Wheel Test to Predict Giant Tire TMPH Road Performance

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Executive Summary

Excessive Heat Buildup is the main cause of Giant tire's non-hazard failures.

The TMPH system is designed to prevent tire overheating by matching the tire temperature capability, which is a function of Tire Load Capacity, Tire Gauge, Tread Pattern, and Tread Compound, to the operating demands of a vehicle, which is a function of the Vehicle Load, Speed, and the Tire Inflation.

The objective of this study is to replace the standard Road Track tire TMPH test with a faster, less costly Wheel TMPH test that uses regression modeling to account for the higher temperature stresses introduced by a curved wheel.

<u>Introduction:</u>

The International Mining Industry uses giant dump trucks running on giant Off-the-Road-Tires (OTR) to carry payloads of up to 360 tons (e.g. Cat 797 series).

Figure 1

Figure 1: 33.00R51 OTR Tires on CAT 785C

There are two major operational costs for mining operations: Vehicle Fuel and Tires.

Premature tire removals increase tire cost, overhead, and vehicle downtime losses.

Tire heating is associated with operating stresses. Stresses that exceed the tire's temperature capability cause internal component separations. Overheating and separations are usually the leading cause of non-hazard tire removals.

The Tire and Mining Industry addresses the tire overheating issue with a tire temperature and performance index system called TMPH, Ton-Mile-Per-Hour.

The Job's TMPH is its average vehicle load per tire multiplied by it's average speed during a round-trip work-cycle between the ore source to the ore dumping station.

The Tire's TMPH rating is limited by the tire's maximum safe operating temperature as recommended by the manufacturer.

The tire's deflection and rotation frequency acting on the tire's tread rubber, tread design, and tread thickness generate internal heat. Tire deflection flexing is a function of load, inflation, and the contour of the contact surface.

Tire deflection and tread flexing and the resulting temperatures are greater for a Curved Test Wheel surface than for a Flat Road surface.

Matching the tire's TMPH index to the job's TMPH index prevents tire overheating in service and avoids early tire removal.

Figure 2:

Fig 2: OTR Tire Test Wheel

Objective:

Predict giant tire TMPH Index using Wheel test results and regression modeling to replace slower and more expensive test track procedure.

Experimental Design:

A Paired Design Experiment was used to collect data for Wheel and Road TMPH test results.

Paired Designs blocks most of the uncontrolled experimental variation due to the tire; reduces regression model error; and these simple designs are usually easy to implement in industrial settings. The increased statistical power of a Paired Design is ideal when studying Giant OTR Tires, with usually a limited number of test tires available.

A Paired Design is similar in power to a “One Sample Mean” type of comparison. The means used in this study is the difference between the Flat Road and Curved Wheel OTR tire Temperature and TMPH.

Each Off-the-Road tire was tested both on a Vehicle at a road test track and again on a test wheel. Tire TMPH, Maximum Internal Temperature, and the Ambient Air Temperature where measured for both the Wheel and the Vehicle tests.

Table Number I:

TMPH_Raw1.jmp

12/0 60/0	Tire ID	INF PSI	Field 80% LOAD Lbs	Field MPH	Field DegF	Field AMB	Field TMPH	Wheel 80% LOAD Lbs	Wheel MPH	Wheel DegF	Wheel AMB	Wheel TMPH
1	409	76	12940	11.9	181	69	77.381	12880	6.22	197	90	40.056
2	471	76	12940	11.9	185	69	77.381	12880	6.22	195	90	40.056
3	352	76	12860	11.9	201	61	77.031	12880	4.98	194	85	32.071
4	495	76	12960	11.9	185	61	77.630	12880	4.98	196	83	32.071
5	413	102	90500	7.49	157	60	338.92	90800	3.68	167	83	167.07
6	413	102	90500	9.9	178	63	447.97	90800	3.68	167	83	167.07
7	413	102	90500	7.49	157	60	338.92	90800	6.14	207	81	278.75
8	413	102	90500	9.9	178	63	447.97	90800	6.14	207	81	278.75
9	413	102	90500	7.49	157	60	338.92	90800	7.38	221	83	335.05
10	413	102	90500	9.9	178	63	447.97	90800	7.38	221	83	335.05
• 11	413	102	90500	10.5	182	64	475.12	90800	7.22	223	82	327.78
12	415	102	91300	6.56	149	53	299.46	90800	3.67	163	78	166.61
13	415	102	91300	8.75	171	62	399.43	90800	3.67	163	78	166.61
14	415	102	91300	9.9	179	60	451.93	90800	3.67	163	78	166.61

Table I: Sample Data Table for the TMPH Paired Design Experiment.

Sample Data Table:

The Data Table rows contain 60 Test Runs performed across the 15 individual tires. Tires were tested at the same relative %Load and %Inflation pressures for both the Wheel and Road tests.

This data table contains three tire Sizes and four Designs. Each Row in the table is a test run and represents about 75 test hours each plus the preparation and logistics overhead. These 60 Rows of test runs required about 3 years to complete and cost about $4M.

Table Number II:

SIZE	DESIGN	N
20.5R25	P4	4
37.00R57	L4	17
40.00R57	L3	12
	L4	27
All	All	60

Table II: Tire Sizes and Designs in the Paired Experiment.

Data Limitations:

It is not feasible to expect to accurately model and predict tire TMPH for all tire types from only these 15 tires. Alternatively, even a small random OTR tire sampling and testing program across all OTR tire manufacturers would result in huge experimental costs and would still involve the need to unreliably extrapolate predictions.

Can a modeling approach be developed, using this limited data, that could be useful for additional tire Sizes, Designs, Tread Compounds, and Brands?

Modeling Approach:

Model the Relative Percent Change (Δ%), from the tire's baseline wheel test temperature and TMPH to the tires road temperature and TMPH, rather than attempting to predict an actual tire Temperatures and TMPH.

Assume the curved test wheel effect on tire Temperature and TMPH is relatively constant from the curved wheel baseline to the flat road, for all tires, regardless of Brand, Size, and Design.

Tires tested at a hotter ambient will run hotter than when tested in a cooler environment.
An ambient temperature correction factor is used to adjust tire hot-spot tire temperature measurements to be equivalent to a 100F ambient environment.

Adjust Tire Temperatures based on Ambient Temperature Conditions.

Calculate the Ambient Corrected Wheel DegF_AC and Road DegF_AC:

Ambient Corrected Tire Hot Spot Temperature =

```
IF (DegF <= 100.4, THEN
       DegF + 0.6 * (100.4 - DegF),
ELSE  DegF - 0.6 * (DegF - 100.4))
```

Add the Percent Change (Δ%) Columns to data table:

Add New Variables: Δ% = ((:Field - :Wheel) / :Field) * 100

For: Δ% DegF, Δ% MPH, and Δ% TMPH parameters.

Columns added to the data table for regression modeling:

Table Number III:

Field DegF AC	Wheel DegF AC	Δ% DegF	Δ% Load	Δ% MPH	Δ% TMPH
199.8	203.2	-1.7	0.5	48.0	48.2
203.8	201.2	1.3	0.5	48.0	48.2
224.6	203.2	9.5	-0.2	58.4	58.4
208.6	206.4	1.1	0.6	58.4	58.7
181.2	177.4	2.1	-0.3	50.9	50.7
200.4	177.4	11.5	-0.3	62.8	62.7
181.2	218.6	-20.6	-0.3	18.0	17.8
200.4	218.6	-9.1	-0.3	38.0	37.8
181.2	231.4	-27.7	-0.3	1.5	1.1
200.4	231.4	-15.5	-0.3	25.5	25.2
203.8	234.0	-14.8	-0.3	31.2	31.0
177.4	176.4	0.6	0.5	44.1	44.4
194.0	176.4	9.1	0.5	58.1	58.3
203.2	176.4	13.2	0.5	62.9	63.1
177.4	217.8	-22.8	0.5	6.7	7.2

Table III: Δ% Data Columns Added to Sample Data Table:

The Simple Model

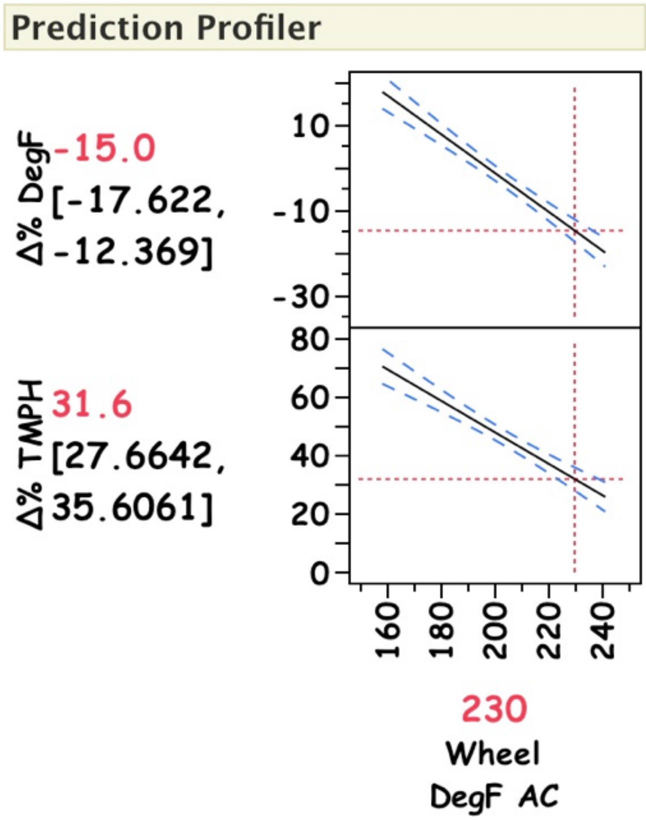
Δ%TMPH and a Δ% DegF as a function of the Wheel DegC_AC (Ambient Corrected)

This model has Δ%TMPH Fit = .67 and a Δ% DegF Fit=.74.

Graphical Snapshot of Regression Models: The Prediction Profiler

The Prediction Profiler is the SAS JMP dynamic graphical embodiment of the regression model. A static snapshot of the model profile below, shows the predicted Δ% change in tire temperature and TMPH from wheel to road conditions, as a function of the tire temperature measured on the test wheel. Prediction variation is minimized when wheel temperatures are measured between 220-240F.

Figure 3:



Prediction Error

~ ±4.0%

~ ±2.5%

The positive aspect of the Simple Model is that only a single model effect, X=Wheel DegC_AC, is the predictor. The Δ%TMPH regression fit is only fair and the prediction error for Δ%TMPH is ±4%.

<u>The Optional Model:</u>

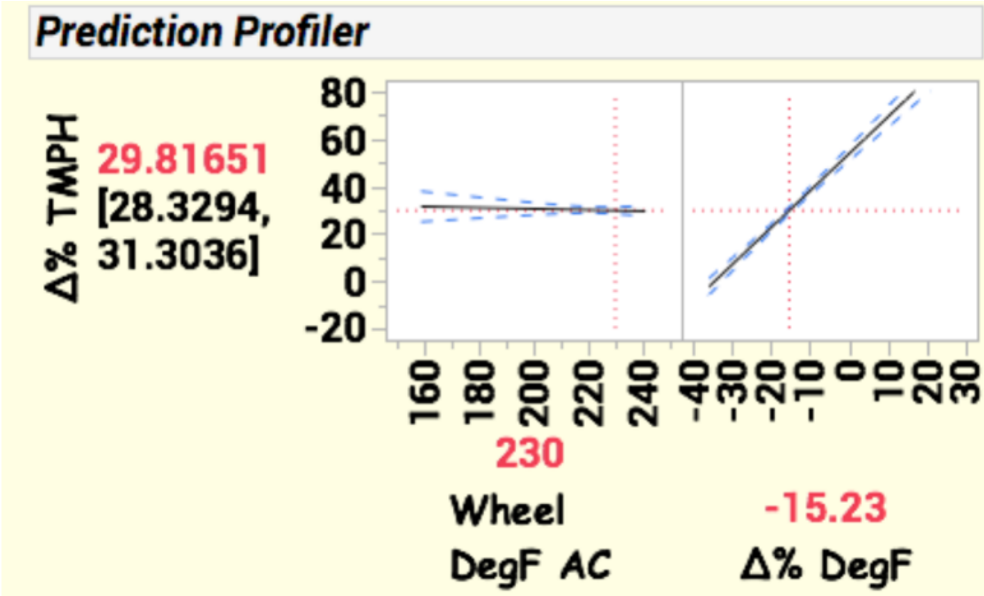
Δ%TMPH is a function of X: Wheel DegF_AC & Δ% DegF_AC

This model has Δ%TMPH Fit = 96, with reduced model error vs. the Simple Model.

<u>Graphical Snapshot of Regression Model: The Prediction Profiler</u>

The Prediction Profiler is the SAS JMP dynamic graphical embodiment of the regression model. The static snapshot below shows the predicted Δ% change in TMPH from wheel to road conditions, as a function of the tire temperature measured on the test wheel. The approximate prediction error is ±1.5% at the selected 230F wheel temperature as shown below.

Figure 4:



~±1.5%

The positive aspects of Optional Model include a better fit, with a lower predictive error of ±1.5%. An estimate of the Δ%DegF is required as input to this model. Estimating Δ% DegC correctly is critical to avoid tire overheating.

The targeted safe operating tire temperature for this dataset was approximately 203F or 95C. The Optional Model allows the Δ%DEGF to be input into the Prediction Profiler to allow for different tire safe operating temperature targets.

Summary

A paired design experiment was described, which compared tire TMPH and Temperature performance when tested on both a flat road surface and a curved test wheel.

The dataset is small, costly, and required a paradigm shift to model the percent change (Δ%) in TMPH and tire temperature from Wheel to Road. The paradigms shift to Δ% parameters provided a more generally applicable model to predict tires TMPH on vehicles with the assumption that the test wheel curvature effect from curved to flat is relatively constant as a percentage of the baseline wheel test.

The Optional Model provides for the input of the Δ% Temperature parameter. This approach improves to the Δ%TMPH prediction accuracy while allowing the modeling of different tire safe operating temperature targets.

Conclusions

OTR TMPH Wheel Test measurements can predict Road TMPH performance.