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ROLLING RESISTANCE OF TIRES FOR LIGHT VEHICLES II: COMPARISON OF ROLLING RESISTANCE VALUES OBTAINED FROM DIFFERENT TEST METHODS AND IN DIFFERENT LABORATORIES

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Rolling Resistance of Tires for Light Vehicles, II: Comparison of Rolling Resistance Values Obtained from Different Test Methods and in Different Laboratories

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Objective

- **Select a Method to Measure Tire Rolling Resistance in Order to Compare Tires**
  - SAE J2452 values at various speed, load, and inflations used to relate tire properties to vehicle
    - SMERF (Standard Mean Equivalent Rolling Force)
  - SAE J1269 and ISO 18164 describe the tire response at various load and inflation conditions
    - SRC (Standard Reference Condition)
  - SAE J1269 and ISO 28580 test a tire at standard conditions of speed, load, and inflation

Measuring Rolling Resistance

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- **Evaluate Sources of Variability in Testing**
  - Tire
    - Different Tire Types
    - Different Tires of Same Type
    - Same Tire – Repeat Testing
  - Lab
  - Test

Test Matrix

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- Five Test Protocols
- 25 Tire Types
- 2 Labs
- Capped or Regulated Pressure (J1269)
- First, Second and Third Tests on Individual Tires
- Different Inflation Gas
- 641 Tests
- Only one tire was an outlier from other tires of the same model

ANOVA

- **Analysis of Variance was conducted on results from each test**
  - SAE J1269 Single-Point
  - SAE J1269 Multi-Point
    - Calculated value at SRC using regression specified
  - ISO DIS28580 Single-Point
  - ISO 18164 Multi-Point
    - Calculated at SRC using J1269 regression method
  - SAE J2452
    - SMERF
    - Calculated value at SRC using J2452 regression

SAE J1269 Single-Point

Dependent Variable: Rolling Resistance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	29	49358.7	1702.0	15122.2	<.0001
Error	191	21.5	0.11		
Uncorrected Total	220	49380.2			

R-Square	Coeff Var	Root MSE	RR Mean
0.995985	2.371565	0.335487	14.14623

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lab Where Tested	1	9.45	9.45	83.99	<.0001
Procedure for Inflation	1	2.99	2.99	26.62	<.0001
Test Order	*2*	*0.07*	*0.036*	*0.32*	*0.7265*
Type (Tire Model)	24	4871.64	202.98	1803.49	<.0001

ANOVA Comparison

Test	J1269 Single-Point	J1269 Multi-Point	ISO DIS28580	ISO 18164 *(10 Tires)*	J2452 SMERF
F Value	15,122.2	15,929.5	8,320.9	2,687.6	23,535
R^2	0.9960	0.9960	0.9967	0.9891	0.9953
F Value - *Lab*	83.99	11.24	2.14	*4.30**	544.34
F Value - *Capped / Regulated*	26.62	NA	NA	NA	NA
F Value – *Test Order*	0.32	0.23	0.68	*4.30**	26.57
F Value – *Tire Model*	1,803.49	4,574.38	853.61	89.94	1,699.70

* *Variables were confounded*

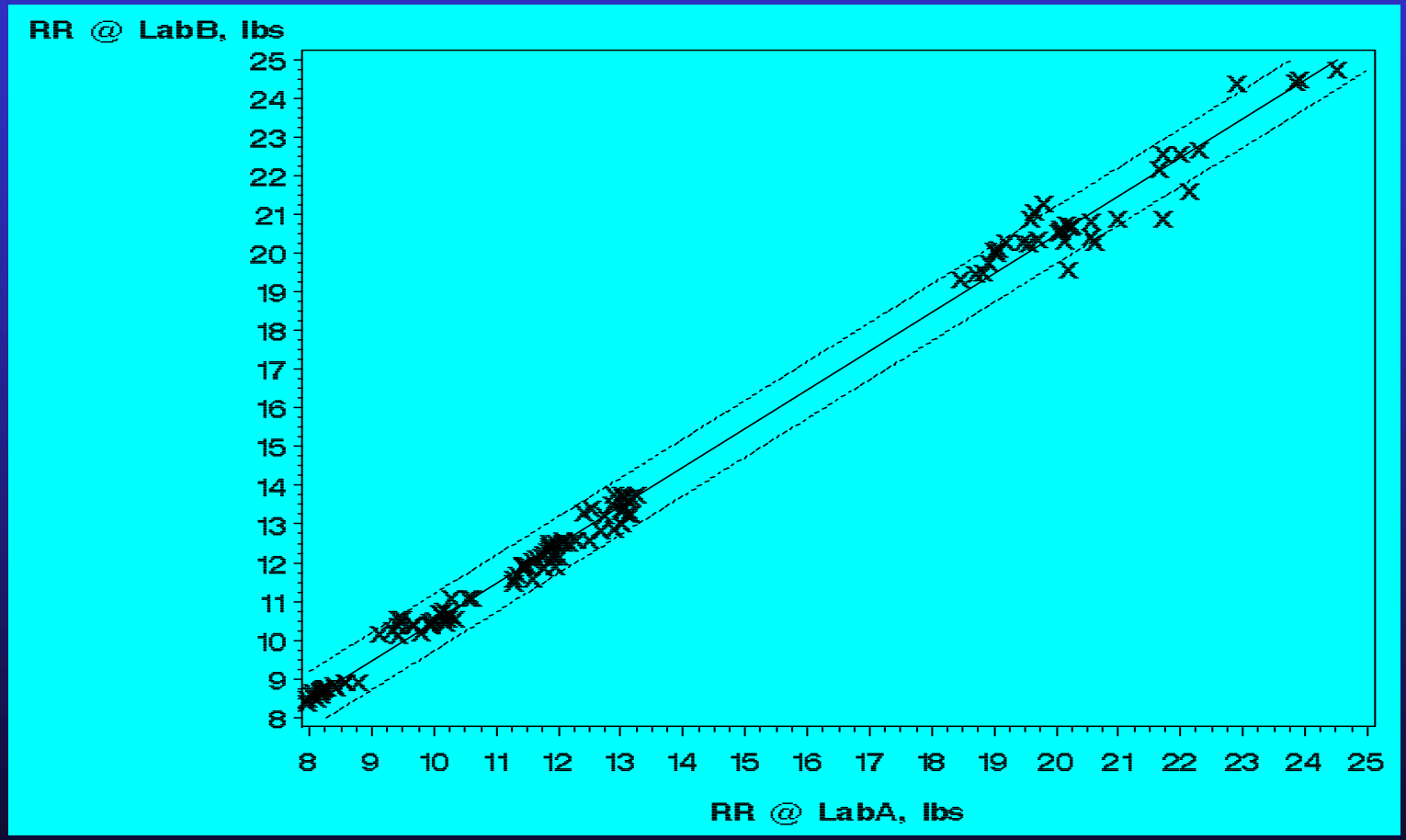
ANOVA Conclusions

- **F and R2 values indicate that the sources of variation are accounted for in model**
  - Tire type is the most significant variable
  - The two labs studied produced significantly different values
  - Capped vs. regulated inflation pressure during the test was significant
  - First, second, or third test on the same tire was not a significant variable

Lab Variation

- **Test order (1st, 2nd, 3rd) ignored**
- **Coefficient of Variation within a lab for a tire type on a test was ≤ 2.5%**
  - Values were normally distributed within each lab
- **There was a significant variation between labs for all tests**

Lab Offset
J1269 Single-Point Test



Rolling Resistance @ Lab B = 0.257 + 1.024*(Lab A)

Lab Offset

Test	Correlation of Lab B to Lab A	R^2
J1269 Single-Point	B = 0.257+1.024*A	0.9975
J1269 Multi-Point	B = -1.746 + 1.012*A	0.9659
ISO 28580 Single-Point	B = -0.099 + 1.012*A	0.9623
ISO 18164	B = 0.714 + 0.908*A	0.9623
J2452 SMERF	B = -0.143 + 1.077*A	0.9915

Lab to Lab Correlation

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- **Statistically significant offset between labs.**
  - Lab B had higher values than Lab A for 3 of the tests
  - Lab B had lower values than Lab A for 1 test
  - Equal on average for 1 test
- **A slightly better prediction of lab offset could be obtained with a non-linear equation, especially for multi-point tests**

Lab-to-Lab Offset

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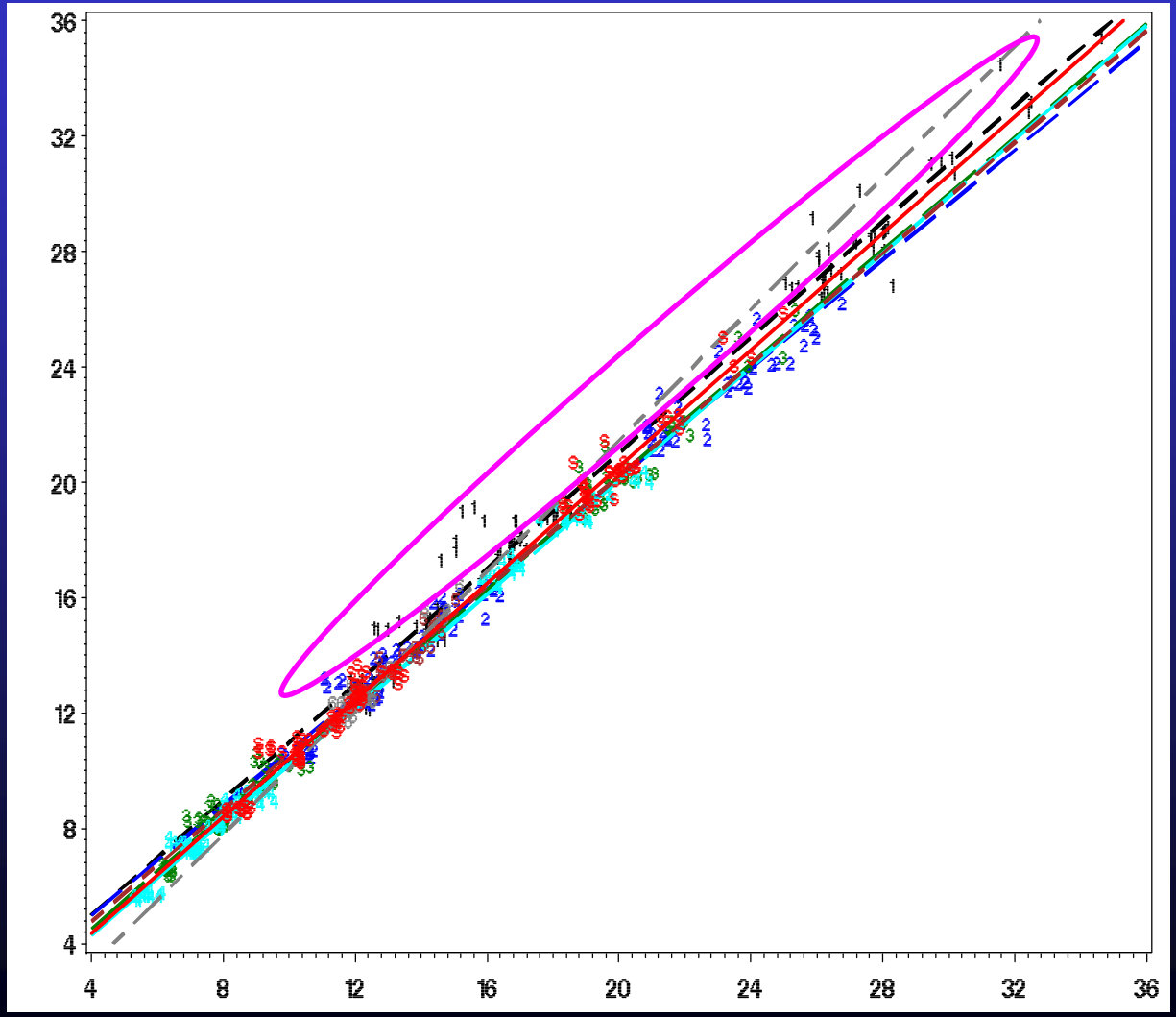
Correlation of Lab B to Lab A for all conditions of the J1269 Multi-Point test.

Test Point 1 *[Capped Inflation]* **is significantly offset**



Variability of Test

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Test	Coefficient of Variation
J1269 Single-Point	2.4%
J1269 Multi-Point	2.4%
ISO DIS28580	2.2%
ISO 18164 *(10 Tires)*	5.2%
J2452 SMERF	1.9%

Measuring Rolling Resistance

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- **Sources of Variability in Testing**
  - Different Tires of Same Type
    - Only 1 Tire significantly different
  - Same Tire – Repeat Testing
    - No significant effect
  - Lab
    - Significant differences
      - Varies by test and conditions
  - Test
    - All tests have low Coefficient of Variation (C.V.)

Ranking Tire Rolling Resistance

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- **Data for values from Lab A corrected to Lab B values using correlation equations**
- **Do tests rank-order tires differently?**
- **Rolling resistance of tires was grouped using least significant differences at 95% confidence level for data from each test**

Correlation of Test Data

1 = ISO 28580 single-point value

2 = SAE J1269 multi-point value @ SRC

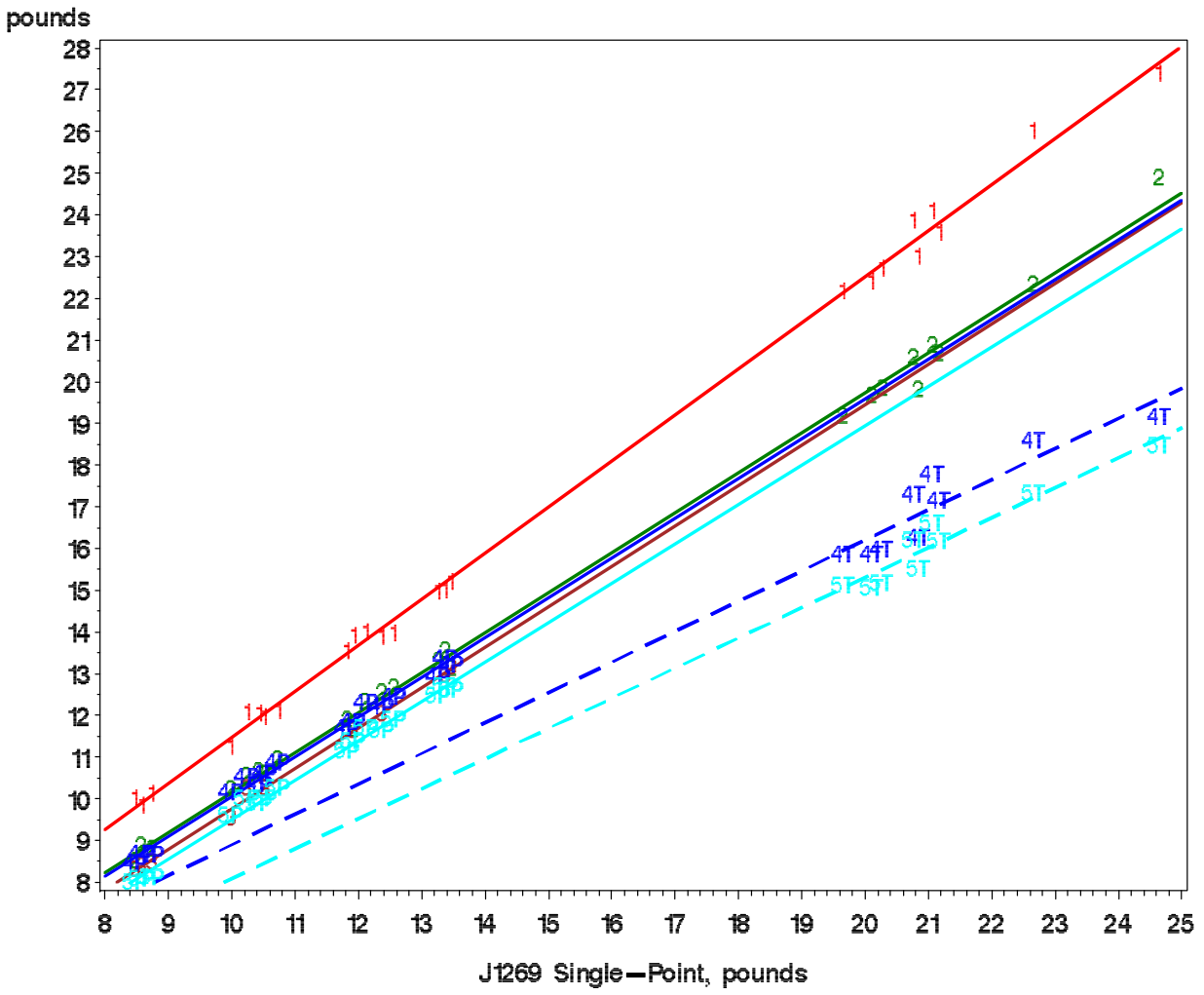
3 = ISO 18164 value @ SRC

4P = SAE J2452 value @ SRC, Passenger Tires

4T = SAE J2452 value @ SRC, Light Truck Tires

5P = SAE J2452 SMERF value, Passenger Tires

5T = SAE J2452 SMERF value, Light Truck Tires



Passenger Tire Groups

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Group	J1269 Single-Point	J1269 multi-point@ SRC	ISO 28580	ISO 18164	J2452 @ SRC	J2452, SMERF
1 *(Lowest)*	B11 G8 G11	G11 B11 G8	G8 B11 G11	G11 G8 B11	G11 B11 G8	G11 G8 B11
2	G9 G10 M13 M14 B10	G9 G10 M14 M13 B10	G9 M13 M14 G10 B10	G9 M14 G10	G9 M13 G10 M14 B10	G9 M13 G10 M14 B10
3	D10 U3 P5 B14 B15	U3 D10 P5 B14 B15	D10 B14 U3 B15 P5	U3 B14	D10 U3 B14 P5 B15	D10 U3 B14 P5 B15
4 *(Highest)*	R4 B13 B12	B12 R4 B13	R4 B13 B12	B13 B12	R4 B12 B13	R4 B12 B13

Light Truck Tire Groups

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Group	J1269 Single-Point	J1269 multi-point@ SRC	ISO 28580	J2452 @ SRC	J2452, SMERF
4 *(Lowest)*	M10 M12 M11 D8 K4 D7 P4	M10 M12 K4 M11 D8 P4 D7	M10 M12 M11 K4 P4 D8 D7	M12 M10 M11 K4 P4 D8 D7	M12 M10 M11 K4 P4 D8 D7
5	D9	D9	D9	D9	D9
6 *(Highest)*	C9	C9	C9	C9	C9

Selection of Method

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- All methods produce data with low variation
- All methods rank tires into the same groups
- Data from any method can be correlated to data from any other method
- Single-point method is most efficient
- Any method selected will need a procedure to account for lab-to-lab differences

Ranking Tires Using RRC

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- **Rolling Resistance Coefficient (RRC) is often used to report the rolling resistance of tires**
  - RRC is Rolling Resistance Force / Normal Force
    - Using same units removes the dimension
- **When comparing tires tested at the same load, there is no change in comparisons**
- **Can RRC be used to compare tires of different load ratings?**

Correlation of Test Data

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1 = ISO 28580 single-point value

2 = SAE J1269 multi-point value @ SRC

3 = ISO 18164 value @ SRC

4P = SAE J2452 value @ SRC, Passenger Tires

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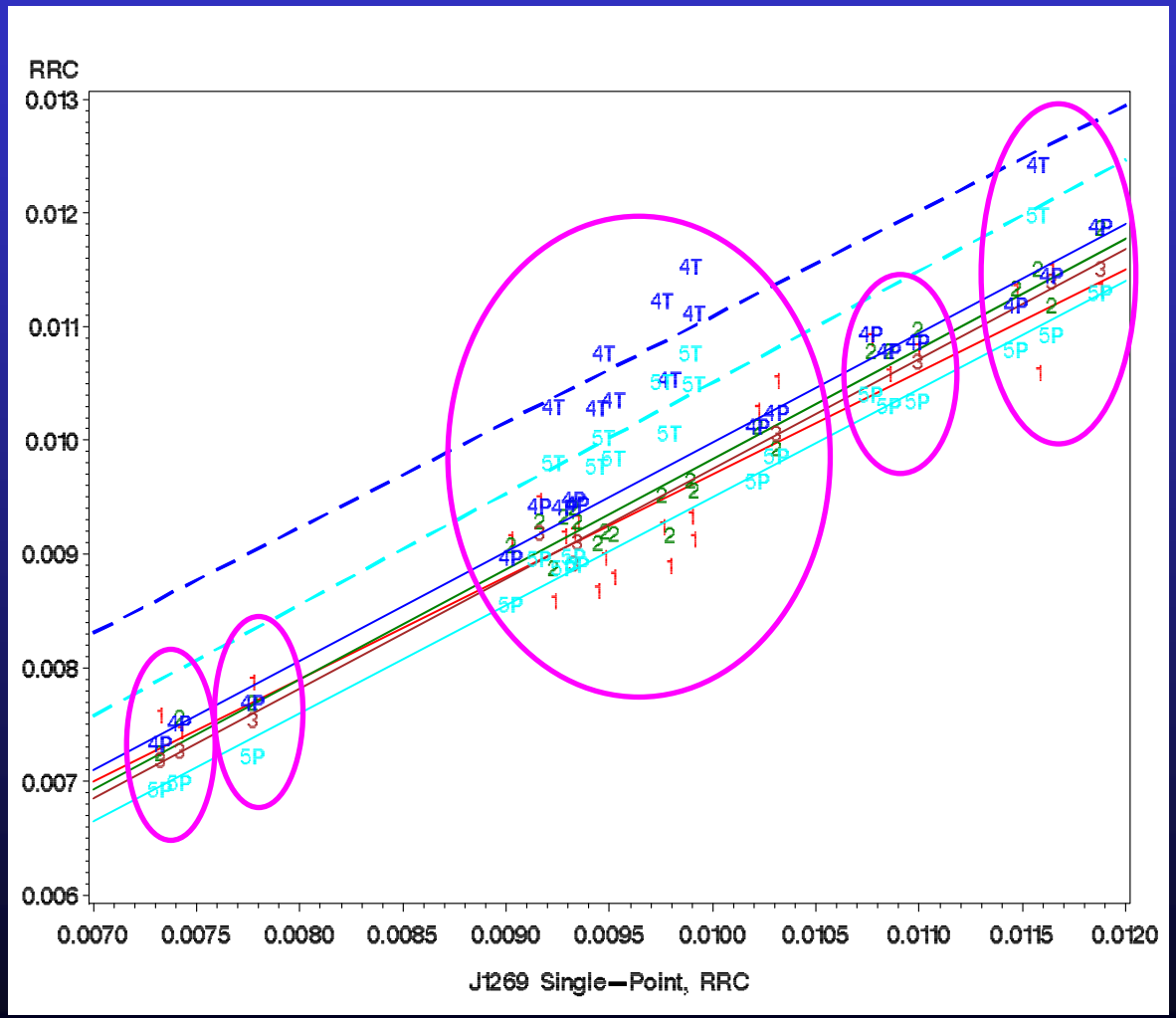


RRC Calculation

- **While RRC is dimensionless, it is not independent of conditions of testing**
- **For passenger tires using J1269 RR:**

$RR_{\_Force} = Load*(A_1 + A_2*Load + A_3 \div Pressure)$

– *Dividing both sides by load*

$RRC = A_1 + A_2*Load + A_3 \div Pressure$

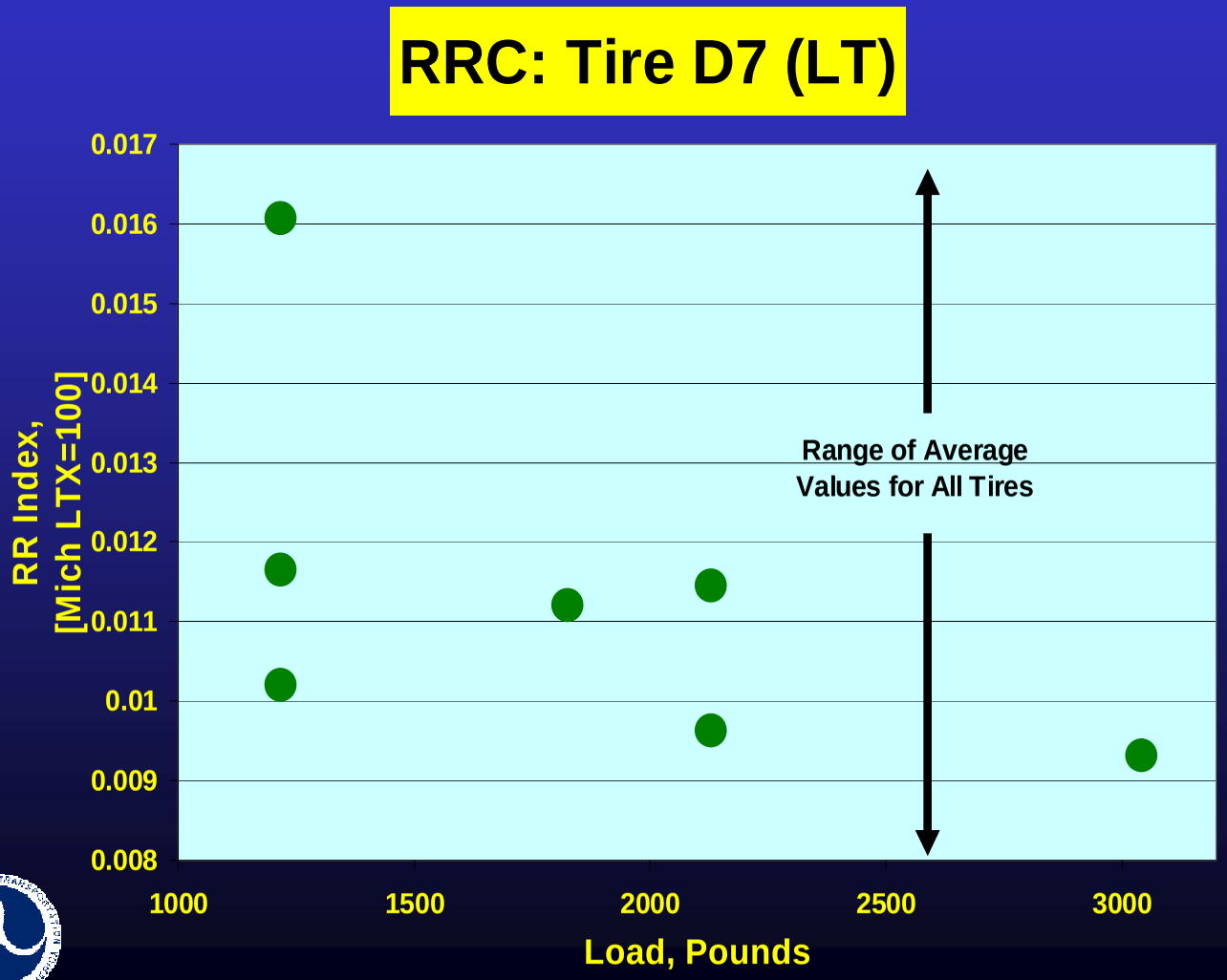
– *At constant pressure*

$RRC = A_2*Load + A_1 + A_3 \div k$

RRC is still a function of load

J2452 and LT tires are even more complex

RRC Vs. Load – Tire Type D7



RRC is between 0.0093 and 0.0161, depending on test condition.

It is not an intrinsic property of the tire

Conclusions (I)

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- **Up to 3 repeat tests of the same tire has no significant effect on rolling resistance values**
- **As expected, testing with capped inflation pressure produces a lower value, due to increased pressure**
- **Tires of the same model and size produce equivalent rolling resistance values, ± ~6%**
  - Data is normally distributed
  - 1 outlier tire discovered

Conclusions (II)

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- **Lab-to-Lab variation is significant**
  - Dependent on test conditions and protocol
- **All tests produce reliable data with low variation**
- **All tests rank order tires into the same groupings**
- **Values for all tests are approximately linear functions of the values of any other test**
- **Rolling Resistance or RR Coefficient describe a tire's response at the conditions of test only**