identical tires should not shift more than 23 percent in successive convoys.* If the clustering of radial tire grades and the test variation are considered, some grade rank inversion among tires is likely. In fact, using the UTQG compliance data, grade rank inversion is observable.

2. Within a 95 percent confidence level, the compliance test grade rank order of two different tires was not spurious if there was a difference of more than 47 points in compliance test grades between these two tires.

3. The course severity adjustment factor (CMT correction) compensated for more than 50 percent of the variability between convoys of identical tires run successively in the NHTSA compliance test data. The CMT correction in the manufacturers' data compensated for 25 to 40 percent of variability between convoys.

4. The lack of a standardized grade assignment procedure caused the manufacturers' assigned grade to be a less precise indicator of tire quality than the attained grade.

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*Successive convoys - Two convoys run closely together in time; usually within a few weeks.

- Environmental (Seasonal) Factor Analysis Results

  1. There was a statistically observable seasonal effect in NHTSA's FY'80-81 radial compliance CMT treadwear data. Indications are that this effect was a factor of 1.1 to 1.2, with the higher treadwear during the warm months. However, the effect of this factor on candidate tire grades was dependent on the response of the CMT tire to the environment relative to the candidate tire.

  2. The CMT variance in the manufacturers' data was higher than the variance measured in NHTSA's compliance tests. This result may indicate that NHTSA exercised better control over testing procedures.

  3. In general, the CMT explained more of the variance in the compliance test data than in the manufacturers' data. Possible causes include: 1) less well-controlled test procedures; 2) poorer test level estimates of treadwear, because manufacturers often used fewer than four tires of the same design in a test (Section 8.1), and 3) wider spacing over time of a candidate tire design in the manufacturers' data.

- CMT Base Wear Rate Analysis Results

  1. Analysis results indicated that different nominal base wear rates assigned to some CMTs may not reflect true differences in the treadwear characteristics of CMTs.

- Car Effect Analysis Results

  1. Tires of one type tested on two cars in a convoy exhibited higher variance than tests of tire type on a single car in a convoy. However, these differences were not statistically significant at the 90 percent level.

- <u>CMT Serial Number Analysis Results</u>

  1. Results indicated that within a single CMT type, treadwear characteristics were not significantly affected by different bandberry batch or cure dates.

Based upon the results of this study, the following actions could be valuable:

1. Maintain the CMT in each convoy, since it accounts for over 50 percent of the test variability.

2. Re-examine the CMT base wear rate to determine whether it reflects true differences in wear characteristics and to provide for testing between generations of CMT tires.

3. Reflect the true precision of the UTQG test in the grade assignment procedure. This could be accomplished either by assigning the grade with an error range, i.e., 200 $\pm$ 45 points, or by assigning letter grades that reflect a range of grades, such as A = 200 to 300 points, B = 100 to 200 points, etc.

4. Standardize the grade assignment procedure.

5. Investigate the validity and practicality of the weight measurement for treadwear loss.

6. Conduct further studies to determine the magnitude of the car effect (see Section 8.2.4).

1. BACKGROUND

The test results from the radial tire treadwear portion of the UTQG standard have been highly variable. Some of the variability was due to differences in tire characteristics and quality, and is considered normal. However, some of the variability may have been due to factors external to tire quality, such as the environmental conditions or the individual vehicle on which the tire was tested.

In the interest of fairness to the manufacturers, as well as usefulness to the public, it is necessary that the UTQG test and grading procedure reflect the tire quality differences only, and make provisions to account for other sources of test variation. Both NHTSA and the tire industry have examined the causes of this variability and reported on them in various docket submissions and at a public meeting held in Washington, DC on August 12, 1982.[1]

Within the tire industry, Uniroyal Tire Co. has examined the sources of variability of the UTQG test procedure in some detail. Their results are considered in Section 6.5 of this report. This apparent test variability had led NHTSA to: (1) temporarily suspend the treadwear portion of the standard and (2) intensify the effort to understand and eliminate the sources of variability. The treadwear test has subsequently been reinstated.

The Transportation Systems Center (TSC) was asked by NHTSA to examine, using statistical techniques, the sources of variability in the test procedure. NHTSA made available to TSC the results of two years (FY'80-81) of treadwear testing on radial tires at San Angelo, TX. The statistical studies of these data are discussed in Sections 6 and 7 of this report.

To address some questions that were raised during the study of these NHTSA compliance tests, data also were requested from tire manufacturers. Data were supplied by Goodyear, Goodrich, Firestone, Uniroyal and General. These data were analyzed and the results compared to the NHTSA compliance information. The results are discussed in Sections 8 and 9. TSC analyzed all data using computer-based statistical packages including SAS, SPSS, and STAT-PAK.

2. OBJECTIVE AND APPROACH

The objectives of this effort were to (1) determine the sources of variability and their significance in the UTQG tread wear test procedure and (2) quantify the precision of the tire tread wear grading method.

To accomplish these objectives, test results from NHTSA and tire manufacturers, as well as other required data, were assembled into data bases. This assembled data was then examined using two statistical techniques: multivariate regression analysis and analysis of variance. These techniques and the results from the application of them are examined in detail in Sections 6 through 9 of this report.

3. TREADWEAR VARIABILITY

The engineering factors generally considered to affect treadwear include speed/acceleration, road condition, load, tire temperature, and tire stiffness. In addition, UTQG measurement procedures (referred to a "test protocol") may affect treadwear. If these variables cannot be directly measured, surrogates variables are required instead. The engineering factors and their associated surrogate variables are shown in Table 3-1.

The rate of treadwear is related to the work performed on the tire. Lateral, axial, and torque forces produce tire treadwear. Any of the variables listed in Table 3-2 that have an impact on these forces could affect treadwear variability. The interaction of these variables is complex and not fully understood.

Tire wear originates from sliding in the rear part of the contact patch. The contact patch depends on the pressure distribution (which is affected by load) and the total sliding distance, which is affected by tire size. An equation that relates the wear per unit travelling distance (W) to the area of the contact patch (ab), the load (L), the circumferential slip (S), and F(c), a function of tire resilience, wheel stiffness and the skid coefficient is:

$$W = {}^{1}/{}_{2}\, ab\, (4L/\pi \ \ abp_o)^n SF(c)$$

where n and p_o are empirical constants characterizing the rubber and the track.[2]

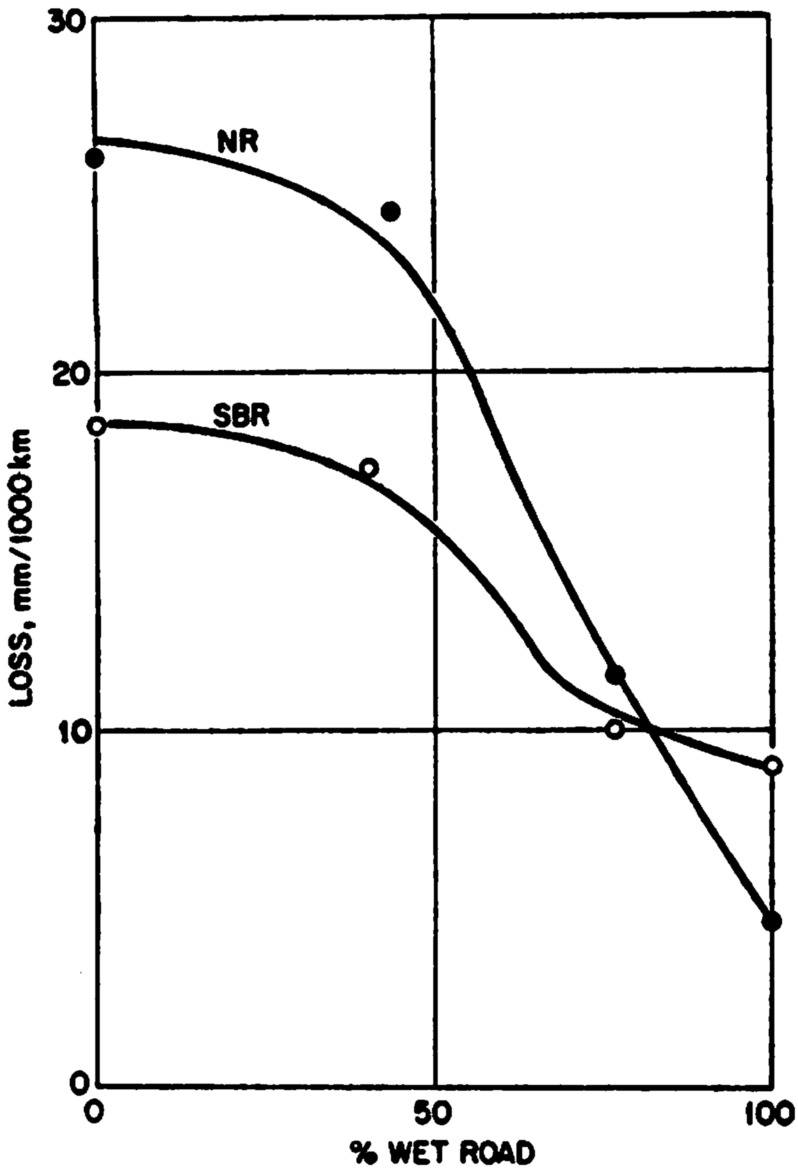
Tire wear is affected by tire composition and construction. The wear of various tire tread compounds can be affected by temperature and road wetness as shown in Figures 3-1 and 3-2. Under the UTQG test procedures, the Course Monitoring Tire (CMT) should compensate for the day-by-day variations in the test course. (This issue is addressed in Sections 6 and 7.) Tire construction (number and composition of belts, plies, etc.) can affect lateral stiffness and slip and, ultimately, wear.

TABLE 3-1. ENGINEERING FACTORS AFFECTING TIRE TREADWEAR AND ASSOCIATED AVAILABLE DATA SURROGATES

Speed/Acceleration:	Car, Driver, Horsepower-to-weight ratio, Convoy position
Road Condition:	Wet miles, Relative humidity, Temperature
Load:	Actual load
Tire Temperature:	Wet miles, Average inflation pressure, Change in average inflation pressure, Ambient temperature, Tread material
Tire Stiffness:	Number of sidewall plies, Number of tread plies, Number of belts, Carcass material, Belt material, Outside diameter, Aspect ratio, Shore hardness, Average inflation pressure, Changes in Average inflation pressure, Number of grooves/section width, Overall groove depth, Traction grade
Test Protocol:	Measures, Depth gauge

TABLE 3-2. SOURCE OF TEST CONDITION DATA ASSOCIATED WITH EACH TREADWEAR MEASUREMENT

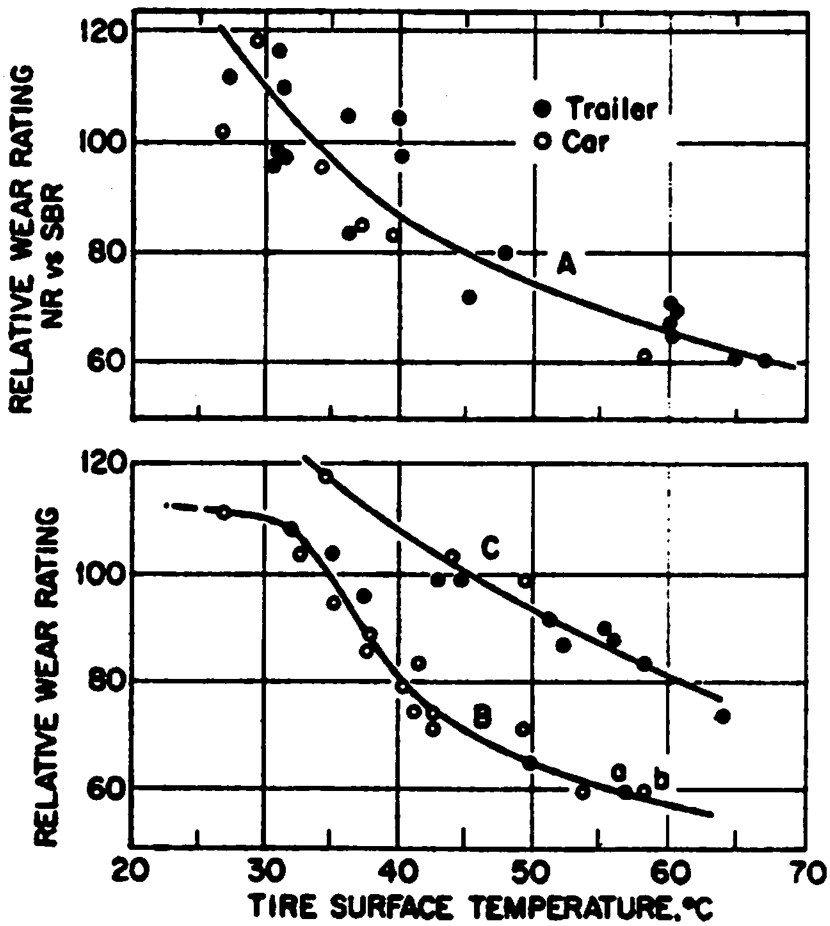
1.	UTQG Compliance Test	Car; Driver; Convoy position; Actual load; Wet miles; Beginning, intermediate and end inflation pressures; Tread materials; Sidewall plies; Tread plies; Belts; Carcass material; Belt material; Outside diameter; Aspect ratio; Shore hardness; Grooves; Section width; Overall average groove depth; Traction grade; Measurer; Depth gauge
2.	Weather Data:	Average ambient temperatures Average relative humidity
3.	MVMA Data:	Horsepower-to-weight-ratio



●-● Results obtained with a constant slip angle trailer under high severity

o-o Test car results

FIGURE 3-1. EFFECTS OF ROAD WETNESS ON WEAR RATE OF TIRE TREAD COMPOUNDS



(A) NR vs. SBR; (B) OENR vs. OESBR and (C) OENR/BR vs. OESBR/BR.

●—● Results obtained with a constant slip angle trailer under high severity

○—○ Test car results

FIGURE 3-2. EFFECTS OF TIRE SURFACE TEMPERATURE ON WEAR RATE OF TIRE TREAD COMPOUNDS

Tire wear is affected by acceleration, which in turn is affected by driver and vehicle characteristics.[2] Environmental factors such as temperature, precipitation, wind speed and direction also can affect the treadwear, both directly and indirectly. For example, the UTQG course conditions can affect the wear of the tread rubber by the moisture in the contact patch and, to a lesser degree, by moisture absorption in the tread rubber.

It is obvious that the sources of variability in a "real world" test such as the UTQG test are complex and difficult to quantify analytically. However, a statistical approach, as performed here, is most likely to yield some insights into the treadwear process during UTQG testing.

4. DATA BASE ORGANIZATION

The data base for statistical analysis was constructed from four major sources: (1) NHTSA's 1980 and 1981 radial tire tests at San Angelo, TX; (2) weather data for San Angelo, TX; (3) manufacturers' data, and (4) miscellaneous data (such as vehicle hp /weight ratio) from various sources. Data from the first two sources were available on computer-compatible magnetic tape. The third source of data was entered manually and, in the case of Uniroyal, was also entered from magnetic tape into the data base. The fourth source was entered manually.

NHTSA's UTQG data base was maintained by Kappa Systems Inc. of Arlington, VA, on an IBM 360 computer. The data from all tests for 1977 to 1982 were structured and delivered to TSC by Kappa Systems on magnetic tape. The contents of each file are shown in Table 3-2. For the initial studies on this effort, the required data on 1980 and 1981 radial tire tests were "stripped" from the Kappa data and placed in the 1022 data management system on the TSC/PDP-10 computer.

Weather data for San Angelo was obtained from the U.S. Weather Service on computer-compatible magnetic tape. As with the Kappa Systems data, the weather information of interest for 1980 and 1981 was "stripped" from the tape and entered into the data management system. Later in this program, all data was transferred to the National Institutes of Health (NIH) IBM 370 computer. Some required information was entered into the data base manually. This information included the hp-to-weight ratio of the test vehicles and some missing weather data.

The NHTSA data base included test results on approximately 100 candidate tire types. (A tire type is defined here as a particular manufacturer, line, and size.) There were typically eight tires tested per tire type. Additionally, 300 CMT tires were tested in approximately 75 convoys. The treadwear of each tire (1200 tires in total) was measured eight times for a total of 9600 observations. There were in excess of 100,000 records, each containing anywhere from 20 to 45 attributes. The data base from Kappa Systems had in excess of 2,000,000 individual values. Of these, more than 500,000 values were utilized for the statistical analysis. Table 4-1 is the complete list of data from Kappa Systems, the U.S. Weather Service and other sources that were ultimately entered into the new data base.

The initial statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) available on the TSC/PDP-10 computer. SPSS is an integrated system of computer programs designed for many different kinds of statistical analyses. SPSS also contains some procedures for data transformation and file manipulation. SPSS can perform descriptive statistics, simple frequency distributions and cross-tabulations, simple correlations, partial correlations, means and variances for subpopulations, analysis of variance, multiple regressions, discriminant analysis, scatter diagrams, factor analysis, and canonical correlations. The analyses performed in this study included descriptive statistics, multiple regressions, and analyses of variance. These techniques and their results are described in Sections 6 and 7.

The data base was divided into two separate data bases: one containing CMT tires and one containing candidate tires. The formation and utilization of the data base for SPSS is shown diagrammatically in Figure 4-1.

Late in this effort, all of the NHTSA compliance data and associated weather information were transferred to the NIH computer and analyzed using the Statistical Analysis System (SAS). SAS is an integrated set of computer programs that performs information storage and retrieval, data modification and programming, statistical analysis, and file manipulation. SAS includes simple descriptive statistics, analysis of variance, discriminant analysis, multiple range tests, simple and multiple regressions, non-linear regressions and other statistical techniques. This transfer of compliance and weather data was accomplished to take advantage of the superior procedures of SAS for data management, and to make the data readily available to NHTSA. The manufacturers' data also were entered into the SAS statistical package.

TABLE 4-1. TIRE ATTRIBUTE DATA

```
ATTRIBUTE TESTNUMBER ABBREV TN TEXT KEYED COL 1 8
ATTRIBUTE RUNNUMBER ABBREV RUN INTEGER KEYED COL 9 10
ATTRIBUTE CARIDENT ABBREV CAR INTEGER KEYED COL 11 13
ATTRIBUTE CONVOYPOSITION ABBREV CVY INTEGER COL 14 14
ATTRIBUTE ALIGNINITIALS ABBREV ALI TEXT COL 15 17
ATTRIBUTE DRIVERID ABBREV DRI TEXT KEYED COL 18 20
ATTRIBUTE STARTDATE ABBREV SD INTEGER KEYED COL 21 25
ATTRIBUTE STARTMILEAGE ABBREV SM INTEGER COL 26 31
ATTRIBUTE STARTTIME ABBREV STIM INTEGER KEYED INACTIVE COL 32 35
ATTRIBUTE ENDDATE ABBREV ED INTEGER KEYED COL 36 40
ATTRIBUTE ENDMILEAGE ABBREV EM INTEGER COL 41 46
ATTRIBUTE ENDTIME ABBREV ETIM INTEGER COL 47 50
ATTRIBUTE WETMILES ABBREV WM INTEGER KEYED COL 51 54
ATTRIBUTE INVENTORYNUMBER ABBREV INV INTEGER KEYED COL 55 60
ATTRIBUTE BRAND ABBREV BRD TEXT KEYED INACTIVE COL 61 76
ATTRIBUTE TIRENAME ABBREV TIRN TEXT KEYED COL 77 104
ATTRIBUTE TIRESIZE ABBREV TSIZE TEXT KEYED INACTIVE COL 105 119
ATTRIBUTE MEASURER ABBREV MSR TEXT KEYED COL 120 122
ATTRIBUTE DEPTHGAUGE ABBREV DPGA TEXT KEYED INACTIVE COL 123 124
ATTRIBUTE STARTADJINFLPRESS ABBREV SAINF INTEGER KEYED INACTIVE COL 125 127
ATTRIBUTE WHEELPOSITION ABBREV WH TEXT KEYED COL 128 128
ATTRIBUTE TESTMILES ABBREV TMIL INTEGER KEYED COL 129 133
ATTRIBUTE ATTAINEDGRADE ABBREV AGR INTEGER KEYED COL 134 136
ATTRIBUTE BASEWEARRATE ABBREV BWR INTEGER KEYED COL 137 139
ATTRIBUTE PREVMINUSCURROA ABBREV PMC INTEGER KEYED COL 140 142
ATTRIBUTE PREVOVERALLAVG ABBREV POA INTEGER KEYED COL 143 146
ATTRIBUTE MAXINFLPRESSUREPSI ABBREV PSI INTEGER KEYED COL 147 148
ATTRIBUTE MAXLOADRATLBS ABBREV LLBS INTEGER KEYED COL 149 152
ATTRIBUTE SIDEWALLPLIES ABBREV SPLY INTEGER KEYED COL 153 154
ATTRIBUTE TREADPLIES ABBREV TPLY INTEGER KEYED COL 155 156
ATTRIBUTE BELTS ABBREV BEL INTEGER KEYED COL 157 158
ATTRIBUTE CARCASSMAT ABBREV CMAT TEXT KEYED COL 159 159
ATTRIBUTE BELTMATERIAL ABBREV BMAT TEXT KEYED COL 160 160
ATTRIBUTE TEMPRESISTANCEGRADE ABBREV RES TEXT KEYED COL 161 162
ATTRIBUTE TRACTIONGRADE ABBREV TRA TEXT KEYED COL 163 164
ATTRIBUTE NUMBEROFGROOVES ABBREV GRVS INTEGER KEYED INACTIVE COL 165 166
ATTRIBUTE OUTSIDEDIAMETER ABBREV ODIA INTEGER KEYED COL 167 170
ATTRIBUTE SECTIONWIDTH ABBREV WDT INTEGER KEYED COL 171 174
ATTRIBUTE RECOMMRIMSIZE ABBREV RIM TEXT KEYED INACTIVE COL 175 180
ATTRIBUTE ALTERNATERIMSIZE ABBREV ARIM TEXT KEYED INACTIVE COL 181 186
ATTRIBUTE STARTADJINFLPRESS2 ABBREV SAIN2 INTEGER KEYED COL 187 189
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ATTRIBUTE ENDINFPRESS2 ABBREV EINF2 INTEGER KEYED INACTIVE COL 199 201
ATTRIBUTE HPTOWEIGHTRATIO ABBREV HP REAL KEYED INACTIVE COL 202 206
ATTRIBUTE MEANTEMP ABBREV MTEMP REAL KEYED COL 207 212
ATTRIBUTE RELATIVEHUMIDITY ABBREV RHUM REAL KEYED COL 213 215
ATTRIBUTE ACTUALLOAD ABBREV ALD INTEGER KEYED COL 216 219
ATTRIBUTE TREADWEARGRADE ABBREV TRDG INTEGER KEYED INACTIVE COL 220 222
ATTRIBUTE SHOREHARDNESS ABBREV DUR INTEGER KEYED COL 223 225
ATTRIBUTE TESTCODE ABBREV TCOD TEXT KEYED INACTIVE COL 226 226
ATTRIBUTE FIRSTMECHFAIL ABBREV FMF TEXT KEYED INACTIVE COL 227 229
ATTRIBUTE SECONDMECHFAIL ABBREV SMF TEXT KEYED INACTIVE COL 230 232
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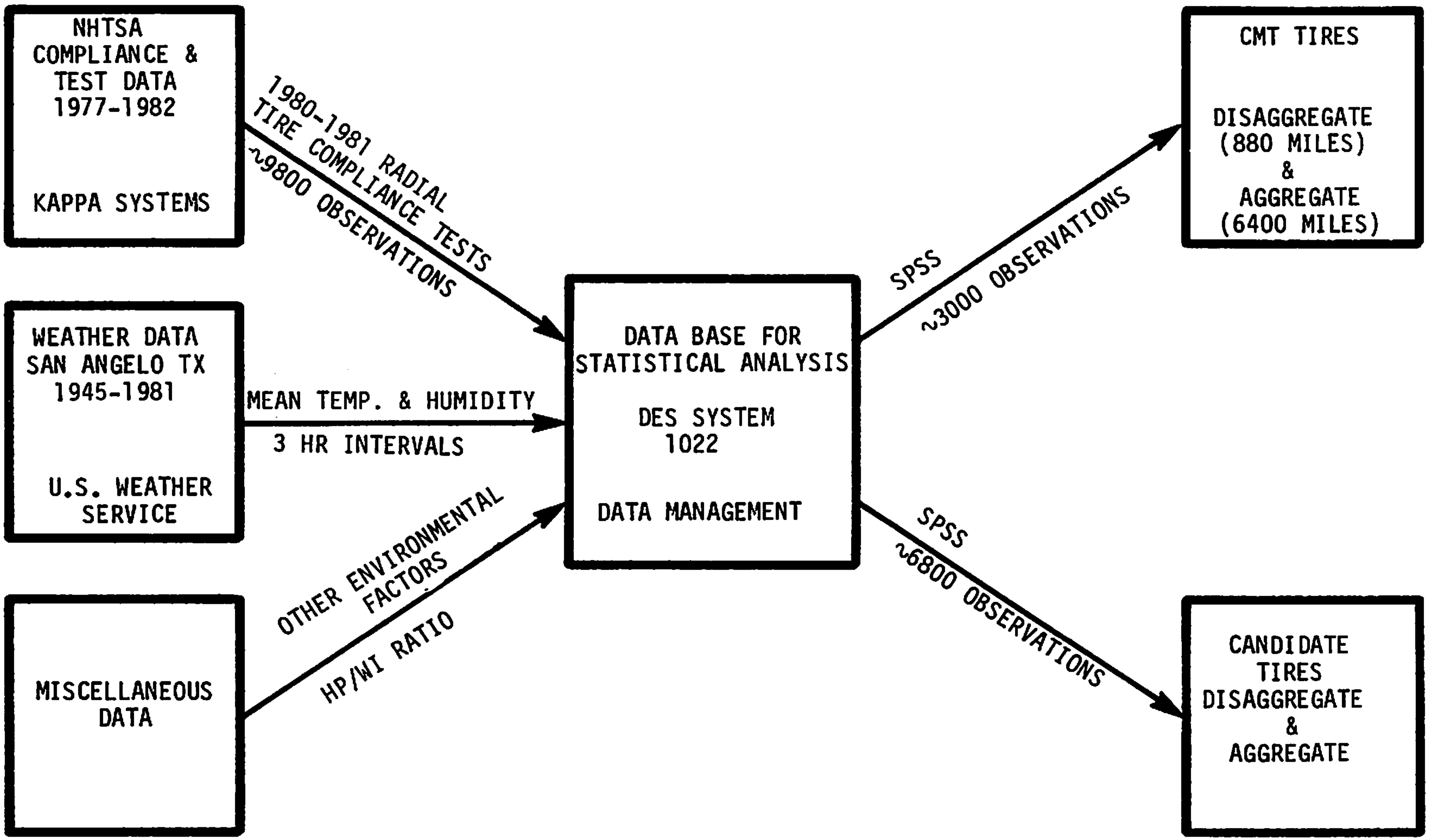

*SPSS = Statistical Package for the Social Sciences

FIGURE 4-1. FORMATION AND UTILIZATION OF SPSS DATA BASE

5. DESCRIPTIVE STATISTICS OF THE DATA BASE

The tire information in the data base was examined to determine its content and the standard deviations, means, and ranges of some of the more important tire-related attributes. As indicated previously, each identical tire type generally was tested twice in two separate convoys. This permitted an analysis of variance, the results of which are discussed in Sections 7 through 9. It is important to note that these identical tire-type convoys usually were run consecutively. This raised a question of whether candidate tires were subjected to the full range of environmental effects. Further discussion on the implications of this fact can be found in Section 7 and 8.

6. REGRESSION ANALYSIS

6.1 DESCRIPTION OF REGRESSION ANALYSIS TECHNIQUES

Regression techniques analyze the reasons (sources) for observed variation in the value of some parameter of interest (dependent variable), such as the rate of wear of a tire. A regression analysis assumes that the observed variation is partly due to a "non-random" explainable component. This non-random explainable component is a specified function of a set of factors (independent variables), and is typically a linear or log-linear relationship. For instance, in the case of tires:

Tire Treadwear=

$A_0 + A_1 \times$ Temperature $+ A_2 \times$ Average Tire Inflation Pressure + Error

or

Log (Tire Treadwear)=

Log $B_0 + B_1 \times$ Log (Temperature) $+ B_2 \times$ Log (Average Tire Inflation Pressure) + Error

The regression utilizes a least-square error approach to determine the constants (coefficients) which provide the best fit of the specified equation to the observed data.

A successful regression analysis should explain most of the scatter in the data. To determine how much of the scatter has been explained, scatter about the regression curve is compared with the baseline scatter. Baseline scatter (prior to the regression analysis) is defined to be the scatter of the values of the parameter of interest about its mean, measured by the sum of the squared differences of the observed values from the mean of the observed values. Scatter about the regression curve is the sum of the squared differences of the observed values from their corresponding regression estimates. The regression estimate of the value of the parameter of interest is obtained by using the values of the explanatory factors to the "best fit" regression equation. The percent of the scatter explained (R^2) is given by:

$$R^2 = 1 - \frac{\text{Sum of squares about the regression}}{\text{Sum of the squares about the mean}}$$

Regression analysis describes how the factors (independent variables) affect the parameter of interest (dependent variable). In the case of a linear regression, the coefficients (A_i) of the factors (X_i) represent the predicted change in the value of the parameter of interest with respect to a unit change in each factor X_i. As with other types of regression, the effect of coefficients can be easily understood from an examination of the functional form.

Other outputs of the SPSS regression analyses[3,4,5] allow for sensitivity and significance testing, and for the analysis of the relative contribution of the factors. Examples of the regression analysis output data and results are given in Section 6.3.

6.2 SURROGATE VARIABLES

In some instances a factor (independent variable) cannot logically be represented directly by a numerical variable. An example is the influence of different cars on the treadwear of tires. Approximately 70 different vehicles were used in UTQG radial tire testing during FY'80-'81. Assigning the vehicles values from 1 to 70 would not have yielded a meaningful regression factor, because this numerical assignment is random with respect to the influence of each of the vehicles on tire treadwear.

A standard regression technique is to create a set of "dummy" independent variables for each of the factors not represented by numerical variables. A dummy variable coefficient in the simplest case is a linear regression in which the equation consists only of a dependent variable explained by a set of dummy variables - representing, for instance, the vehicles. The i^{th} coefficient represents the difference between the mean value of treadwear for observations when the tire was on that vehicle and the overall mean treadwear value.

For this analysis there are several problems with a traditional dummy variable approach. One practical problem is economy: the cost associated with manipulating large numbers of such variables is quite high. A single SPSS regression analysis with 70 to 100 variables and over 6000 observations can cost thousands of dollars to solve.

Another problem with the approach is that the result tends to overestimate the value of the R^2. As the ratio of the number of dummy variables to the number of independent observations increases, this overestimation becomes significant. As the variable begins to identify a progressively smaller subset of the data, each value in the subset exerts a greater influence on the mean of the subset. Thus, an equation which includes a variable identifying a small subset tends to identify specific observations rather than factor effects.

A further problem with the use of dummy variables occurs because the UTQG experimental design is not statistically balanced with respect to potential treadwear factors. Consider the problem of deciding whether the difference in average treadwear between car I and car J, is due to (1) a car effect; (2) a difference between the tires used on car I and car J, or (3) some other effect, such as car I being used in more winter tests than car J.

An alternative approach to the use of dummy variables was chosen. This approach solved the excessive cost problem. The problems of overestimating the R^2 and ambiguous effects were somewhat diminished but still remained.

This alternative approach consisted of constructing what were termed "surrogate" variables for drivers, seasons, cars, and wheel position. These variables appeared to have had significant effects in the Analysis of Variance (Section 7), although, as noted, the effects may have been overstated.

6.2.1 Drivers

In general, the same group of drivers participated in any given convoy (a group of tests performed simultaneously on three sets of four candidate tires each and one set of four course-monitoring tires). A complete test (6400 miles plus break-in) consist of eight runs of 800 miles each with a treadwear measurement taken at the completion of each run. During a test, tires were rotated on a given vehicle and drivers were rotated among vehicles. Thus, each tire was subjected to each of four drivers twice during its eight test runs. Each convoy usually had different groups of drivers. Over 100 drivers were used in FY'80-81 radial tire tests. Driver participation ranged from several runs to hundreds of runs. In one case, a driver participated in over 1100 runs.

A driver surrogate variable was constructed in which drivers were separately identified only if they participated in at least 100 runs. All other drivers were treated as one. For each driver, the value of the driver surrogate variable was taken to be the average value of treadwear per run during CMT runs in which he or she participated. Only CMT runs were used so that the tire effect would not mask the driver effect. If a given driver were "better" or "worse" than another, it was presumed that his or her average treadwear would reflect this effect. The value that was determined for each driver surrogate was inserted into the data set in which that driver participated.

6.2.2 Seasons

In this report, seasons were defined as four successive 90-day segments, beginning on January 1st of each year. For the i^{th} season, the value of the season surrogate was taken to be the average value of treadwear per run for CMT tires whose start-date occurred in Season I. A seasonal surrogate attribute was, therefore, created and a value inserted into each record.

6.2.3 Cars

Over 50 vehicles were used in FY'80-81 radial tire UTQG tests. Each run in which a vehicle participated was represented by four measurements. The number of measurements taken for any individual vehicle ranged from a minimum of four to a maximum of 636. Because some vehicles could not accomodate CMT tires, it was necessary to abandon the approach of restricting the car surrogate to the average value of treadwear on the CMT tires alone and the surrogate was constructed from both CMT and candidate tires. Thus the "car effect" was confounded at least with the "tire effect." However, the car surrogate was constructed in a similar manner to the driver surrogate.

6.2.4 Wheel and Convoy Position

In general, each tire experienced an equal number of runs at each wheel station and in each convoy position (lead, second, third, rear). The test was balanced in regard to these factors. The wheel position and a convoy surrogate were, therefore, constructed using treadwear data for both candidates and CMT tires. The relative effect of wheel position on wear, as reported by Uniroyal and others, was confirmed during the construction of this variable. That is, for the UTQG course, the relative wear rates in decreasing order were: (1) right rear, (2) left rear, (3) right front, and (4) left front.

6.3. DISAGGREGATE (RUN LEVEL) REGRESSION ANALYSES PERFORMED

Each tire tested had a total of eight runs of 800 miles each; treadwear was calculated subsequent to each run. The disaggregate data set consisted of a treadwear measurement and associated independent variables such as the mean temperature during the run, wet miles, and tire load. Separate regressions were run for the CMT tires and the candidate tires.

6.3.1 CMT Disaggregate Regression Analyses Results

The independent variables considered for this regression were:

- run number (an integer value from one to eight corresponding to the first through eighth 800-mile segment)
- average groove depth prior to the run
- horsepower-to-weight ratio of the vehicle
- average temperature during the run
- average relative humidity during the run
- actual load on the tire
- shore hardness of the tire
- average inflation pressure of the tire during the run
- number of wet miles during the run (defined as the number of miles during which a spray was visible from the tires of the lead vehicle)
- car surrogate
- driver surrogate
- seasonal surrogate
- convoy surrogate
- wheel surrogate.

The dependent variable was the treadwear per 800-mile run.

The results of the stepwise linear regression* are shown in Table 6-1. The R^2 (.3043) even after 11 steps, indicates that most of the variance is unexplained, and the first four variables account for most of the explained variance (R^2=.2759). In order of importance, these variables are: (1) wet miles, (2) run number, (3) driver, and (4) wheel position. Beyond this point, the possibilities for confounded effects are great.

The correlation coefficients of treadwear with these top four variables are .320, .245, .280, and .211 respectively. An additional variable, the average groove depth prior to the run, would be among this list, correlating with treadwear, (.288). However, it is also highly correlated with run number (-.895) and thus does not

*SPSS allows two options with respect to records with missing data: (1) deletion of the entire record (listwise) or (2) use of all available data in the record (pairwise).

TABLE 6-1. STEPWISE LINEAR REGRESSION OF CMT-INDEPENDENT VARIABLES

VARIABLE LIST number 1. Listwise deletion of missing data.

	MEAN	STD DEV	VARIANCE	LABEL
RUN	4.523	2.298	5.279	RUNNUMBER
PMC	41.225	16.786	281.770	PREVMINUSCURROA
POA	3211.685	104.550	10930.705	PREVOVERALLAVG
HP	0.041	0.008	0.000	HPTOWEIGHTRATIO
MTEMP	61.860	14.373	206.589	MEANTEMP
RHUM	0.738	0.139	0.019	RELATIVEHUMIDITY
ALO	473.673	27.582	760.784	ACTUALLOAD
DUR	66.757	2.363	5.586	SHOREHARDNESS
AVINF	27.617	0.552	0.305	
WM1	50.262	127.681	16302.427	
CARP	41.314	2.392	5.723	
DRIP	40.568	4.649	21.610	
SEAS	40.925	1.815	3.296	
NCVY	42.855	0.878	0.772	
NWH	42.870	4.219	17.799	

N OF CASES = 1699

CORRELATION, COVARIANCE, SIGNIFICANCE

TABLE 6-1. STEPWISE LINEAR REGRESSION OF CMT-INDEPENDENT VARIABLES (CONT.)

Summary table

Step	Multr	Rsq	Adjrsq	F(equ)	Sigf	Rsqch	Fch	Sigch		Variable	Betain	Correl
1	0.3202	0.1025	0.1020	193.856	.000	0.1025	193.856	.000	IN:	WM1	0.3202	0.3202
2	0.4285	0.1836	0.1827	190.769	.000	0.0811	168.543	.000	IN:	FUN	-0.2850	-0.2950
3	0.4809	0.2312	0.2299	169.928	.000	0.0476	104.879	.000	IN:	DRIP	0.2211	0.2799
4	0.5252	0.2759	0.2742	161.336	.000	0.0446	104.446	.000	IN:	NWH	0.2113	0.2106
5	0.5377	0.2891	0.2870	137.709	.000	0.0133	31.559	0.000	IN:	SEAS	0.1172	0.1149
6	0.5431	0.2950	0.2925	117.984	.000	0.0059	14.052	0.000	IN:	POA	0.1745	0.2876
7	0.5453	0.2973	0.2944	102.213	.000	0.0023	5.642	.018	IN:	AVINF	-0.0547	-0.0426
8	0.5476	0.2999	0.2966	90.494	.000	0.0026	6.245	.013	IN:	ALO	-0.0515	-0.0333
9	0.5493	0.3018	0.2981	81.111	.000	0.0019	4.533	.033	IN:	HP	-0.0441	-0.0262
10	0.5525	0.3052	0.3011	74.161	.000	0.0035	8.408	.004	IN:	CARP	0.0654	0.0765
11	0.5516	0.3043	0.3006	82.087	.000	-0.0009	2.271	.132	OUT:	FUN		-0.2950

contribute significantly to the R^2. The regression equation has 14 outliers (an outlier is a point that lies three or more standard deviations from the regression estimate). None appears to significantly influence the equation, based on the low values of Cook's "D" test. The results indicated that treadwear increased with wet miles. This effect has been reported in other studies; however, as seen in Figure 3-1, there were indications that the opposite effect can also take place.[5,6]

In addition, the results indicated that treadwear decreased with increasing mileage. Possible explanations include an inadequate break-in period or, as reported by Uniroyal,[1] compression of the grooves during break-in, causing an apparent exaggeration of the initial treadwear.

This regression result, as previously noted, did not explain the major sources of variation in the treadwear. These results might have been improved by a better choice of a model. A model is a selection (given a set of variables) from a family of curves that best approximates the data. Examples of some models, or families of curves, are linear, log-linear, exponential, and power series models, etc.

After a series of reasonable models (including the linear and log-linear) were investigated, bivariate plots to determine if some other curve-form would be discernible were examined. The data scatter was so shapeless that the search for a better model was abandoned. It was also determined that any model validation would not be useful with such a low R^2.

6.3.2 Candidate Tire Disaggregate Regression Analyses

The independent variables included in these regression analyses were the same variables included in the CMT regression runs, with the addition of a number of variables to identify tire characteristics. These additional variables were:

- rated maximum inflation pressure
- maximum load rating
- number of side wall plies
- the number of tread plies
- the number of belts
- number of grooves

- outside diameter
- section width
- number of belts plus sidewall plies plus tread plies
- outside diameter multiplied by section width.

In addition, there was a variable called the "Base Wear Factor," which was the reciprocal of the Course Severity Adjustment Factor. The Course Severity Adjustment Factor is determined as:

$$\frac{\text{(Base Wear Rate for CMT)}}{\text{(Test Level Average Wear Rate for CMT)}}$$

The total R^2 for this regression (Table 6-2) was only .34 after 18 steps. This is a very low result. When compared to the CMT regression, the car surrogate in this regression replaced the driver surrogate among the top four variables. The ranking and signs of the two regressions were generally consistent: the sign of wet miles was positive, and the sign of run number was negative in each regression. The absence of driver effect and car effect in the candidate and CMT regression analyses respectively, indicated that the detection of either effect, based on these results, is inconclusive. As mentioned previously, the driver surrogate was constructed using CMT trials only, whereas the car surrogate was constructed using candidate and CMT trials (but candidate tire trials outnumber CMT trials by eight to three).

There are 49 outliers in this regression; none was influential. As was noted with the CMT tires, the bivariate plots indicated the existence of excessive noise in the test results. It was concluded that the form of the model could not be improved over the form already attempted, and that any model validation would not be meaningful given the low accountability observed here.

6.4 AGGREGATE (TIRE LEVEL) REGRESSIONS

After the disappointing disaggregate regression result, the possibility that the noise in the measurement of treadwear obscured the effect of the explanatory factors was considered. To reduce the "noise-to-information" ratio of the data set, the data were aggregated to the tire (6400 mile) level; i.e., the values of the

TABLE 6-2. STEPWISE LINEAR REGRESSION OF CANDIDATE TIRE INDEPENDENT VARIABLES

	MEAN	STD DEV	VARIANCE	LABEL
RUN	4.522	2.287	5.232	RUNNUMBER
PMC	45.800	20.369	414.880	PREVMINUSCURRPOA
POA	3031.312	292.774	85716.815	PREVOVERALLAVG
PSI	34.172	1.486	2.208	MAXINFLPRESSUREPSI
LLBS	1327.762	219.101	48005.097	MAXLOADPATLPS
SPLY	1.761	0.427	0.182	SIDEWALLPLIES
TPLY	4.022	0.796	0.633	TREADPLIES
BEL	2.261	0.635	0.403	BELTS
GRVS	4.029	1.170	1.368	NUMBEROFGROOVES
ODIA	2504.133	136.952	18755.900	OUTSIDEDIAMETER
WDT	760.084	69.098	4774.582	SECTIONWIDTH
HP	0.038	0.006	0.000	HPTOWEIGHTPATIO
MTEMP	61.878	14.467	209.302	MEANTEMP
RHUM	0.737	0.139	0.019	RELATIVEHUMIDITY
ALO	649.466	244.352	59707.975	ACTUALLOAD
DUR	62.585	3.406	11.599	SHOREHARDNESS
AVINF	27.404	1.346	1.811	
WM1	48.760	125.444	15736.237	
BWF	1.346	0.161	0.026	
CARP	44.140	6.012	36.139	
DRIP	40.462	4.633	21.469	
SEAS	40.926	1.819	3.310	
THICK	8.044	1.591	2.533	
VOL	191.184	27.157	737.503	
NCVY	42.854	0.879	0.773	
NWH	42.853	4.222	17.824	

N OF CASES = 4993

CORRELATION, COVARIANCE, SIGNIFICANCE

TABLE 6-2. STEPWISE LINEAR RERESSION OF CANDIDATE TIRE INDEPENDENT VARIABLES (CONT.)

Summary table

Step	Multr	Rsq	Adjrsq	F(equ)	Sigf	Rsqch	Fch	Sigch		Variable	Betain	Correl
1	0.2790	0.0779	0.0777	421.367	.000	0.0779	421.367	.000	IN:	WM1	0.2790	0.2790
2	0.3785	0.1433	0.1429	417.226	.000	0.0654	381.002	.000	IN:	CARP	0.2566	0.2779
3	0.4394	0.1931	0.1926	397.975	.000	0.0498	308.116	.000	IN:	NWH	0.2232	0.2228
4	0.4841	0.2343	0.2337	381.647	.000	0.0412	268.620	.000	IN:	FUN	-0.2032	-0.2138
5	0.5078	0.2578	0.2571	346.529	.000	0.0235	158.006	.000	IN:	TPLY	0.1536	0.1636
6	0.5235	0.2740	0.2731	313.630	.000	0.0162	110.940	.000	IN:	AVINF	0.1291	0.1661
7	0.5380	0.2894	0.2884	290.054	.000	0.0154	108.153	.000	IN:	POA	-0.1361	-0.0289
8	0.5478	0.3001	0.2990	267.153	.000	0.0107	76.213	.000	IN:	BWF	0.1095	0.2213
9	0.5591	0.3126	0.3114	251.794	.000	0.0125	90.530	.000	IN:	MTEMP	-0.1229	-0.0818
10	0.5651	0.3193	0.3179	233.682	.000	0.0067	48.891	.000	IN:	GRVS	0.0855	0.0402
11	0.5683	0.3230	0.3215	216.027	.000	0.0037	27.190	0.000	IN:	DUR	-0.0677	-0.0606
12	0.5709	0.3259	0.3243	200.668	.000	0.0030	21.798	0.000	IN:	CDIA	-0.0678	-0.0955
13	0.5747	0.3302	0.3285	188.853	.000	0.0043	32.062	0.000	IN:	ALO	0.0770	0.0646
14	0.5771	0.3331	0.3312	177.599	.000	0.0029	21.289	0.000	IN:	PSI	0.1737	0.0752
15	0.5769	0.3328	0.3310	191.018	.000	-0.0003	2.436	.119	OUT:	AVINF		0.1661
16	0.5792	0.3354	0.3336	179.462	.000	0.0026	19.843	0.000	IN:	SPLY	0.0756	0.0457
17	0.5814	0.3380	0.3360	169.423	.000	0.0026	19.518	0.000	IN:	FHUM	0.0566	0.2077
18	0.5824	0.3392	0.3371	159.638	.000	0.0012	8.862	.003	IN:	NCVY	0.0343	0.0278

attributes for each tested tire were averaged over the eight runs. Therefore, treadwear per run became the average treadwear per run for the entire eight runs; mean temperature for a given run became mean temperature during the test, etc.

The effect of aggregation on the surrogate variables was significant. Two surrogate variables, wheel position and convoy position, had no meaning at the aggregate level. This was because each tire was equally subject to each wheel convoy position. The surrogate variables of season and car should not have been affected by the aggregation because a tire was most likely subjected to only one season and only one vehicle during a test. However, with respect to the driver surrogate, a tire was subjected to a group of drivers in the aggregate data set. This driver surrogate, therefore, represented the effect of a group of drivers. If the driver surrogate were a good measure of the driver effect at the disaggregate level, it should reflect driver group effect at the aggregate level.

Twelve aggregate (tire level) regression analyses were performed. There were four CMT analyses: two linear and two log-linear. Listwise and pairwise deletion modes were compared for each model.

At the aggregate (tire level), there were two possible dependent variables: the average treadwear and the test grade received. The grade calculation included the course severity adjustment factor and the initial tire groove depth in addition to the treadwear rate. A choice of two dependent variables, two models (log and linear), and two deletion modes (pairwise and listwise) yielded eight combinations for the regression runs.

6.4.1 Aggregate CMT Regression Results

A representative variable list with descriptive statistics and a regression summary table are shown in Table 6-3. The R^2 was improved but still low, and wet miles and mean temperature had the largest effect. The signs of these variables were consistent with the previous results. After the fourth step, results were probably confounded and not meaningful. The effective R^2 at the fourth step was .54. If the surrogate variables were assumed to be confounded and were deleted

TABLE 6-3. CMT AGGREGATE REGRESSION RESULTS: REPRESENTATIVE VARIABLE LIST

	MEAN	STD DEV	VARIANCE	CASES
PMC	40.579	4.670	21.807	255
HP	0.040	0.007	0.000	255
MTEMP	62.450	13.123	172.221	209
RHUM	0.743	0.095	0.009	255
ALO	473.397	8.833	78.028	255
DUR	66.612	1.891	3.576	255
AVINF	27.621	0.299	0.089	255
WM1	47.111	57.677	3326.677	255
BWF	0.000	0.000	0.000	0
DRIP	40.420	1.468	2.156	255
CARP	41.109	2.437	5.937	255
SEAS	40.836	1.784	3.183	255
POA1	3368.765	44.178	1951.708	255

Summary table

Step	Multr	Rsq	Adjrsq	F(equ)	Sigf	Rsqch	Fch	Sigch		Variable	Betain	Correl
1	0.4718	0.2226	0.2189	59.286	.000	0.2226	59.286	.000	IN:	WM1	0.4718	0.4718
2	0.6718	0.4514	0.4461	84.743	.000	0.2287	85.888	.000	IN:	MTEMP	0.4902	0.3631
3	0.7192	0.5172	0.5101	73.201	0.000	0.0668	27.946	0.000	IN:	DRIP	0.2636	0.3375
4	0.7434	0.5527	0.5439	63.013	0.000	0.0355	16.184	0.000	IN:	CARP	0.1912	0.2134
5	0.7601	0.5777	0.5673	55.543	.000	0.0250	12.032	.001	IN:	ALO	-0.1609	-0.2451

from the regression, then the effective R^2 would drop to .45. However, the CMT responded to environmental conditions such as wet miles and temperature.

6.4.2 Aggregate Candidate Tire Regression Results

A representative variable list with descriptive statistics and a regression summary table are shown in Table 6-4. The R^2 was very low, although somewhat better than the disaggregate result. One encouraging result was that the base wear factor (CMT correction) correlated highly in the treadwear model. The base wear factor correlated with the log of wet miles (.53); log of seasonal surrogate (.37); log of average temperature (.33) and log of relative humidity (.29). This base wear factor appears to reflect environmental conditions and helps to explain the treadwear of candidate tires. This result is substantiated in Section 7.

6.4.3 Regression on Differences

The major confounding factors in the candidate tire regression analysis were differences between candidate tire types. It was not the purpose of this study to explain why different tire types had different treadwear characteristics. Rather, the research focused why a tire type varied in UTQG-observed treadwear/grade. Including different tire types in a single regression with insufficient variables to explain differences in treadwear properties diluted the utility of the regression.

Thus, it was proposed that a series of regression tests be performed. Each test consisted of four tires of a tire type tested on a car in a convoy. For each tire type tested twice, the values of treadwear/grade on each test were averaged. The average treadwear/grade result of the first test was subtracted from the second. Then a similar averaging and difference procedure was performed on the explanatory variables, and the differences in average treadwear/grade were regressed against explanatory variables differences.

This regresssion was a test-level aggregate regression, and attempted to explain the variation between tests of a tire type. Thus, this regression differed from previous regressions, which were at the "run" and "tire" levels. Run level

TABLE 6-4. CANDIDATE TIRE AGGREGATE REGRESSION RESULTS: REPRESENTATIVE VARIABLE LIST AND SUMMARY

	MEAN	STD DEV	VARIANCE	CASES	LABEL
LPMC	3.693	0.275	0.076	767	
LHP	3.624	0.131	0.017	767	
LALO	6.399	0.357	0.127	767	
LDUR	4.136	0.049	0.002	767	
LAVINF	3.309	0.045	0.002	767	
LMTEMP	4.097	0.220	0.048	626	
LWM1	4.232	0.341	0.116	767	
LBWF	0.283	0.117	0.014	767	
LTHICK	2.056	0.186	0.035	767	
LVOL	14.459	0.139	0.019	767	
LPSI	3.531	0.044	0.002	767	
LLLBS	7.185	0.163	0.026	767	
LGRVS	1.354	0.329	0.108	767	
LRNUM	4.281	0.136	0.019	767	
LPOA1	8.080	0.303	0.092	767	
LCARP	3.774	0.111	0.012	767	
LDRIP	3.696	0.033	0.001	767	
LSEAS	3.704	0.046	0.002	767	
LTRARE	2.801	0.555	0.308	743	

CORRELATION, COVARIANCE, SIGNIFICANCE, N OF CASES

	LPMC	LHP	LALO	LDUR	LAVINF	LMTEMP	LWM1	LBWF
LPMC	1.000	-0.015	0.047	-0.022	0.278	-0.005	0.329	0.403
	0.076	-0.001	0.005	-0.000	0.003	-0.000	0.031	0.013
	0.999	0.676	0.191	0.545	0.000	0.901	0.000	0.000
	767	767	767	767	767	626	767	767

TABLE 6-4. CANDIDATE TIRE AGGREGATE REGRESSIOIN RESULTS: REPRESENTATIVE VARIABLE LIST AND SUMMARY (CONT.)

Summary table

Step	Multr	Rsq	Adjrsq	F(equ)	Sigf	Rsqch	Fch	Sigch		Variable	Betair	Correl
1	0.4031	0.1625	0.1611	117.208	.000	0.1625	117.208	.000	IN:	LBWF	0.4031	0.4031
2	0.5187	0.2690	0.2666	110.973	.000	0.1065	87.879	.000	IN:	LCARP	0.3304	0.3849
3	0.5604	0.3141	0.3106	91.675	.000	0.0450	39.507	.000	IN:	LAVINF	0.2140	0.2784
4	0.5934	0.3521	0.3478	81.657	.000	0.0381	35.299	0.000	IN:	LTHICK	0.1967	0.2363
5	0.6160	0.3795	0.3743	73.388	.000	0.0274	26.469	0.000	IN:	LMTEMP	-0.1766	-0.0050
6	0.6325	0.4001	0.3941	66.578	.000	0.0206	20.564	0.000	IN:	LGPVS	0.1466	0.0536
7	0.6498	0.4223	0.4155	62.450	.000	0.0222	23.004	0.000	IN:	LVCL	-0.1768	-0.0846
8	0.6607	0.4366	0.4290	57.820	.000	0.0143	15.103	0.000	IN:	LDUR	-0.1289	-0.0219
9	0.6742	0.4545	0.4463	55.176	.000	0.0179	19.605	0.000	IN:	LTRAPE	-0.1724	-0.2335
10	0.6780	0.4597	0.4507	50.631	.000	0.0052	5.762	.017	IN:	LPSI	-0.1750	0.1491

regressions attempted to explain variations in 800-mile treadwear measurements using various tire characteristics, test, and environmental conditions. Tire level regressions attempted to explain variations between an individual tire grade or average treadwear over a 6400-mile test using various tire characteristics as well as test and environmental conditions.

The results of these new regressions using the differences generally confirm other analysis results. The best one-variable model explains the difference between tests of a tire type by the course-severity adjustment factor. R^2 for this regression was .65. This regression confirmed the ANOVA section of this report; i.e., the course severity adjustment factor explained over 50 percent of the variance. The best four-variable model included the course severity adjustment factor, wet miles, actual load, and mean inflation pressure. The R^2 for the best four-variable model was .79. All variables were shown to be significant in the F-Tests.

Wet miles added only .07 to the R^2. Subsequent variables added even less. However, this model has not been tested to verify the less explanatory variables. Thus, the major results of this regression analysis were: (1) the course severity adjustment factor explained more than half of the variation between tests of a tire type; and (2) wet-road conditions should be given consideration in UTQG procedures, as these conditions may affect the accuracy of test results. (Results of this analysis may be obtained from R. Walter, DTS-45, Transportation Systems Center, Cambridge, MA 02142.)

6.5 COMPARISON WITH UNIROYAL RESULTS

Uniroyal has run a series of special tests on the UTQG circuit. On the basis of these tests, the company has stated that they have explained all of the significant major causes of variability in tire treadwear grading procedure. This claim, based on the regression equation Uniroyal developed from their own test data, appears to be inaccurate. One table in their submission showed an R of .9225 in the first step attributed to the constant.* This was not the standard R^2. Uniroyal's R was thought to be calculated as:

*Uniroyal Docket Submission to 49 CFR Part 575 Docket No. 24; Notice 43, Petition, January 21, 1983, Table 2.

$$R = 1 - \frac{259 \text{ (Standard Error of Regression)}}{272 \text{ (SEY)*}}$$

Where $SEY = \sqrt{Y^2/272}$

Y = observed treadwear.

Uniroyal's data was used to compute a standard R^2. After the 15th step of the regression, .43 was obtained and was consistent with the study results. Furthermore, the Uniroyal tests were closely controlled. Two nominally identical two-car convoys were run on the same dates. The first convoy was the day convoy, starting at noon. The other - the night convoy - started at midnight. After 6400 miles (plus 800 mile break-in) the convoys switched, with the day convoy running at night and vice-versa. The convoys were equipped with four different tires - two Uniroyals of the same line but of different sizes, and two competitive products matching the size of Uniroyal's tires. Each car, therefore, was equipped with two Uniroyal and two competitive products.

This closely controlled test subjected tires to less environmental variation than the tires in test data obtained in this study. In addition, Uniroyal's regression used a dummy variable for each identical tire. Thus, the Uniroyal regression was able to directly account for the tire effect. In order for a similar regression to be accomplished in this study, a surrogate variable could have been used (dummy variables would have been too expensive) for tire types similar to the tire label variables in the disaggregate data set. However, the results of such a regression should have been comparable to the disaggregate CMT data results that were performed (the CMT is an identical tire). Both Uniroyal and TSC considered temperature, wet miles, and wheel position. As mentioned above, the TSC result with other variables included was an R^2 of .30 after 11 steps.

Uniroyal also included a regression which was run using the measurement of tread loss calculated by weight. With this wear measurement, it was shown that R^2 rose to .76. This indicated that the weight measurement technique probably represented a true improvement and eliminated some of the data scatter.

*SEY is not the usual standard error of Y about the mean, but about zero.

7. ANALYSIS OF VARIANCE: THE PRECISION OF UTQG

The precision of the UTQG test can be defined as the ability of the test to yield the same result for identical tires. An analysis of this precision does not consider whether or by how much the treadwear experienced by consumers differs from the treadwear results obtained from the UTQG. Furthermore, it is clear that this precision measurement will be confounded by manufacturing variabilities among tires of a particular line and size: tires of a given tire type may not necessarily be identical. Note that the interest here is in the degree of variability, not the reasons for it. The basic methodology employed for this precision analysis was the one-way analysis of variance technique (ANOVA). A description of ANOVA methodology and utilization is described in the following section.

7.1 ANOVA METHODOLOGY

To understand how the ANOVA technique was applied to the UTQG test, the treadwear measurment data should be considered as aggregated, so that each observation represents the average treadwear per test for each tire. There were approximately 1100 observations* of average treadwear in the NHTSA compliance data. Of these, approximately 800 observations were candidate tires and the remainder were CMT tires.

The 800 tires were divided into subsets with each subset consisting of a candidate tire type. In the majority of cases in this data set, tires of a tire type were tested twice in two different convoys. Thus, each subset had eight tires (two sets of four tires).

*An observation is the average treadwear of one tire over eight runs of the UTQG course.

If each tire type had the same treadwear properties (mean and variance), there would be three estimates of the treadwear variance. These are (1) the estimate derived from the sample variance of each individual tire about the mean of all tires; (2) the estimate derived from the sample variance of each tire about the mean of the subset within which it resides, and (3) the estimate derived from the variance of each subset mean about the overall mean. If all tire types had the same treadwear properties as measured by UTQG, then all three variance estimates would estimate the same value. This assumption is tested using the F-statistic, where F is the computed ratio of variance estimates from items (2) and (3) above. The significance of F is the probability that a value of F as large as the calculated value would occur under the assumption of equal tire treadwear for all tire types.

If it is assumed that all tire types have the same treadwear variance, then a low probability (e.g., less than five percent) that the calculated F would occur indicates that the assumption of equal mean treadwear for all tire types is probably false, and that the UTQG procedure is able to distinguish between at least some tire types.* Thus, the F-statistic, one result of an ANOVA analysis, was useful in this analysis for testing the ability of the UTQG procedure to distinguish tire types. In addition, the within-tire-type variance estimate is of interest regardless of whether the assumption of equal mean treadwear for all tire types is valid. Note that this variance estimate is the average subset variance: where the subsets are tire types, the average subset variance is the best estimate of the variance of a tire type's treadwear.

With an estimate of the variance of the treadwear of a tire type, it was a simple matter to obtain an estimate of the standard deviation. (With the large number of degrees of freedom typical in this analysis, estimated standard deviations are assumed to be precise). For measures of this precision, a one-way ANOVA was used, since it was the variance associated with the test of a tire type, not the component causes of the variation, that was of interest.

*Appendix C examines the equal variance assumption.

7.2 ANOVA ANALYSES ISSUES

The issues addressed by the ANOVA analyses were:

- Did the test distinguish candidate tires at all; i.e., did candidate tires vary more among tire types than within tire types?
- Did CMT tires reflect changing environmental conditions? If so, then CMT tires should have varied more between tests than within tests.
- Did the CMT tire improve the test; i.e., did the course severity adjustment factor account for differences between the treadwear of a particular type of tires run in different convoys?
- What was the best estimate of the variance due to tire quality in the UTQG test?
- What was the within-tire-type tire variance of the UTQG test-attained grade?
- If eight tires of one type were tested (four tires at a time in two different convoys), to what extent were the sets of four likely to differ from each other?

In order to properly address the ANOVA issues, the concept of the log of the variable will be introduced here. This concept has advantages relative to manipulating and interpreting data. The first advantage is that when the treadwear variable is transformed by taking its natural log, the standard deviation can be expressed as a fraction (or percent) of the average treadwear, an easily understood concept. The second advantage relates to the ANOVA assumptions. ANOVA assumes that the within-cell differences from the cell mean are normally distributed and that the variances of the normal distributions are equal across all cells. The log transformation acts on the data to make it conform better to these assumptions. See the end of Appendix C for evidence of this.

Note that where cells represent tire types, equal variance across cells means equal variance across tire types. Hence, the variances of different tire types can be pooled. Pooling the tire types through this process allows the sample size to be significantly increased.

7.2.1 Distinguishing Candidate Tires

Candidate tires varied much more between tire types than within tire types (Table 7-1), indicating that the test distinguished between at least some tires.

7.2.2 Effect of Environmental and/or Convoy Changes on CMT Tires

CMT tires varied much more between convoys than within convoys (see mean square, Table 7-2). The CMT tires, therefore, appear to have reflected environmental or other differences between convoys. The F value was very large, indicating significant differences between convoys.

7.2.3 Effect of Course Severity Adjustment Factor Account on Variance Between Convoys

The adjusted treadwear had a smaller within-tire-type variance (mean square) at the tire level than the unadjusted treadwear (Table 7-3). Therefore, the course severity adjustment factor accounted for some of the variance between convoys.

At the test level, the course severity adjustment factor improvement could be more readily observed because at this level only the between-convoy effect was observable for a tire type. Each observation at the test level consisted of the average treadwear (of four tires) and the average attained grade on a test for a tire type on one car, in one convoy (Table 7-4).

When the CMT correction was applied to treadwear, the variance within tire type between convoys was reduced by more than half* (0.01503 vs. 0.00649).

*The factor is obtained by dividing the log treadwear mean square within tire type (.01503) by the log adjusted treadwear mean square within tire type (.00649). Thus, .01503/.00649 = 2.315.

TABLE 7-1. VARIATION IN CANDIDATE TIRES: TIRE TYPE

Candidate Tires ANOVA

Tire Level

	Degrees of Freedom	Mean Squares	Std. Dev.
Between Groups	99	.47101	
Within Groups	696	.00698	.0835

F=67.47/Significance of F .00001*

Factor: Tire type Dependent variable: Log Attained Grade**

*Note that there were indications of heteroscedasticity (see Appendix C) which reduced the significance level of F. However, the F factor was so high that it was extremely unlikely that the F was not significant at a 95 percent level.

**The standard deviation of a log transformation of a variable is approximately the standard deviation of the original (non-transformed) variable divided by the mean of the original variable.

TABLE 7-2. VARIATION IN CMT TIRES: CONVOY CHANGES

CMT ANOVA

Tire Level

	Degree of Freedom	Mean Square	Std. Dev.
Between Groups	66	.04989	
Within Groups	192	.00127	.0356

F=39.35/Significance of F .0001

Factor: Convoy Dependent variable: Log Attained Grade

TABLE 7-3. CANDIDATE TIRES ANOVA: TIRE LEVEL

Dependent Variable	Degrees of Freedom	Mean Squares	Std. Dev
Log Treadwear (within group)	696	.01152	.107
Log Adjusted Treadwear (within group)	696	.00666	.082

Factor: Tire Type

TABLE 7-4. CANDIDATE TIRES ANOVA: TEST LEVEL

Dependent Variable	Degrees of Freedom	Mean Square	Std. Dev.
Log Treadwear	99	0.01503	.122
Log Adjusted Treadwear	99	0.00649	.081
Log Attained Grade	99	0.00683	.083

Factor: Tire Type

Because the CMT accounts for more than 50 percent of the within-tire type/between-convoy variance in candidate tires, it would appear advisable to retain the CMT in each convoy.

7.2.4 Best Estimate of Treadwear Variance Due to Tire Quality

The best estimate of tire quality variance as measured by the UTQG test (for both candidate and CMT tires) was obtained from observing the variance of identical tires tested on one car in one convoy. This variance was subject to the most uniform test conditions. Thus, this variance maximized the influence of tire quality relative to test conditions (see Table 7-5).

TABLE 7-5. CANDIDATE AND CMT TIRE ANOVA: TIRE LEVEL WITHIN GROUPS

Dependent Variable	Degrees of Freedom	Mean Square	Standard Deviation
Candidate Tire Log Treadwear	597	.00346	.058
CMT Tire Log Treadwear	192	.00127	.0356
Factors: Candidate Tire, Test CMT, Convoy			

Therefore, the best estimates of the standard deviation of the candidate and CMT tires due to tire quality are .058 and .036 respectively.

7.2.5 Variance of UTQG Test Attained Grade: Identical Tires

The within-group (factor: tire type) standard deviation of the UTQG test attained grade was .0835 (Table 7-1). The CMT within-test standard deviation (factor: convoy) shown in Table 7-2 was somewhat less (.0356) than the comparable within-test standard deviation for candidate tires, perhaps reflecting the uniformity of the CMT tire.

7.2.6 Variance of One Tire Type Between Two Different Convoys

The 95 percent confidence bounds on the average attained grade of a tire type indicated that the grade would not shift more than 23 percent between tests. This estimate was calculated from values in Table 7-4 as follows: If $Z = X - Y$ and X and Y are independent, then $\mathrm{Var}(Z) = \mathrm{Var}(X) + \mathrm{Var}(Y)$. In this case the average grade on test number one (X) of a tire design is independent of test two (Y). In addition, the estimates are presumed to have the same variance and standard deviation (.083). Thus the variance of the difference of two tests $\mathrm{Var}(Z) = \mathrm{Var}(X) + \mathrm{Var}(Y) = 2\,\mathrm{Var}(X) = 2 \times .083^2$. The 95 percent confidence bound, using the normal approximation, is estimated as $1.96 \times \sqrt{2} \times .083 = .23$.

7.3 POTENTIAL FOR GRADE INVERSION

To determine the potential for grade inversion, this section focuses on the differences in average grade received by different tire types between convoys. This section graphically displays the summary views implicit in the ANOVA results. As shown in the the bar graph (Figure 7-1), the value of the attained grade for tires of a given tire type varied between convoys by 30 or fewer points, 88 percent of the time. The range of attained grade values in the calculations indicated differences from zero to nine. A difference of one attained grade was a difference of 10 points. Assuming grades were normally distributed, there was a 95 percent confidence level that two different tire types had different grades if their average grades differed by more than 47 points.* A similar analysis which considered the effect of mean attained grade on the size of a 95 percent confidence interval required the use of the scatter plot shown in Figure 7-2.

This scatter plot shows the results of attained grades received by each tire type set for each convoy test. The grades again were in units of 10 points. Figure 7-2 can be read by looking down the column labeled "Attained Grade - Test 1" to row 16 (attained grade of 160). By following across this row to column 16, the intersection (number 2) is derived. This number actually represents the results of four tests. These four tests were conducted on two different tire types. Both tire types received average grades of 160 on each test.

*See Appendix A.

```
***** BAR GRAPH FOR VARIABLE: AGDIF *****
ABSOLUTE VALUE OF
THE DIFFERENCE        FREQ   PCENT +----+----+----+----+
      0                 25    26.3 IXXXXXXXXXXXXX
     10                 24    25.3 IXXXXXXXXXXXXX
     20                 23    24.2 IXXXXXXXXXXXX
     30                 12    12.6 IXXXXXX
     40                  5     5.3 IXXX
     50                  3     3.2 IXX
     60                  1     1.1 IX
     70                  1     1.1 IX
     80                  0     0.0 I
     90                  1     1.1 IX
                      ----         +----+----+----+----+
                        95              ^    ^    ^    ^
                                      10.0 20.0 30.0 40.0
                                                 PRECENTAGE
```

FIGURE 7-1. HISTOGRAM OF ATTAINED GRADE DIFFERENCE:
SUCCESSIVE TIRE TESTS

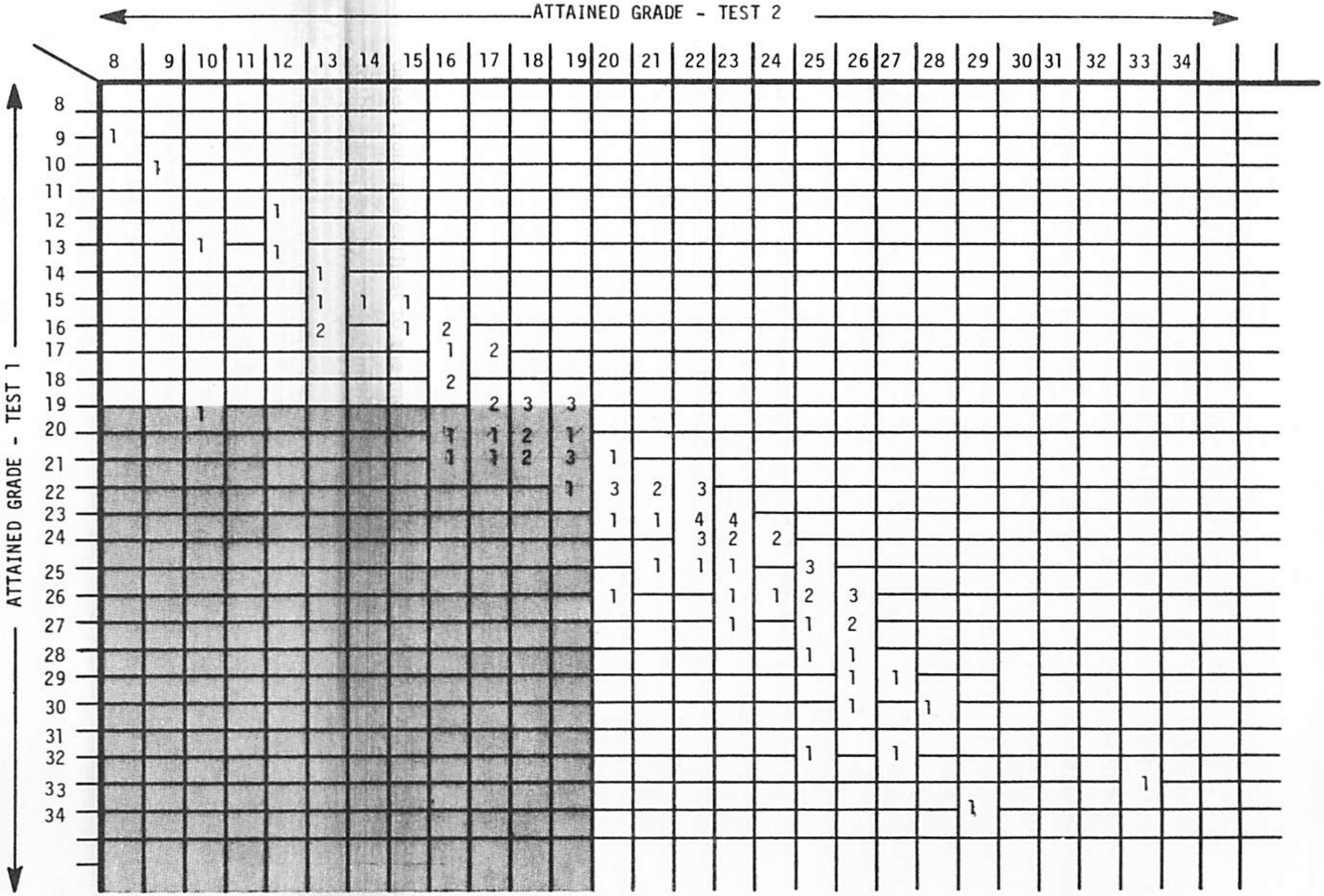

FIGURE 7-2. SCATTER PLOT OF ATTAINED GRADES: TWO TESTS

This chart can be used to determine the number of inversions in the relative grading of two different tire types. There are four possible comparisons of two different tire designs, each of which has been tested twice. First, tire types may be compared using the higher grade received by each of the types. Second, tire types may be compared using the lower grade received by each of the tire types. Third, tire types may be compared using the higher grade received by one of the tire types and the lower grade received by the other tire type. The fourth alternative is similar to the third, with the comparison procedure reversed among the tire types. Relative grade inversion has occurred if the comparisons of the two tire designs do not yield the same results using each of the four ranking schemes.

The use of the scattergram to determine the number of inversions is illustrated in the following example. As mentioned previously, three different tire types were graded 190/190 in successive tests. Tire types having grades inverted relative to these three types were those with two grades including a 190 and a different grade, or those receiving both a grade above 190 and a grade below 190 (see the shaded region in Figure 7-2). In this case, 19 different tires were inverted with the tire types that received a 190 in the test.

7.4 UTQG GRADING PROCEDURE

The UTQG tire treadwear labeling information is assigned by the manufacturers based on their test results. There is no government-specified, standardized procedure for grade assignment. Manufacturers, therefore, may adopt different strategies with respect to their grade assignment.

Figure 7-3 is a distribution of the differences between the manufacturers' assigned grade and the compliance-test attained grade in units of ten points. This figure may be compared with the distribution of the differences between the grades achieved on the two compliance tests of a tire type (Figure 7-1). It is likely that the broader distribution of the former is due to the unstandardized grade assignment procedure.

DIFFERENCE	FREQ.	CUM.	DIFFERENCE	FREQ.	CUM.	DIFFERENCE	FREQ.	CUM.
-7	1	1	2	12	38	11	7	95
-6	1	1	3	19	48	12	3	97
-5	2	2	4	18	57	13	2	98
-4	1	3	5	19	67	14	1	98
-3	4	5	6	15	75	15	1	99
-2	9	9	7	17	84	16	1	99
-1	8	14	8	3	86	18	1	100
0	20	24	9	8	90			
1	14	32	10	3	92			

FIGURE 7-3. COMPARISON OF MANUFACTURER-ASSIGNED AND NHTSA-ATTAINED GRADES

It may be noted from Figure 7-3 that nine percent of the tests failed compliance* by no more than 20 points, and 24 percent passed by no more than 20 points. Twenty points is less than the approximately ± 47 points which represented the 95 percent confidence limits on the differences between successive tests of a tire type. Thus, there is not a 95 percent confidence level such that tire types passing by 20 points would not fail on retest, or that tires failing by twenty points or less would not pass on retest.

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*It was assumed that compliance was achieved only if test average attained grade was less than or equal to assigned grade.

8. MANUFACTURERS' DATA ANALYSIS

Manufacturers collect data for test purposes and for UTQG grade assignment. Manufacturers' data was used in this analysis to: (1) evaluate the impact of environmental changes on UTQG test precision; (2) compare the manufacturers' results with NHTSA compliance data results and (3) evaluate the impact on test precision of CMTs with different base wear rates. Data were obtained from five manufacturers: Goodyear, Goodrich, Uniroyal, General and Firestone.

The issue of the impact of environmental changes on UTQG precision arose because NHTSA's compliance tests of a tire type typically consisted of two sets of four tires tested in convoys run consecutively within two weeks of each other. The question is twofold: (1) How does the treadwear of a candidate tire type vary in convoys run more widely-spaced in time? (2) How well does the CMT account for environmental changes under those conditions? Not all of the manufacturers' data included tests of a single tire type more widely spaced in time, although some did. These data are analyzed in this section.

In the NHTSA compliance data it should be noted that the CMT tests were more widely-spaced in time than candidate tire tests. The CMT variance between tests was measured in both NHTSA's compliance data and the manufacturers' data. This section includes a comparative analysis of compliance and manufacturers' CMT data.

Another issue explored in this section is the issue of CMT base wear rate. CMT base wear rate was a nominal wear rate assigned to the CMT for the purpose of computing the course severity adjustment factors.

In accordance with UTQG procedure (CFR 49, part 575.104, p. 467, Revised as of 10/1/81), the course severity adjustment factor (CSAF) was computed by dividing the base wear rate by the average of the wear rates (computed by the UTQG regression procedure) of the CMTs in the convoy. The candidate tire adjusted wear rate was determined by multiplying its wear rate by the CSAF. The adjusted wear rate was used in turn in the computation of tire grade. Thus, the nominal base wear rate was significant in the determination of candidate tire grades.

It was noted above that CMT tires of different base wear rates were used by manufacturers to grade tires. UTQG radial compliance test data, on the other hand, used only one CMT for all tests. However, special CMT-only tests, predating the compliance tests, employed CMTs of different base wear rates. These special tests in the NHTSA data base were used in conjunction with manufacturers' data to analyze whether the different nominal base wear rates accurately reflected CMT wear characteristics.

8.1 MANUFACTURERS' DATA

This subsection discusses the contents of the manufacturers' data. However, because this data was compared to NHTSA's data, it is appropriate to point out the differences between the sources.

The NHTSA compliance test data was consistent in its procedures in the following ways: (1) Candidate tire types were not mixed on a test vehicle; i.e., only one tire type was tested in any given test on a vehicle; and (2) Eight tires of a tire type were tested on two vehicles in two convoys. Thus, aggregating the data to the "vehicle" or "test" level would yield averages of four tires of a particular tire type. To assure consistency, the data were excluded if each of the four tires had not completed all eight "runs" of the 6400 mile test.

In the manufacturers' data, tire types were mixed on a vehicle in a test. Thus "test" level aggregation for a tire type often contained fewer than four tires. This introduced an additional source of variance between tests of a tire type into the manufacturers' data analysis. This additional variance source did not apply to the CMT analyses because there were typically four CMT tires on a vehicle in each convoy. In the manufacturers' CMT analyses, four CMT tires that completed eight runs on one vehicle in one convoy were a criterion for acceptable data.

8.1.1 Goodyear Data

The Goodyear data consisted of 158 individual candidate tires of 26 different types tested in 35 convoys. CMTs with three base wear rates were used: 3.74, 4.16, and 4.44. The data for each individual tire included a tire-type identifier (for proprietary reasons, not the actual tire name), tire size, tire grade, course severity adjustment factor, CMT-base wear rate, vehicle number, mils of tread lost in each 800-mile run, number of wet miles, date, and driver during each 800 mile run. The data included tests of tire types done at widely-spaced intervals.

Goodyear often mixed tire types on a single vehicle in a test. Thus, the "test level" aggregations of candidate tire types included averages with different numbers of tires. The analyses performed on Goodyear data included test level ANOVAs, with the factor being the tire type of (1) the log of treadwear, (2) the log of adjusted treadwear using the assigned nominal base wear rates, and (3) of the log of adjusted treadwear assuming all CMTs had a base wear rate of 3.74.

8.1.2 Goodrich Data

The Goodrich data consisted of 67 individual candidate tires of nine different tire types tested in nine different convoys. CMTs with three base wear rates were used: 3.74, 4.16, and 4.44. The data from Goodrich included a variety of tire label data (e.g. rim size), weather data, and test condition data (e.g., inflation pressure). However, in the interest of expedience (the data was in hardcopy format, and had to be entered manually), not all data were entered into an SAS data set. The data entered for each individual candidate tire included: tire identifier, start and end dates of tire trials, course severity adjustment factor and average adjusted and unadjusted wear rates during the tests. The data included some tests of tire types at widely-spaced intervals. Goodrich also mixed the tire types on a single vehicle in a test. Thus, at the test level, candidate tire types included averages with different numbers of tires.

Analysis performed on Goodrich data included test level aggregate ANOVAs, with the factor being the tire type of (1) the log of unadjusted treadwear; (2) the log of adjusted treadwear using the assigned base wear rate, and (3) the log of adjusted treadwear assuming all CMTs had base wear rates of 3.74. In addition, as part of the analysis to determine whether the base wear rate accuately reflected treadwear characteristics, the variance of the log of the course severity adjustment factor was computed (1) using the assigned base wear rate, and (2) using an assumed base wear rate of 3.74.

8.1.3 Uniroyal Data

Data acceptance criteria were established for the Uniroyal data requiring a candidate tire to complete eight runs (6400 miles) and be tested in a convoy that included four CMT tires which had completed eight runs on one vehicle. Using these criteria, there were 494 individual candidate tires of 62 tire types. The tires were tested in 47 different convoys. The CMT base wear rate was always 3.74.

Uniroyal included a variety of weather and test conditions (car number, driver numbers, convoy position, wheel position), treadwear data, tire type, and convoy identifiers. As the actual course severity adjustment factor was not given, it was approximated using the arithmetic average wear rate (as opposed to the UTQG regression method) of the CMT tires in the convoy. The data included some tire types tested at widely-spaced intervals.

Uniroyal often mixed tire types on a single vehicle in a test. Thus, the "test level" of candidate tire types were averages of one to four tires, whereas NHTSA's compliance data were test level averages of four tires. In addition, tires of some types were tested on more than one vehicle in the same convoy. Thus, the Uniroyal data presented the opportunity to investigate a "car" effect as distinguished from a convoy effect. Analyses were performed to determine this effect.

Other analyses performed on the Uniroyal data included ANOVAs aggregated at the test level, with the factor being the tire type of (1) the log of the treadwear and (2) the log of the adjusted treadwear. In addition, the variance of the log of the treadwear between convoys for CMTs was computed.

8.1.4 General Data

The only radial tires in the General Tire data were CMTs. There were 108 CMT tires tested in 27 convoys (four tires on one car per convoy). The average treadwear of CMTs per convoy was used as a surrogate for the course severity adjustment factor. The variance of the log of the course severity adjustment factor was computed.

8.1.5 Firestone Data

Firestone data consisted of 242 individual tires of 91 tire types. All but five of the tire types were tested on a single car in one convoy. Thus, these data were not useful for the typical test-level one-way ANOVA analyses reported here. However, the data did include the course severity adjustment factor, and the variance between tests/convoys of CMTs was computed.

8.1.6 NHTSA Compliance Data

NHTSA compliance and test data is used in this section to evaluate the environmental factors and the base wear rate.

To evaluate the environmental factors, 67 tests of CMTs used in FY'80-81 radial compliance testing were grouped by date. The tests were sorted by start date, from the earliest to the most recent. This sorting allowed the test variability to be observed by weeks, months, or seasons. Analyses performed included a test-level ANOVA with the factor being the group and the dependent variable being the log treadwear. In addition, the variance of the log treadwear between groups was computed.

To evaluate the base wear rate issue, CMT test data preceding the FY'80-81 UTQG compliance tests were used in conjunction with CMT compliance test data. The pre-compliance test data included convoys of CMTs with four different base wear rates. For various experimental reasons, some individual tires were subject to repeated testing; i.e., more than one 6400-mile UTQG procedure. Analyses performed include test level aggregate ANOVAs with the factor being base wear rate, and the dependent variable being the log of the treadwear. Analyses were performed which included and excluded repeat tests on the same individual tire. The issue of whether different nominal base wear rates accurately reflected CMT wear characteristics was examined, using the simple descriptive statistics computed for nominal base wear rate; i.e., means, standard deviations and variances.

The existence of repeated tests on individual CMT tires allowed a determination of whether individual tires had constant wear rates as their mileage increased. Toward this purpose, plots were produced of convoy average wear rate versus number of repetitions of the UTQG test. In addition, a regression analysis was performed that related wear rate to the number of repetitions of the test.

8.2 ANALYSIS RESULTS: ENVIRONMENTAL/CONVOY EFFECT

This analysis was performed to determine the potential impact on UTQG test treadwear of spacing tests of a candidate tire type more widely in time than was observed in the NHTSA compliance data. For the FY'80-81 UTQG radial compliance tests, NHTSA typically tested a tire type twice in two convoys occurring within two weeks of each other. Thus, the effects of a longer time interval between tests are addressed in this section. Also considered was the ability of the CMT to explain the variance between tests of a tire type when the tests were spaced over a longer time interval.

The analysis used data from both NHTSA's FY'80-81 UTQG compliance testing and the tire manufacturers' testing. Tire types were tested over longer time intervals in some of the data provided by Uniroyal, Goodrich, and Goodyear (see Section 8.1).

The CMT was an identical tire type for the FY'80-81 NHTSA compliance data. It appeared that the variability of the CMT over widely-spaced conditions would indicate how the precision of the measured wear of a candidate tire of one tire type would be affected by the environment. The CMT tire data first was sorted into 14-day intervals, and the between-group and within-group variances were compared. Although the between-group variance was higher than the within-group variance (.0159 vs. .011) the F-factor of 1.48 indicated that this result was not significant at the 95 percent level. The CMT test results were then sorted by the four seasons and by month, and an ANOVA that compared CMT test level log treadwear averages was performed.

The ANOVA for seasons had a significant F (Table 8-1); hence, test level variance of treadwear is somewhat seasonally dependent. To indicate the range of seasonal variation, it was noted that the ratio of the highest average treadwear month (September, average CMT treadwear 4.4687 mils/800 miles) to the lowest average CMT treadwear (March, 3.7833 mils/800 miles) was 4.4687/3.7883 = 1.18. The ratio of the highest average treadwear season (July/August/September, 4.3089 mils/800 miles) to the lowest average treadwear season (January/February/March, 3.8601 mils/800 miles) was 4.3089/3.8601 = 1.12. Thus, indications are that the seasonal factor is between 1.1 and 1.2.

TABLE 8-1. ENVIRONMENTAL FACTORS ANOVA: LOG AVERAGE TREADWEAR, TEST LEVEL AGGREGATION FOR FY'80-81 RADIAL COMPLIANCE TEST DATA

Source	Degrees of Freedom	Mean Square	F	Pr>F
Between Groups*	3	.047416	4.24	.0088
Within Groups*	62	.011194		
TOTAL	65			

*Groups are groups of test level averages of log of treadwear, grouped by season.

It was further noted that colder seasons of January/February/March and October/November/December have lower treadwear than the warmer seasons of April/May/June and July/August/September.

It should be pointed out that the potential effect of the seasonal factor on candidate tire test grade cannot be determined from this analysis. The seasonal variation that was seen on the CMT results may have been an indicator of the CMT accounting for environmental factors (according to the test design). In other words, if the candidate tire had responded in the same way as the CMT tire, than tire grading would have been unaffected by the CMT seasonal factor. If the response were different (which was more likely considering differences in tire compounding, design, etc.), the CMT may not have completely removed the seasonal effect.

Therefore, a subset of the environmental factor issue considered was how well the CMT explained the variance of tests of a candidate tire type when tests of that type were spaced over longer time intervals. This issue was addressed by comparing the variances of adjusted and unadjusted treadwear under longer and shorter time intervals. The variance of the adjusted log treadwear should always be lower than the variance of the unadjusted log treadwear. The ratio of the adjusted to the unadjusted is the "best estimate" of what percentage of the variance is explained by the CMT.

The manufacturers' data contained some tests of identical candidate tire types that were conducted over longer time intervals than the NHTSA compliance data. Unfortunately, there were not enough of these tests to form a separate subgroup for statistical analysis. Therefore, ANOVAs were run with these tires grouped with other tires that were tested during shorter time intervals. The ANOVAs compared the unadjusted and adjusted treadwear for both NHTSA's compliance candidate tests and the manufacturers' tests (Table 8-2). In all cases, the CMTs adjusted the treadwear variability downward. However, the most interesting result was that the test variability of the NHTSA data, both adjusted and unadjusted, was lower than the manufacturers' data. This result may indicate that NHTSA controlled their test procedures better than the manufacturers. It was also noted that in some instances the manufacturers used fewer than four identical tire types in a test, thus giving a poorer estimate of the average treadwear.*

*Note that the standard deviation of the mean of samples of size n is inversely proportional to the $\sqrt{n}$; hence the confidence limits on average treadwear are broader for the manufacturers' data than for NHTSA compliance data.

TABLE 8-2. REDUCTION IN VARIANCE OF CANDIDATE TIRE DESIGN DUE TO CMT ADJUSTMENT

	Log Treadwear		Log Adjusted Treadwear		
Data Source	Degrees of Freedom	Variance	Degrees of Freedom	Variance	Reduction in Variance**
NHTSA Compliance	99	01503	99	.00649	57%
Goodyear	32	.02188	32	.01363 .01681*	38%
Goodrich	20	.03390	20	.01959 .01856*	42%
Uniroyal	70	.02002	70	.01544	23%

*Assumes base wear rate of 3.74, see Sections 8.1.1 - 8.1.2.

**Computed as 100 (1 - (Variance Log Adjusted Treadwear/Variance Log Treadwear))

Although the results shown in Table 8-2 (higher manufacturers' variance and better CMT adjustment with NHTSA's compliance test) may indicate the inability of the CMT to fully compensate for environmental effects, this would at best be a supposition. This is because the results are confounded by the aforementioned factors of control procedures, number of tires tested, and the manufacturers' data, which was a mix of tests conducted over both long and short time intervals.

8.3 BASE WEAR RATES

CMT tires of different base wear rates were used by the manufacturers to grade tires (see Section 8.1). The base wear rate was a "nominal" CMT wear rate used in the computation of adjustment factors. The adjustment factor was the base wear rate divided by the average wear rate of CMT in the convoy (computed by the UTQG regression-based procedures). Thus, the base wear rate was significant to the computation of a grade. A question of appropriateness arose when CMTs of different base wear rates were used to grade tires: the issue was whether the different nominal rates accurately reflected CMT wear characteristics. Since Goodyear and Goodrich used CMTs of different base wear rates to assign grades, this issue was legitimate.

The NHTSA pre-compliance test data included tires of four different base wear rates, and these were used in this analysis. Some CMTs were used in repeated tests. Individual tires were run in as many as nine complete UTQG tests, a total of 9 x 7200 = 64,800 miles. The existence of repeat runs was discovered after preliminary ANOVAs were completed.

The analyses were performed with the factor being base wear rate and the dependent variable being the log of treadwear (both including and excluding the repeat runs - see Table 8-3). These repeat runs are shown here because the results of the "repeat run" ANOVAs were felt to be of value. The ANOVA that included the repeat runs indicated no difference between CMTs of different base wear rates.* The ANOVA that excluded the repeat runs (i.e., used only the first test of 6400 miles in which an individual tire was run) showed a significant difference. However, an analysis based on the means and their standard errors showed that the only tires with a significantly different wear rate from other CMTs were the 5.50 base wear rate tires. The 5.50 base wear rate CMTs were not used in assigning Goodyear or Goodrich grades.

*More detailed analysis of the repeat runs indicated that the first test of these tires had high average wear rates. The high average wear rates during the first test accounted for the difference in the ANOVA results between the inclusion and exclusion of repeated runs. This apparent non-linearity in wear rates raised potential issues of stability of the 5.50 BWR CMT Tire and for the linearity of treadwear in general.

In addition, the average wear rates of CMTs (Table 8-3) did not increase uniformly with increasing base wear rate. This was a preliminary indication that the different base wear rates of the CMTs may not have reflected actual differences in their treadwear characteristics. Note that there were not enough tire tests for the 4.16 and 4.4 base wear rate (BWR) CMTs to have established the treadwear characteristics of these tires with any statistical certainty.

TABLE 8-3. NHTSA TESTS: BASE WEAR RATE ANOVAS, TEST LEVEL

	Data Source	DF	Mean Square	F	Pr> F
Includes Repeats	Between Groups	3	.05061		
	Within Groups	125	.02900		
	TOTAL	128		1.75	.1595
Excludes Repeats	Between Groups	3	.20545		
	Within Groups	89	.01379		
	TOTAL	92		14.90	.0001

FACTOR: Base Wear Rate

	BWR	N*	M**	D***
	3.74	85	3.639	.159
Includes Repeats	4.16	6	3.740	.141
	4.44	3	3.535	.102
	5.50	35	3.691	.201
	3.74	75	3.679	.119
Excludes	4.16	6	3.740	.141
	4.44	3	3.535	.102
	5.50	9	3.934	.082

*N = Number of tests.
**M = Average of log wear rate. Wear rate expressed in 10th of a mil.
***D = Standard deviation of test average of the log of the treadwear.

The impact on the CMT explanatory factor of assuming that the BWR was 3.74 for all cases was considered. In the Goodyear data, an assumed base wear rate of 3.74 reduced the explanatory capability of the CMT from 38 to 24 percent. In the Goodrich data an assigned value of 3.74 increased the explanatory capability of the CMT from 42 to 45 percent. These results cannot be generalized but indicate that this issue is worthy of further study.

8.4 CAR EFFECT

One proposed source of variation in the treadwear is the vehicle itself. In the FY'80-81 compliance test data, the two tests of a tire type were typically conducted in two separate convoys. Thus, it was not possible to separate any car effect from a convoy effect. The Uniroyal data, however, had 13 examples of tire types in which eight tires were tested on two vehicles in one convoy. Thus, with the Uniroyal data it was possible to look for a car effect as distinguished from a convoy effect.

Estimates of the variance of each of these 13 tire types based on the samples of eight tires (on two vehicles in the convoy) were computed. These variance estimates were averaged (Table 8-4). There were also 52 examples of tests in which exactly four tires of one tire type on one vehicle were tested in one convoy. Estimates of the variance of each of these 52 tire types based on the samples of four tires (on one car) also were computed and averaged (Table 8-4). As expected, the variance of the tires on two vehicles was greater than the variance of the tires on one vehicle. The ratio of the variance estimates was 1.55 (.009632/.006226). However, this ratio (with 13 and 52 degrees of freedom for numerator and denominator, respectively) was not statistically significant at the 90 percent level.

TABLE 8-4. ESTIMATION OF CAR EFFECT

	Number of Designs	Average Variance of Log Treadwear
Tire types in which 8 tires were tested on 2 cars in one convoy	13	.009632
Tire types in which 4 tires were tested on one car in a convoy	52	.006226

8.5 SERIAL NUMBER ANALYSIS

The CMTs used in FY'80-81 compliance tests (BWR of 3.74) came from two bandberry batches (material mixtures). In addition, tires from each bandberry batch were cured on two different dates. Thus, there were four different bandberry batch cure date combinations. The question arose as to whether these bandberry batches differed significantly from one another, thereby introducing a bias into candidate tire grades.

The four bandberry batch and cure date combinations corresponded to four CMT tire serial numbers. The analysis using NHTSA's compliance data was conducted two different ways, and yielded a consistent result. The result was that, within the current accuracy of the test, it was not possible to detect a difference in the wear characteristics of the four CMT bandberry batch cure date combinations.

There were 51 tests of CMTs which mixed CMT serial numbers for the four tires on the car in the convoy. There were 156 tests of CMT tires which had only a single serial number for the four tires on the car in the convoy. If bandberry batch cure date affected tire treadwear characteristics, then the mixed-serial-number convoy's variance (.00101) should have been higher than the single-serial-number convoy's variance (.00171). As can be seen in table, the opposite was true.

A second approach averaged the treadwear of tires of the same serial number on a vehicle in a convoy and computed a "test"* level ANOVA with the factor being serial numbers. As can be seen in Table 8-5, the F was not significant. Thus, under current UTQG procedures, both approaches indicated that the bandberry batch cure date combination did not appear to be a significant source of variation.

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*All tires on a vehicle of the same bandberry batch/cure date combination were averaged for the ANOVAs. These include averages of from one to four tires.

TABLE 8-5. CMT SERIAL NUMBER ANOVAS

	DR	Treadwear Within Test	F	Pr > F	
With Mixed Serial Numbers	51	.00101	0.5906		
With Only One Serial Number (factor Test)	156	.00171			
All CMTs					Factor-Serial #
Between Groups	3	.02488	2.09	.1058	Dependent Variable Log Tread
Within Groups	82	.011878			Wear

APPENDIX A

ESTIMATING THE 95 PERCENT LIMITS ON THE DIFFERENCE BETWEEN AVERAGE GRADES IN SUCCESSIVE TESTS OF A TIRE TYPE

Assuming normality, 95 percent of the differences between average grades in successive tests of a tire type lie within 1.96 standard deviations of the mean difference. By symmetry, there is no reason to suppose that the first test of a tire type should grade consistently higher than the second test of a tire type, or vice versa; i.e., the mean difference should be zero.

The standard deviation of differences between average grades in successive tests of a tire type can be estimated using the bar graph in Figure 7-1. Note that the "range of values" is in 10-point increments. The standard deviation σ is estimated as:

$$\sigma = \Big[(25 \times 0^2 + 24 \times 10^2 + 23 \times 20^2 + 12 \times 30^2 + 5 \times 40^2 + 3 \times 50^2 + 1 \times 60^2 + 1 \times 70^2 + 0 \times 80^2 + 1 \times 90^2)/94\Big]^{1/2}$$

$$= 24.079.$$

The estimate procedure consists of first multiplying the square of the point difference (10 times the range of values) by its corresponding frequency. For example, the range of values 1.000 to 1.000 (see Figure 7-1) has a 10-point difference and occurs 24 times. Thus, 10 is squared and multiplied by 24 to yield 2400. This procedure is repeated for all differences listed in the bar graph of Figure 7-1. The resulting values are added and divided by the total frequency minus one (94) to yield the variance estimate. The standard deviation estimate is the square root of the variance estimate.

With an estimate of the standard deviation of 24.079, 95 percent of the differences between average grades on successive tests are estimated to lie within $1.96\sigma = 47.2$ points.

APPENDIX B

EVALUATION OF AN ALTERNATIVE TO THE LINEAR REGRESSION GRADE ASSIGNMENT TECHNIQUE

As currently constituted, the UTQG procedure measures wear eight times on each tire during the 6400-mile test. Each time the measurement is taken, tires must be removed from the vehicle and allowed to cool. Each tire is measured at six equally-spaced points in each groove. These groove depth measurements are averaged and compared with the previous average groove depth to determine the wear rate of the tire for that run. The values of wear are normalized to rates per 1000 miles. A linear regression through the eight normalized wear rates of each tire determines the overall test unadjusted wear rate for that tire. This unadjusted wear rate is then adjusted by the course severity adjustment factor. The projected mileage of the tire is then computed according to the formula below:

$$\text{Projected Mileage} = \left[\frac{1000\,(a-62)}{b'}\right] + 800$$

Where a is the Y intercept of the regression (reference tread depth)
b' is the adjusted wear rate.

The grade of the tire is then computed as

$$\text{Attained Grade} = \frac{\text{Projected Mileage} \times 100}{300{,}000}$$

To avoid the costly, time-consuming process of nine individual measurements, Dr. Jose Bascunana, (NHTSA/NRD-11), proposed that the measurement be made only twice, and that the unadjusted wear rate per thousand miles be computed as the difference in average groove depth before and after the 6400-mile test, divided by 6.4. The reference groove depth would then be the average groove depth after the 800-mile break-in period. All other computations would be unchanged.

This appendix addresses the differences in attained grade using the two methods. The feasibility of a longer break-in period is also considered; i.e., a test length of 1600 miles, 2400 miles or 3200 miles is lengthened to 5600 miles, 4800 miles, or 4000 miles, respectively.

The new, unadjusted wear (b) rate would then be

$$b = \frac{a-e}{\text{Test Mileage}/1000}$$

where a is the average groove depth after break-in
e is the final groove depth

The projected mileage is

$$\left[1000 \frac{(a-62)}{b'}\right] + F$$

Where a is the average groove depth after break-in
b' is the adjusted wear rate

F is the break-in mileage.

The grade computation is unchanged.

This analysis compares all four methods with the original UTQG procedure using the available radial tire FY'80-81 test data. The means and standard deviations of the differences in attained grade computed by the procedure are shown in Table B-1. The differences are in the range of the test error with the 800 mile break-in period most closely approximating the original procedure.

TABLE B-1. ATTAINED GRADE DIFFERENCES: MEANS AND STANDARD DEVIATIONS

Break-in	Mean	Standard Deviation (j)
800	2.951	16.718
1600	6.443	23.013
2400	11.370	23.713
3200	14.369	26.157

APPENDIX C

HETEROSCEDASTICITY

An assumption of ANOVA is that the cells are homoscedastic; i.e., the groups have the same variance. Standard tests for heteroscedasticity (unequal cell variance) are the Bartlett Test and the Hartley test (Applied Linear Statistical Models, Neter and Wasserman, pp. 509-513), and an approximate test based on an ANOVA of logarithms of the sample variances (The Analysis of Variance, Scheffe, pp. 83-87). These require more observations per cell than exist in a typical ANOVA. A typical ANOVA with a convoy factor and with the dependent variable being a test level average of the log of treadwear or the grade, has two observations per cell.

There is, however, some evidence of heteroscedasticity with respect to candidate tire variance. Note that CMT tires within a test have a variance of .00127 (see Table 7-5), and candidate tires within test have a variance of .00346 (Table 7-5). It is reasonable to assume that if CMT tire variance differs from pooled candidate tire variance, then different candidate tire types may have different variances.

One way to observe heteroscedasticity is to construct a sample in which the average treadwear grade is computed for each candidate tire type. The average treadwear grade for each candidate tire type is subtracted from the treadwear grade from each observation for that tire type. If all tire types have the same variance, σ^2, then the resulting population will be normal, with mean 0 and variance σ^2. If the variances are not all equal, then the resulting population will not be normal and will exhibit some kurtosis*. This analysis was done for the cases of the candidate tire, tire level ANOVA (Table 7-1), the CMT tire level ANOVA (Table 7-2), the candidate tire test level ANOVA (Table 7-4), and Environmental Factor ANOVA (Table 8-2).

*A normal population has kurtosis 0.

The analysis indicates computation of kurtosis and the Kolmogorov-Smirnov D statistic (a test of normality). At the 95 percent confidence level, the hypothesis of normality cannot be rejected for all but the candidate tire, tire level, group test (Table C-1).

TABLE C-1. KURTOSIS OF POPULATION: LOG OF TREADWEAR DIFFERENCES FROM GROUP MEAN

Tire Type	Level	Group	Kurtosis	D	Pr> D
Candidate	Tire	Test	2.89799	.05814	.01
Candidate	Tire	Tire Type	0.45360	.02779	.067
CMT	Tire	Convoy	2.79691	.06997	.053
Candidate	Test	Tire Type	0.04433	.02814	.15
CMT	Test	Two Week Groups*	1.92492	.105945	.065

However, the ANOVA may be valid, although it apparently does not yield this result. Note that the value of F (Table 7-1) is greater than the ANOVA, even though the ANOVA, at 198 and 597 degrees of freedom, would seem likely to remain significant under observed levels of heteroscedasticity. Therefore, the conclusion that the test distinguishes at least some tire types, is likely to remain valid. In addition, this ANOVA is used in the treadwear analysis to obtain an estimate of tire quality as a source of variability. The estimate is the within-group mean square, factor test (Table 7-3). Due to abnormalities, 98 percent of observations would not be within ± 2.33 standard deviations of the mean. In the sample distribution, 98 percent of the observations are within +2.988 and -2.620 standard deviations of the mean. Thus, the spread of tire treadwear is approximately 20 percent greater than the normality assumption values apparent.

*CMT tests occuring within two weeks of each other.

This analysis also can be used to compare log transformed variates with original variates, with respect to ANOVA normality and heteroscedasticity assumptions. The ANOVAs tested have log-transformed variates with lower sample kurtoses (Table C-2); hence they conform better to ANOVA assumptions.

TABLE C-2. COMPARISON OF KURTOSIS BETWEEN LOG AND ORIGINAL TRANSFORMED VARIATES

Candidate Tires

Variable	Level	Group	Log Transform Kurtosis	Original Variate Kurtosis
Treadwear	Tire	Test	2.8799	7.69841
Treadwear	Tire	Tire Type	0.453601	4.28252
Treadwear	Test	Tire Type	0.04433	2.80732
Attained Grade	Tire	Test	2.55372	3.68292

GLOSSARY

BWR	Base Wear Rate, the nominal wear rate for a one identical type of CMT tire.
CMT	Course Monitoring Tire - a special identical tire used in each convoy to correct for day-by-day variations in the test course and its related environment.
Compliance Test	Test conducted for NHTSA to verify that manufacturers have not overgraded their tires.
Convoy	A group of four vehicles simultaneously performing tests following UTQG procedures including three candidate tire tests and the CMT test.
CSAF	Course Severity Adjustment Factor - the CMT correction; defined as the established BWR of the CMT tire divided by its UTQG estimate of average wear rate during a test.
Driver	A driver of the vehicle used in a UTQG test.
Dummy Variables	A technique used in a regression analysis to represent an independent variable that cannot be logically represented by a numerical variable.
Individual Tire	A tire (as opposed to a group of tires). Note that in this terminology, a tire type consists of a set of individual tires of the same manufacturer, line, size, and design.
Manufacturer's Data	Data from UTQG tests of tire designs collected by manufacturers for the purpose of assigning tire grades.
Pre-Compliance Tests	Tests conducted for NHTSA to establish the wear rate characteristics of the CMT. These test consist of CMT tires only.
Repeat Test	A UTQG test of a set of four individual tires that have been previously tested.
San Angelo Test Track	A 400 mile course over which all treadwear tests are performed.
Surrogate Variable	A special case of dummy variables that were used in the UTQG analysis (see Section 7.2).
Test Level Analysis	A statistical analysis level in which tire level data have been averaged for all identical tires in a test.
Tire Level Analysis	A statistical analysis level in which data from the eight 800-mile runs have been averaged for each individual tire.

Tire Types	Tires of the same manufacturer, line, size, and design.
Treadwear Run	An 800 mile segment of the 6400 mile treadwear test: the treadwear measurement interval.
UTQG	Uniform Tire Quality Grading procedure as specified in Title 49 CFR Part 575.104.
Vehicle	Automobile used in UTQG test.

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