WHEEL FLANGE LUBE BENEFITS

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WRI2025HH

HEAVY HAUL - JUNE 11-12, 2025

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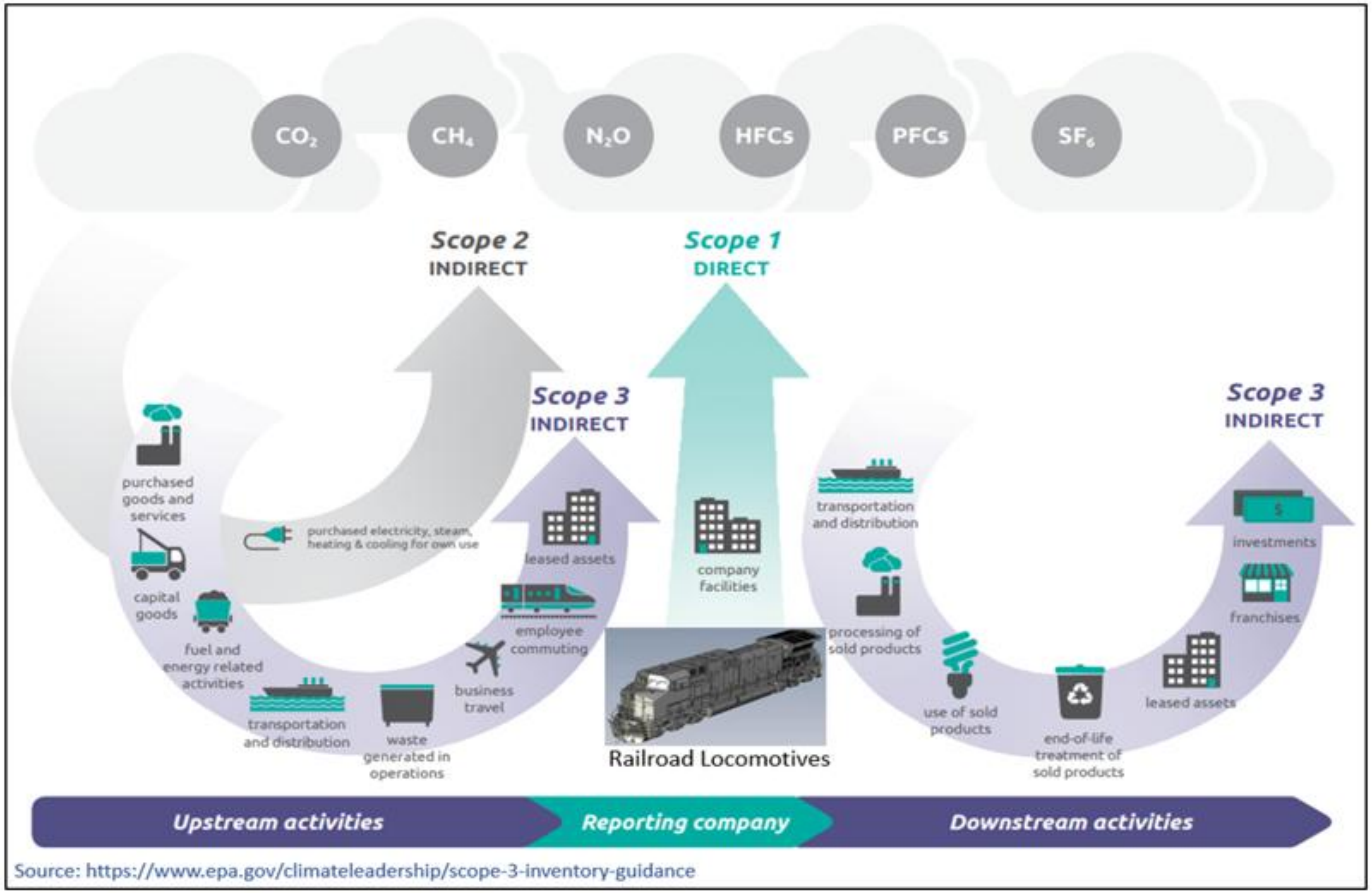
SCIENCE BASED TARGETS

10572 Total no. of companies with targets or commitments	7810 Companies with validated targets
1764 Companies with net-zero targets	2997 Companies with active commitments

The Science Based Targets initiative (SBTi), the global body enabling businesses to set emissions reduction targets in line with climate science, is unveiling a new strategy to increase minimum ambition in corporate target setting from ‘well below 2°C’ to ‘1.5°C’ above pre-industrial levels.

Railroads set SBTi goals in the 2018 timeframe and have all set very aggressive goals to reduce GHG emissions by 2030 and some even have net-zero goals by 2050

EMISSIONS INVENTORY



SCOPE 1

Direct emissions from owned sources

SCOPE 2

Indirect emissions from purchased services

SCOPE 3

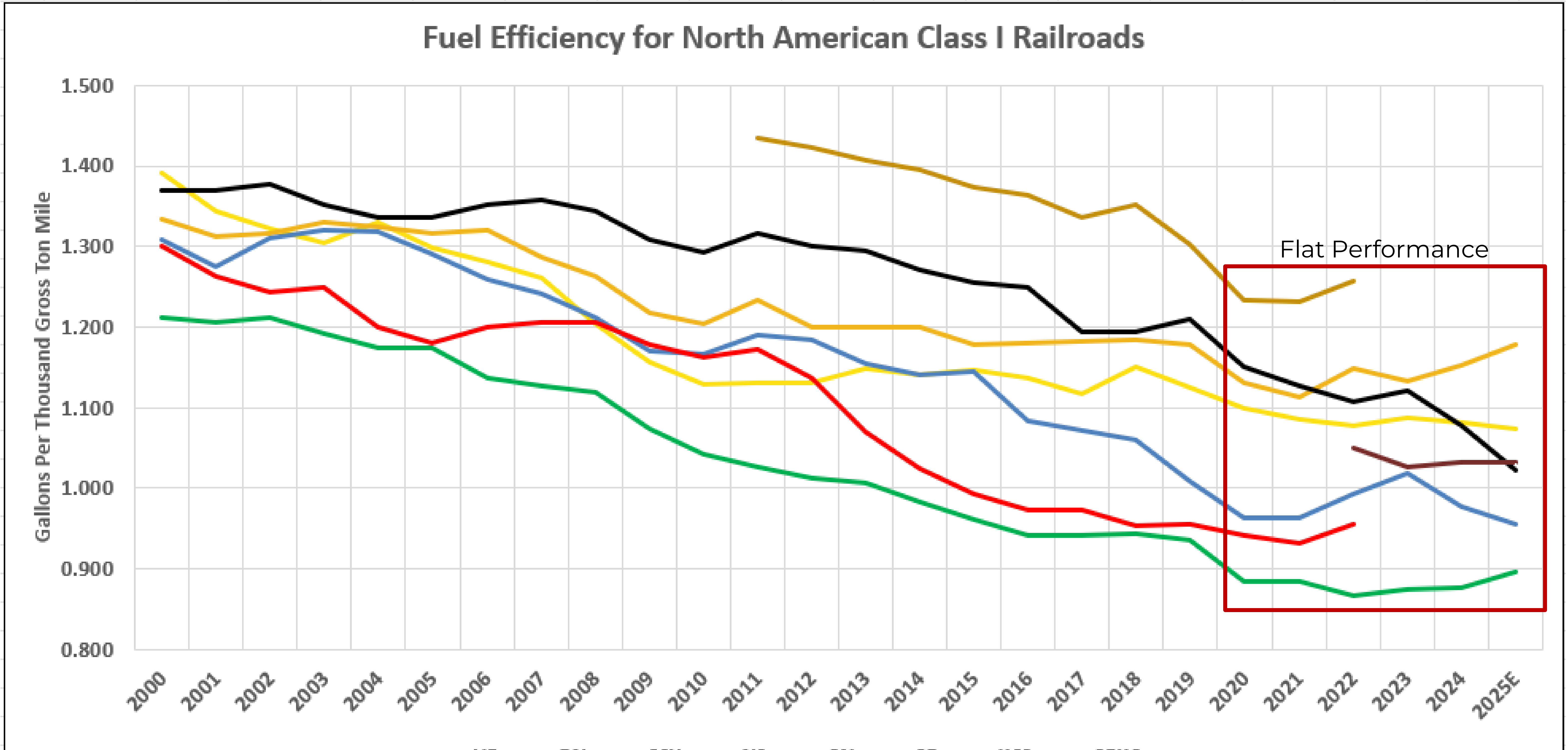
All other indirect emissions from value chain

CLASS I RAILROAD GOALS

Company Name	Full target language	Company Temperature	Scope	Target Value	Type	Base Year	Target	Date Published
BNSF Railway	BNSF Railway commits to reduce absolute scope 1 and 2 and well-to-wheel locomotive GHG emissions 30% by 2030 from a 2018 base year*. *The target boundary includes biogenic emissions and removals from bioenergy feedstocks.	Well-below 2°C	1+2	30%	Absolute	2018	2030	2023-05-25
Canadian National Railway Co	CN commits to reduce scope 1 and 2 GHG emissions 43% per gross ton miles by 2030 from a 2019 base year*. CN commits to reduce scope 3 GHG emissions from fuel and energy related activities 40% per gross ton miles by 2030 from a 2019 base year. *The target boundary includes biogenic emissions and removals from bioenergy feedstocks.	Well-below 2°C	1+2	43%	Intensity	2019	2030	2021-07-21
CSX Corporation	CSX commits to reduce scope 1 and 2 GHG emissions intensity 37% per million gross ton miles by 2029 from a 2014 base year.	Well-below 2°C	1+2	37%	Intensity	2014	2029	2020-01-01
Norfolk Southern Corporation	Norfolk Southern commits to reduce scope 1 and 2 GHG emissions 42% per million gross ton-miles (MGTM) by 2034 from a 2019 base year*. *The target boundary includes biogenic emissions and removals from bioenergy feedstocks.	Well-below 2°C	1+2	42%	Intensity	2019	2034	2021-07-29
Union Pacific Corporation	Union Pacific commits to reduce absolute scope 1 and 2 GHG emissions 50.4% by 2030 from a 2018 base year.* Union Pacific also commits to reduce scope 3 GHG emissions from purchased goods and services, capital goods, and fuel and energy-related activities 50.4% within the same timeframe. *The target boundary includes land-related emissions and removals from bioenergy feedstocks.	1.5°C	1+2	50%	Absolute	2018	2030	2024-03-28
CPKC	CPKC commits to reduce scope 1, 2, and 3 well-to-wheel locomotive GHG emissions 36.9% per gross ton-miles by 2030 from a 2020 base year.	Well-below 2°C	1+2+3	37%	Intensity	2020	2030	2023-11-23

Various Goals, Types and Scopes for Each Railroad – All Very Aggressive

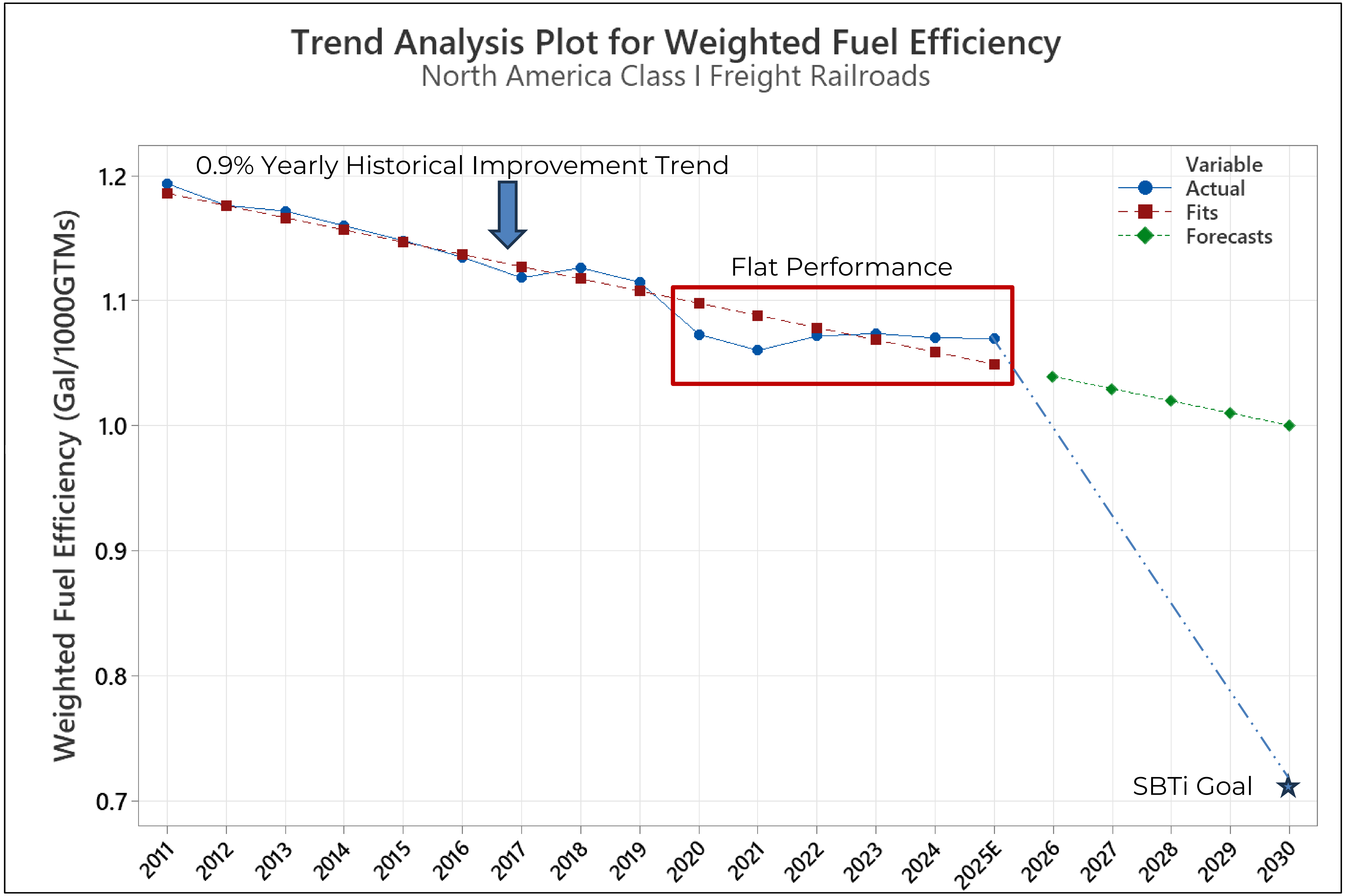
HISTORICAL FUEL EFFICIENCY



Source: Year End Railroad Quarterly Reports

Gradual Improvement Though Flat Performance Since 2020 Post PSR Dip

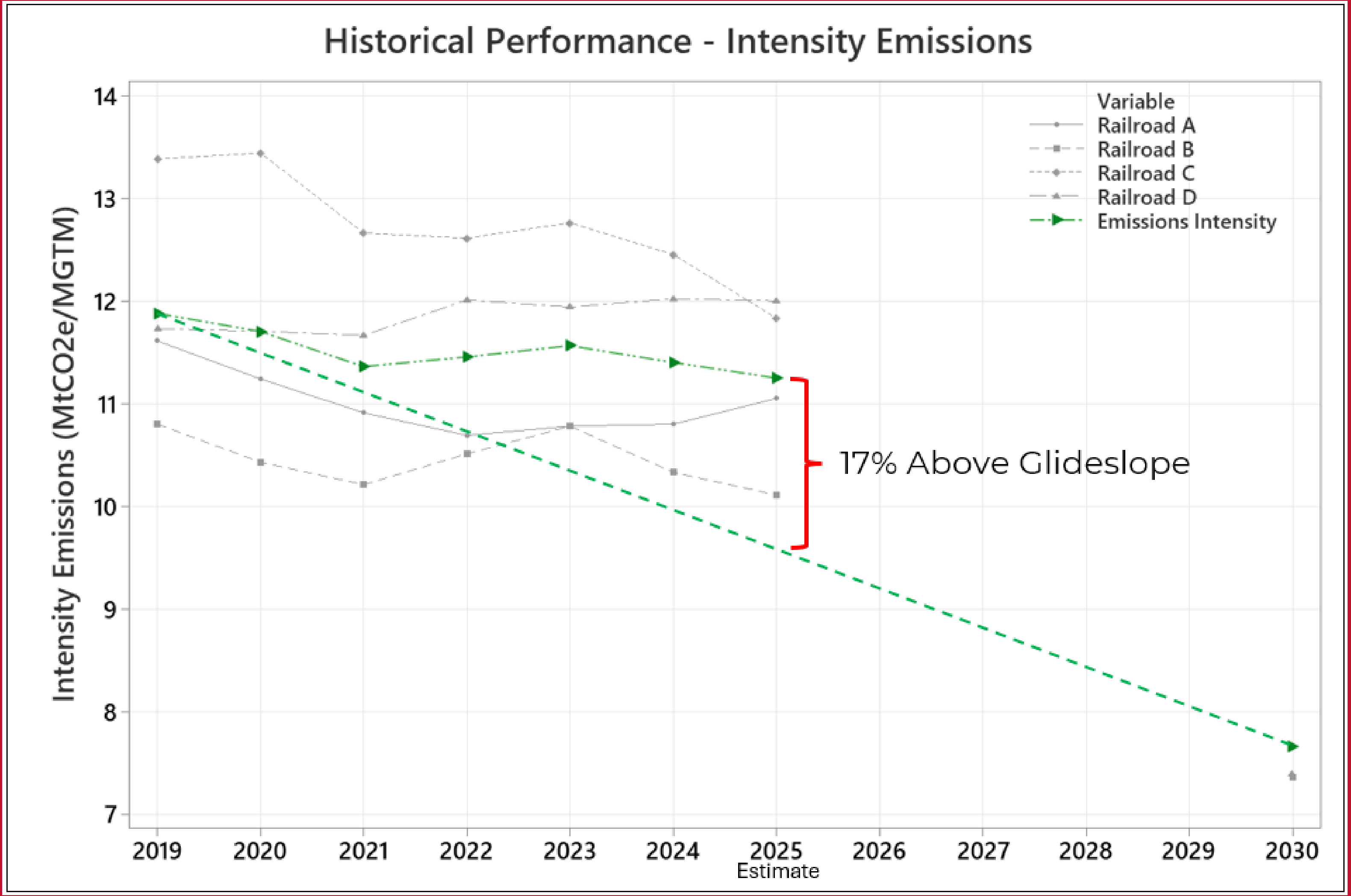
CLASS I INDUSTRY TREND TO 2030 GOAL

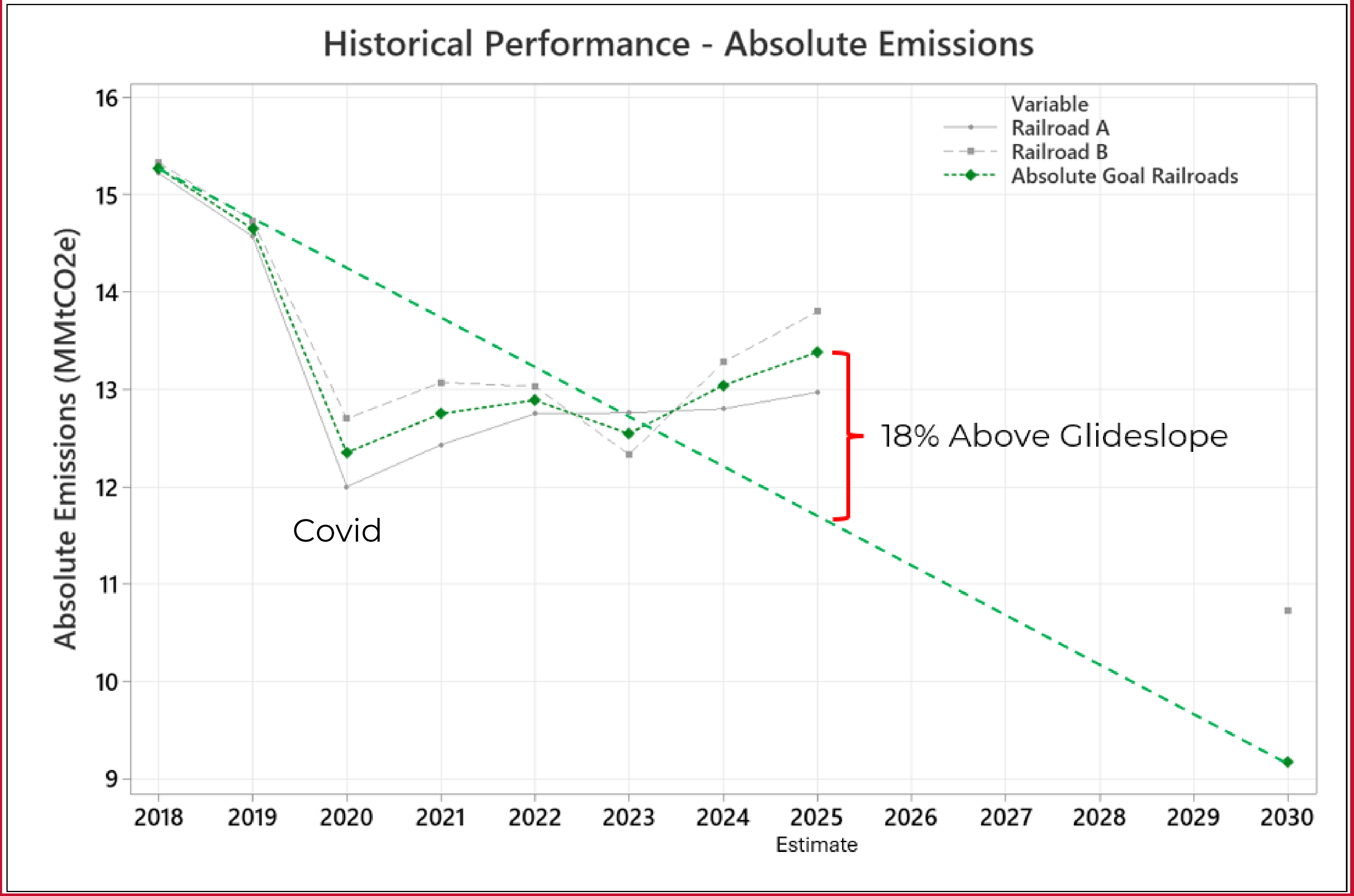


- Weighted industry average shows a very gradual improvement likely due to newer more fuel efficiency locomotive power
- 2020 was the post-PSR effect of storing power and lowering HPTT (Horsepower Per Trailing Ton) with longer trains
- The last five years has seen flat performance overall and if the SBTi goal was pure fuel efficiency, it would be almost impossible to achieve by 2030

Performance Has Flattened Out Since 2020

SBTI PERFORMANCE TO-DATE



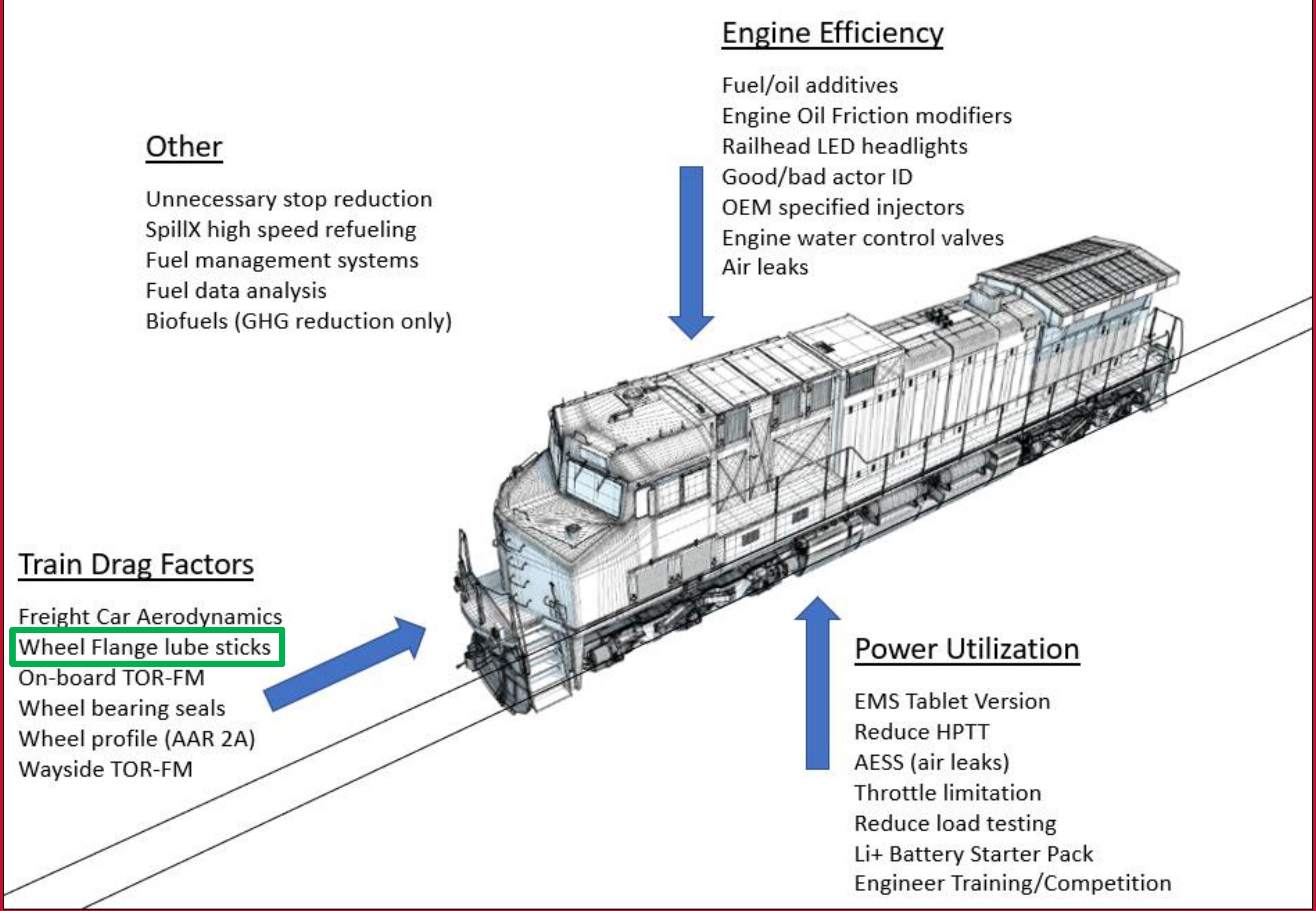


Recent Years Have Seen Degradation to Glideslope
Future Gains Will Become More Challenging

Initial Traffic Volume Drop Has Now Reversed
As Volumes Begin to Slowly Return

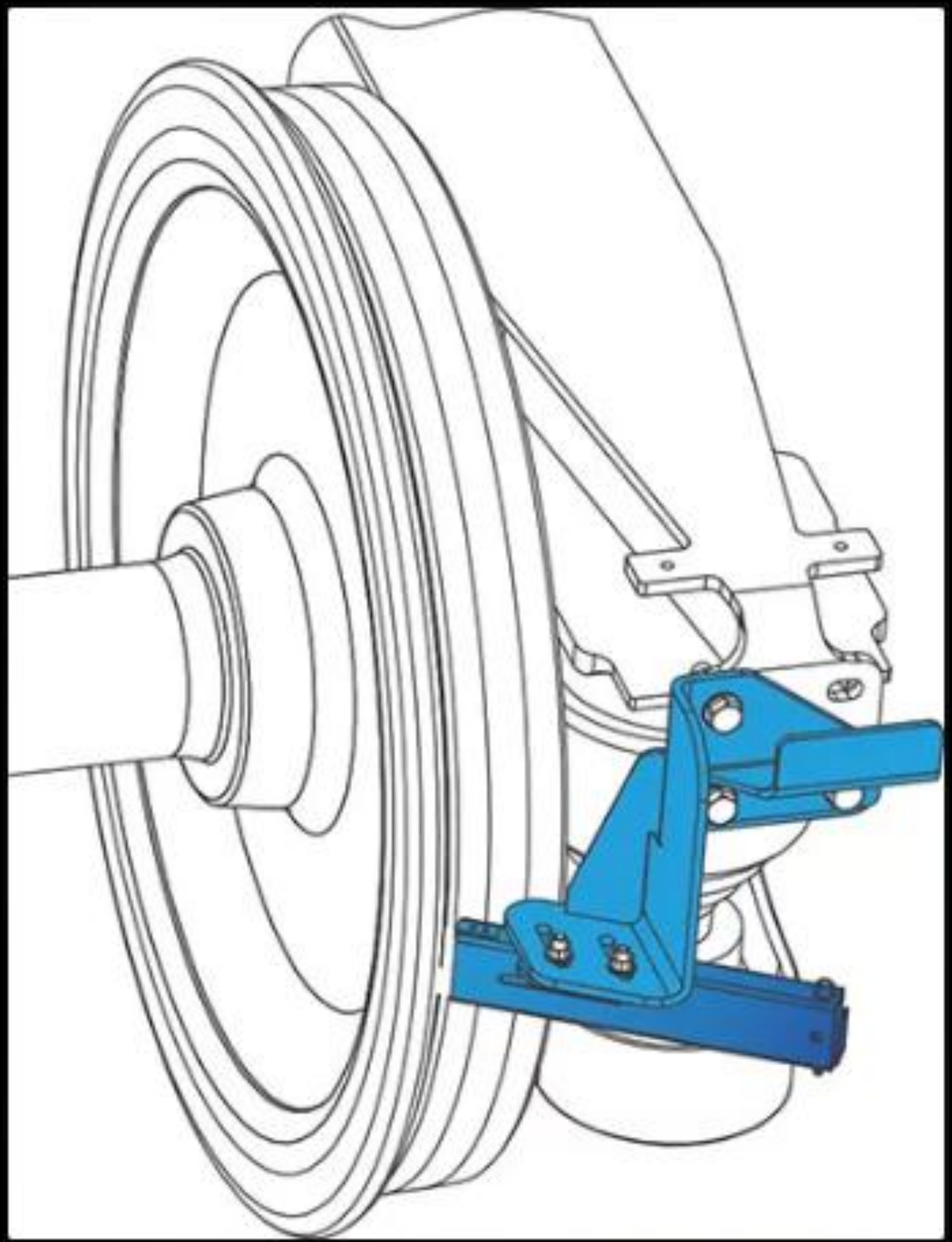
Both Intensity and Absolute Goal Type Railroads Seem Challenged to Meet 2030 Goals

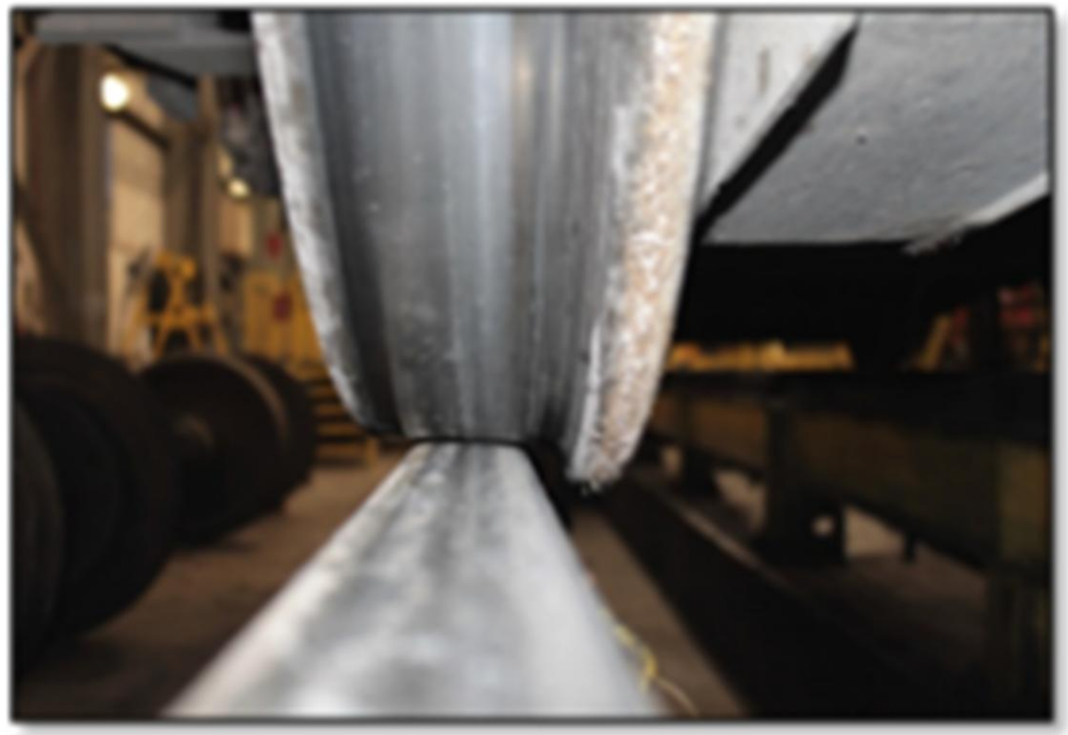
FUEL SAVING TECHNOLOGIES

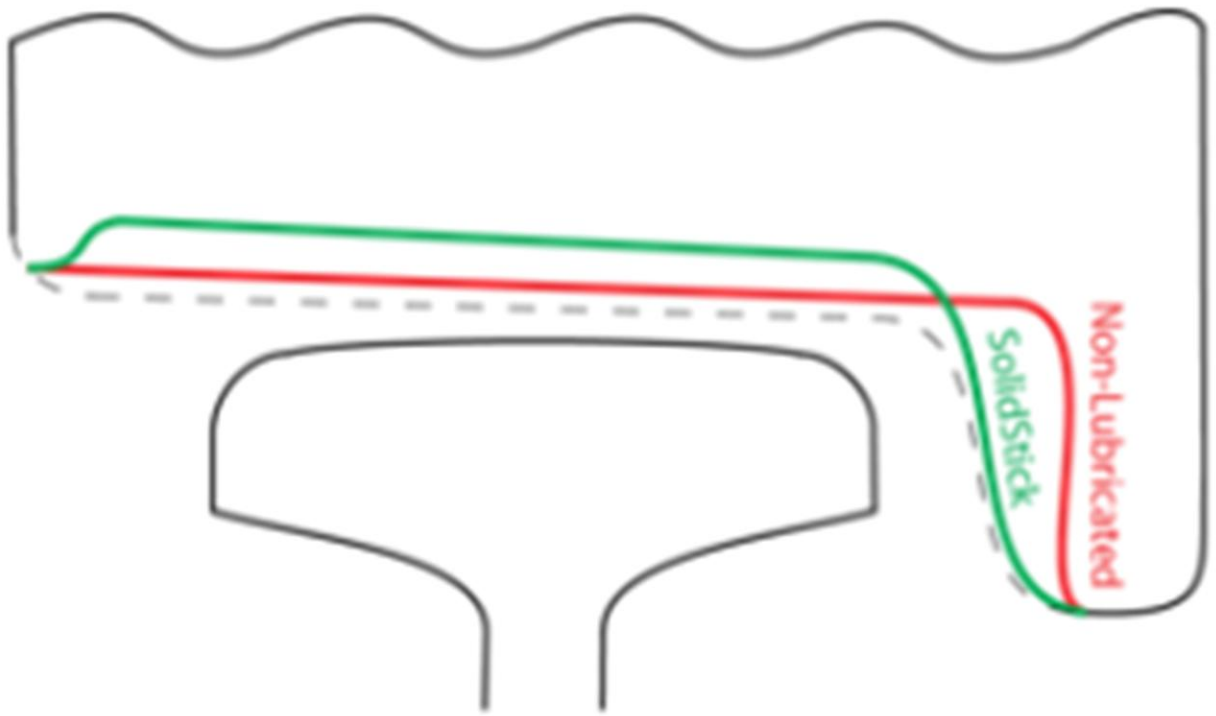


- Many of these technologies are in either low or no levels of adoption
- An inability to validate fuel savings is often the reason why
- High end statistical methods exist to tease out low levels of fuel savings

SOLID STICK FLANGE LUBRICATION







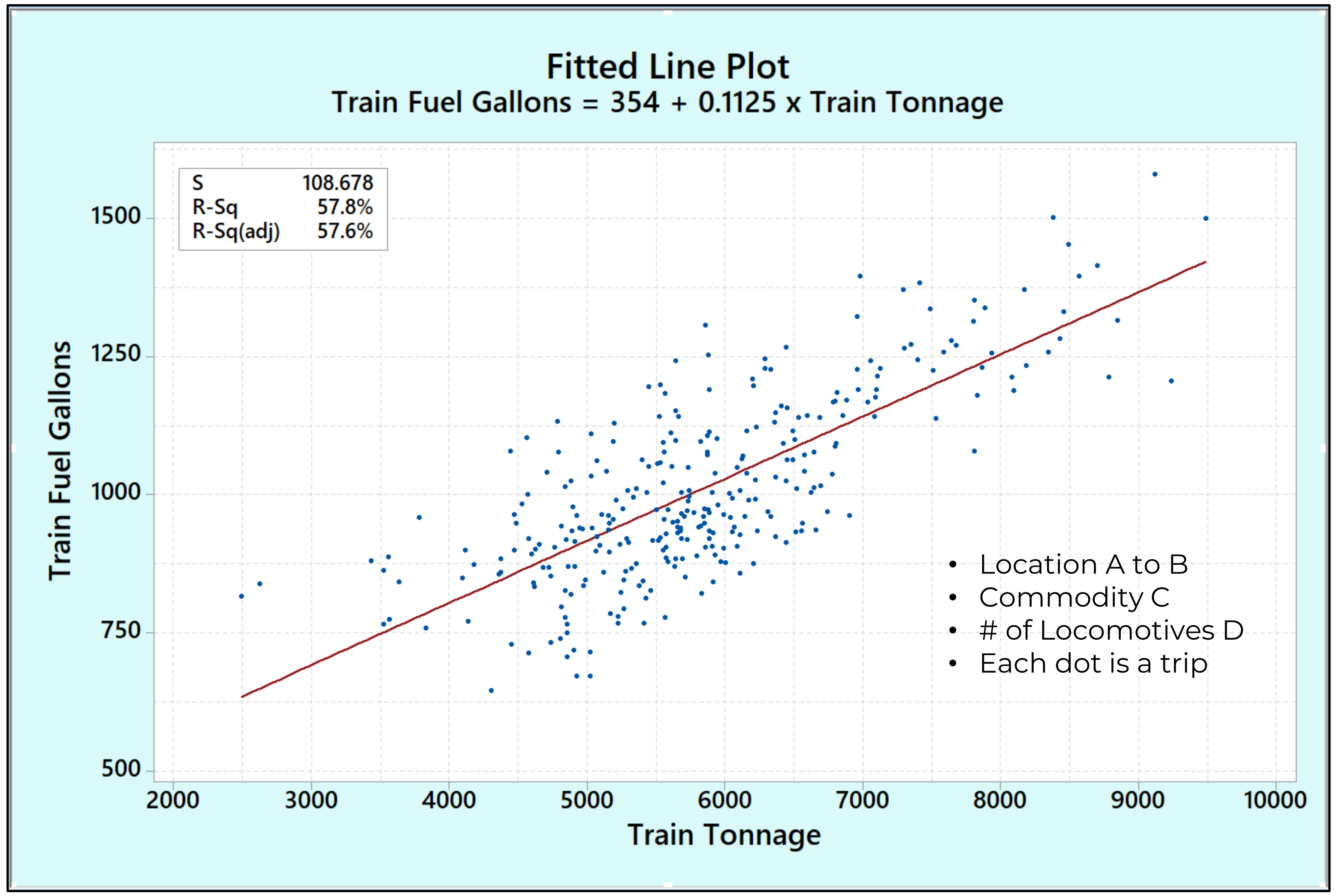
- Reduces friction and wear between locomotive wheels and the rail, extending life and reducing cost
- Reduces fuel consumption and lowers coupler forces thus enhancing safety
- Environmentally friendly, often biodegradable and renewable, lowers maintenance costs and decreases noise levels

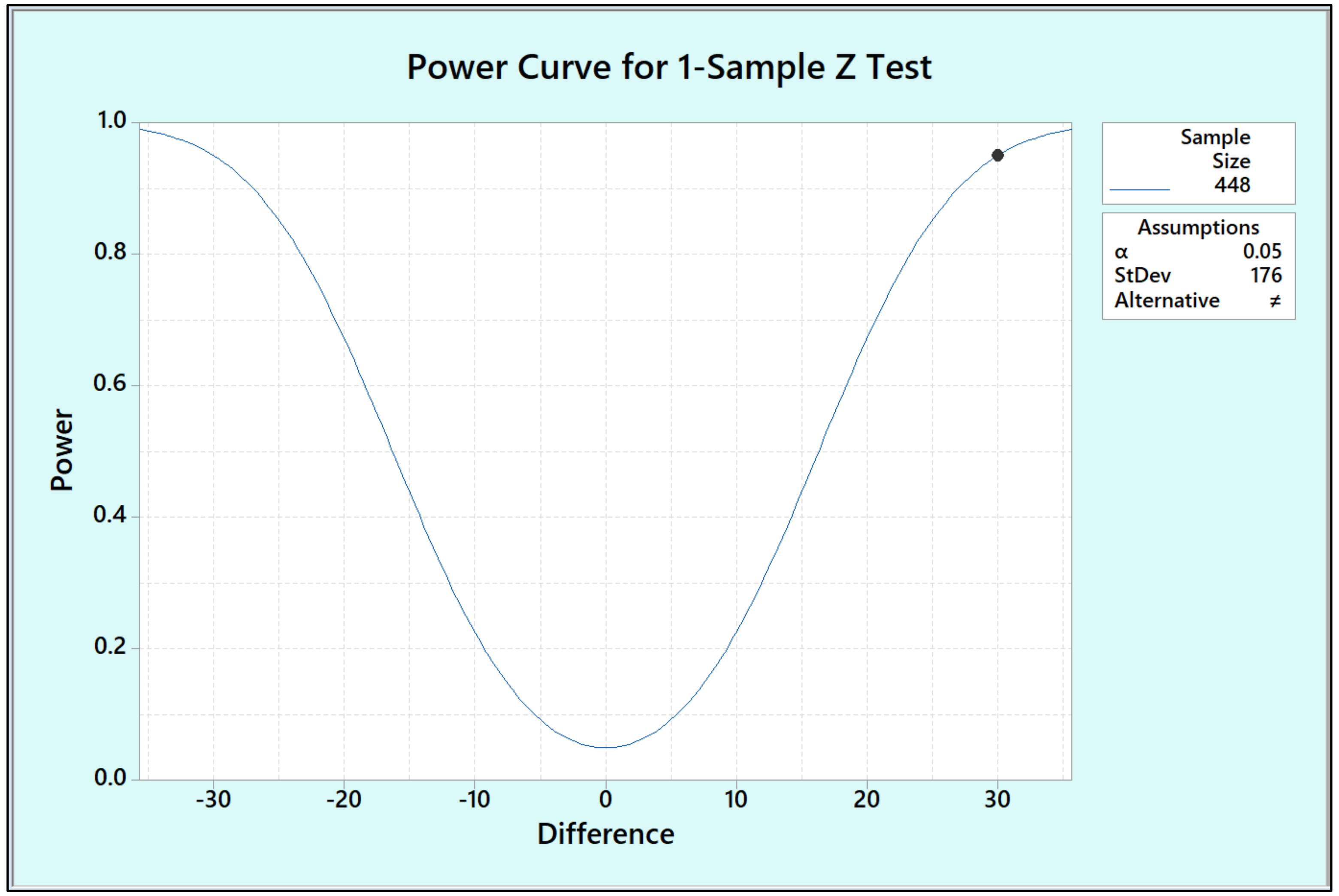
FUEL MEASUREMENT

Fuel consumption is highly variable due to numerous factors such as:

- Train length
- Train weight
- Commodity type
- Horsepower-Per-Trailing-Ton (# locomotives)
- Topography or terrain
- Train Speed and aerodynamic losses
- Locomotive engineer skill level
- Locomotive condition
- Condition of cars on train
- Track and ballast condition
- Episodic events
- Congestion
- Weather
- Location

A common measure of <u>fuel efficiency</u> is needed that can account for many of the variables listed above





Segment Data

Trip fuel consumption (engineer on/off) is the preferred method

Regression

Within each classification, regress fuel against train tonnage

Sample Size

Depending on the mean and SD, you assess how many trips are needed to identify a specific % in fuel savings

REVENUE TESTING

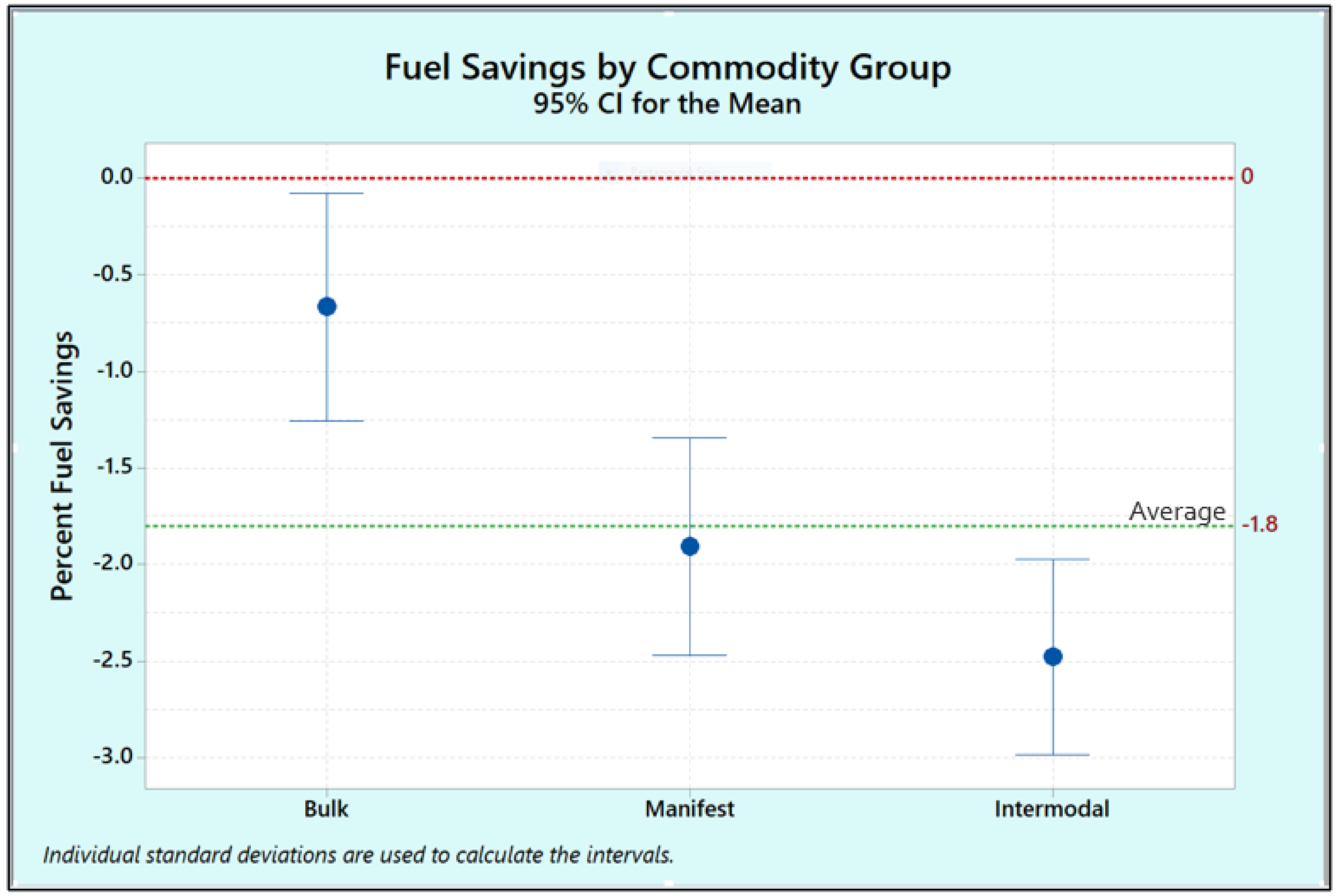
Logistic-regression model using 500,000 trip segments with half of fleet equipped, a 1-year test duration

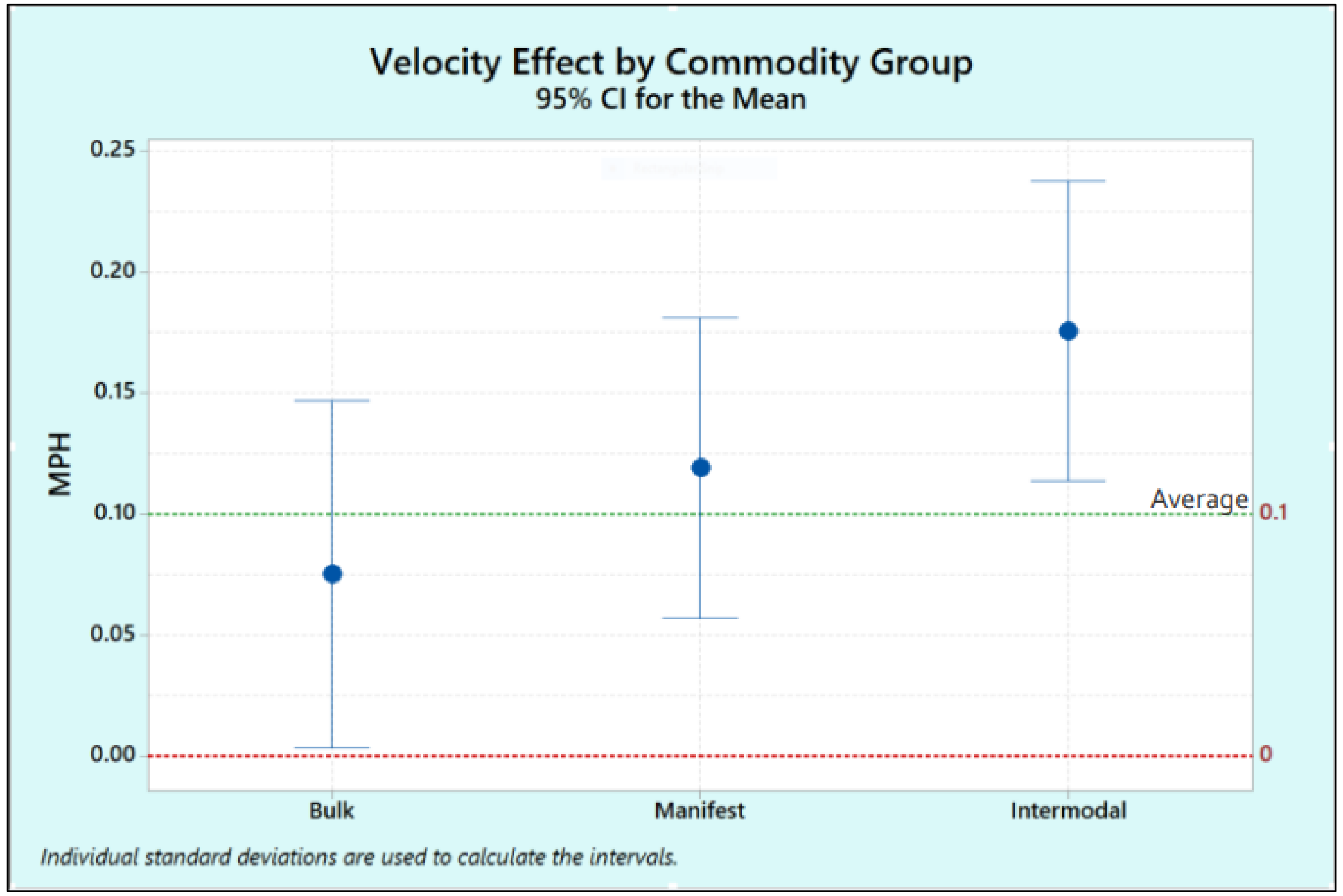
Dependent Variables:

- Fuel consumption G/KGTM
- Train velocity in MPH

Independent Variables:

- Train equipped (Y/N)
- Multiple locos equipped (Y/N)
- Train commodity group
- Horsepower per trailing ton
- Train tonnage and length
- Distributed Power (Y/N)
- Segment route miles
- Wind speed





Commodity

Light / fast show higher savings with heavy / slow show less

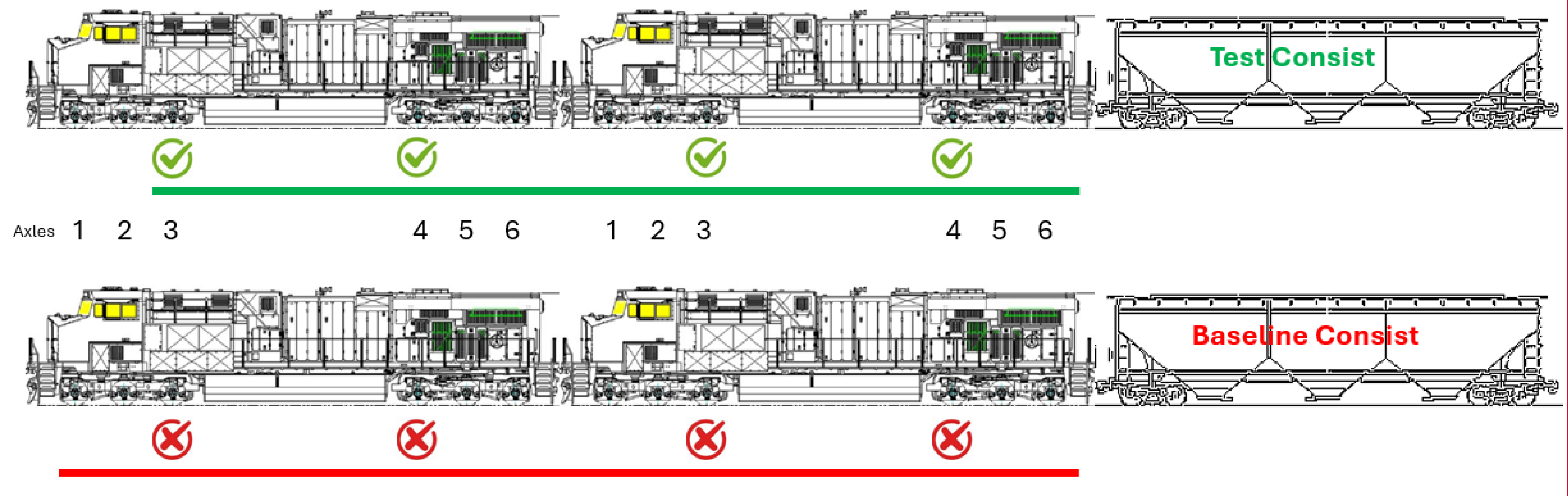
Interval Plot

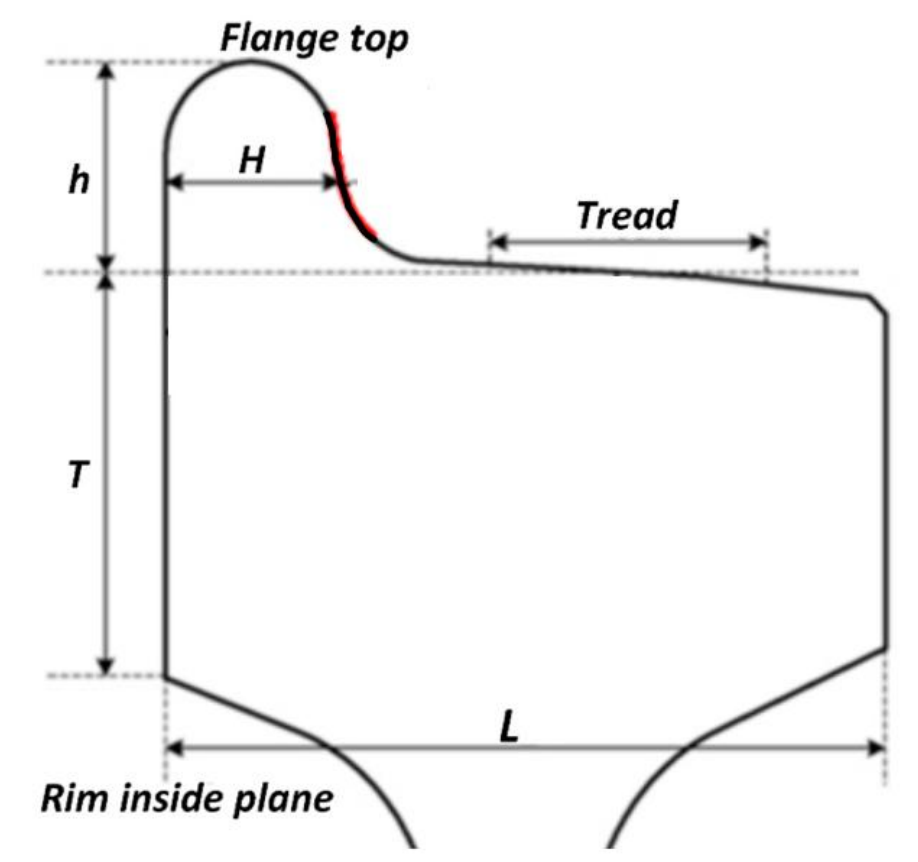
Model shows consistent savings, reasonable intervals

Velocity

Moderate speed improvement, which is an intuitive finding

WHEEL WEAR TEST SETUP





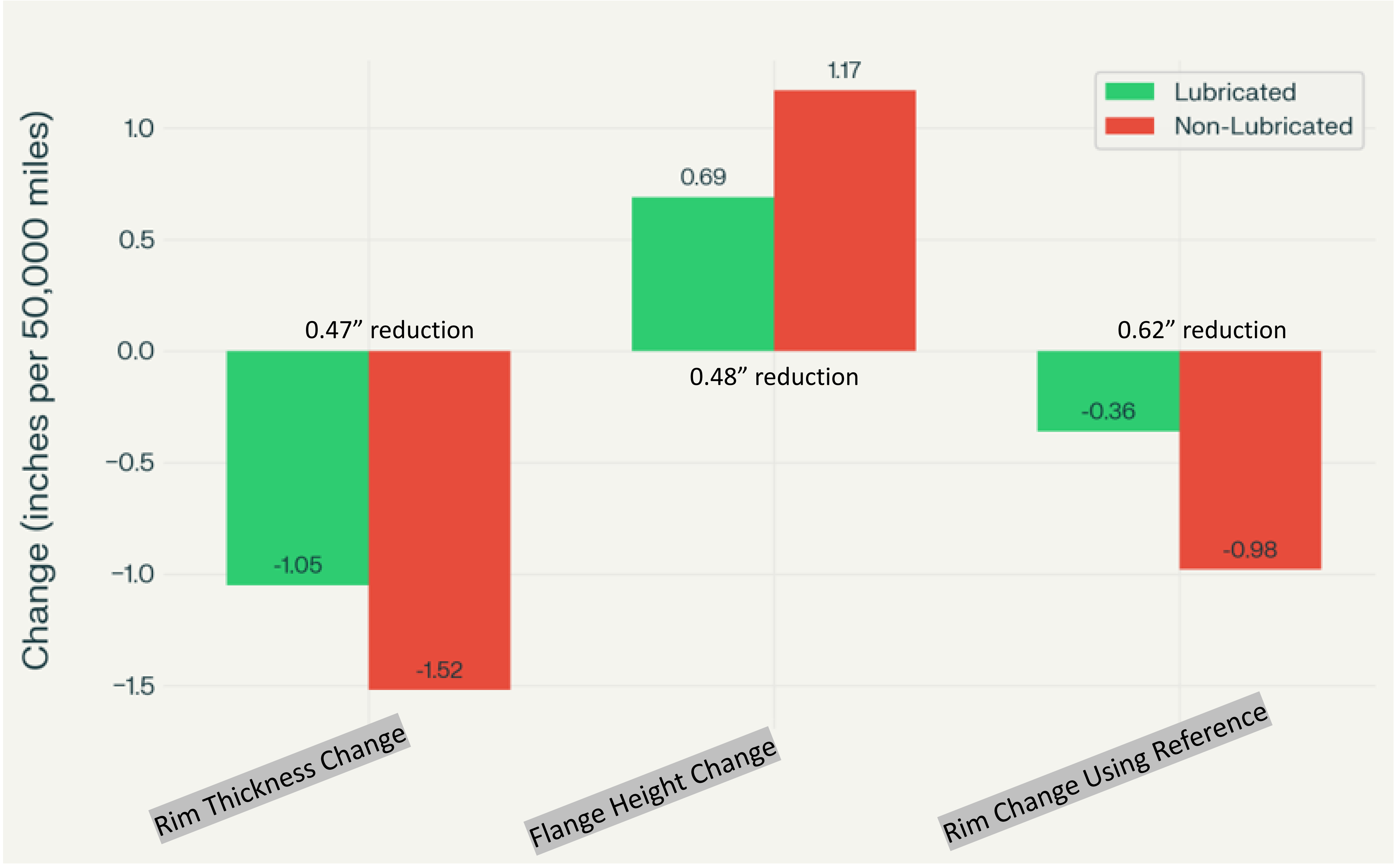
- Test duration was six months
- Two consists pulling on the same route hauling the same commodity
- Static locomotive location in consist
- Average of wheel wear on 10 test axles (post application) and 12 baseline axles (no lubrication applied)
- Applicators located on axles 3 and 4

Both test and baseline trains operated on same heavy haul coal route with locomotives static

An electronic wheel measurement gauge was used to measure all locomotive wheels

Rim thickness (r), flange height (h) and tread to reference groove distance (as a secondary check on rim thickness) were measured at the start and end of the test

WHEEL WEAR TEST RESULTS



- Rim thickness change shows good extension of wheel life and reduced truing maintenance required
- Flange height reduction also shows good life extension and decreased derailment risk
- A very large decrease in reference groove distance preservation which would increase wheel life longevity significantly

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FUEL SAVINGS ANALYTICS

PUEBLO TESTING

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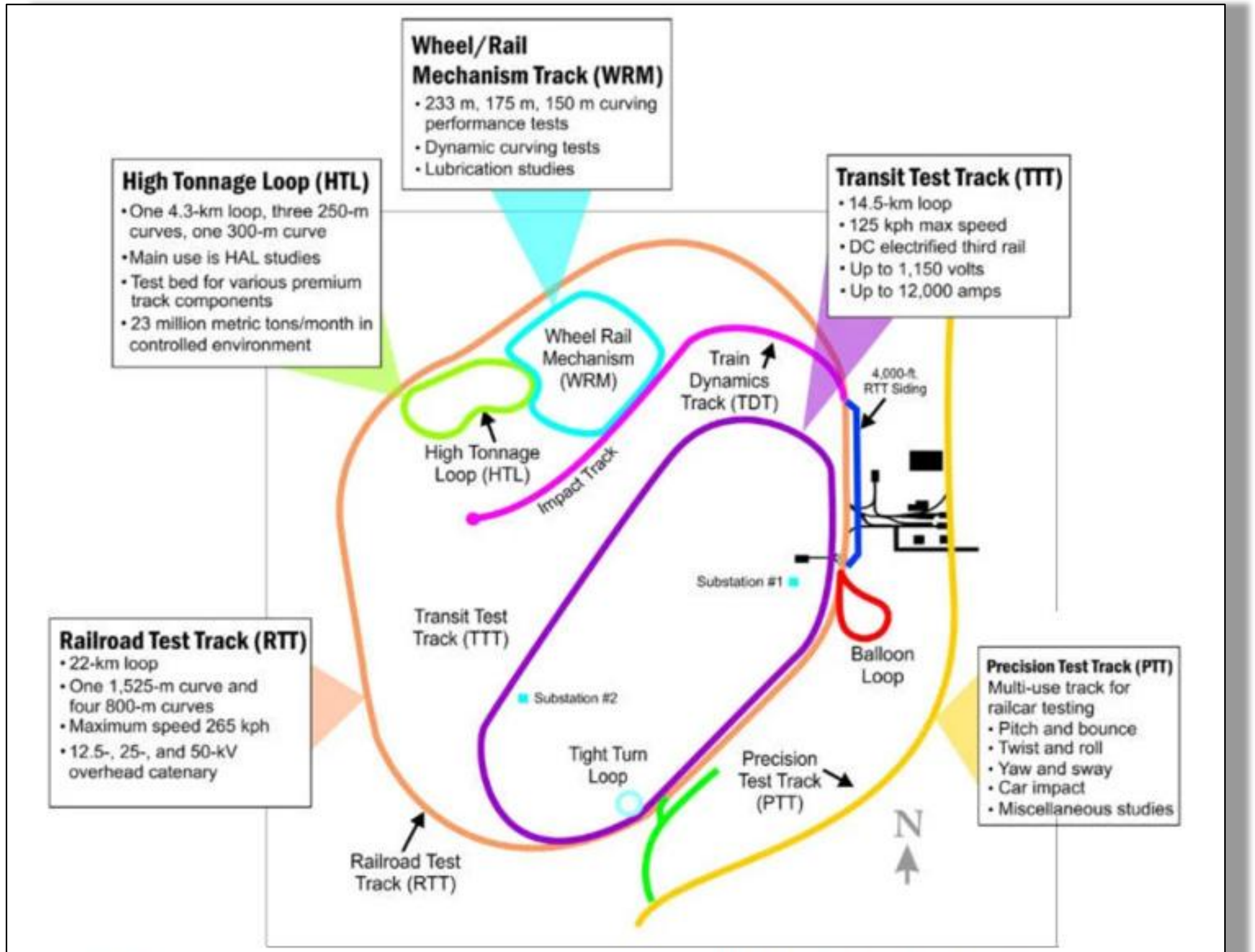
Locomotive Wheel Flange
Solid Stick Lubrication

TESTING: CLOSE TO REAL WORLD

Theme

Rigorous, statistical analysis of data generated from tests



2012 Wheel Rail Mechanism Loop (WRM)

- Target Speed: 30 MPH
- Consist: Two locomotives and thirty hopper cars
- Trailing Tonnage: 4696
- 3.5 mile loop
- 12, 10, 7.5, 5, 4, and two 3 degree curves

2014 Transit Test Track (TTT)

- Target Speed: 50 MPH
- Consist: Two locomotives and thirty hopper cars
- Trailing Tonnage: 4625
- 9.1 mile oval loop
- Mostly tangent rail, with one 0.5 degree and two 0.5 degree curves

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COMPRESSIVE DATA ANALYSIS AND FORMAL STATISTICAL TESTING

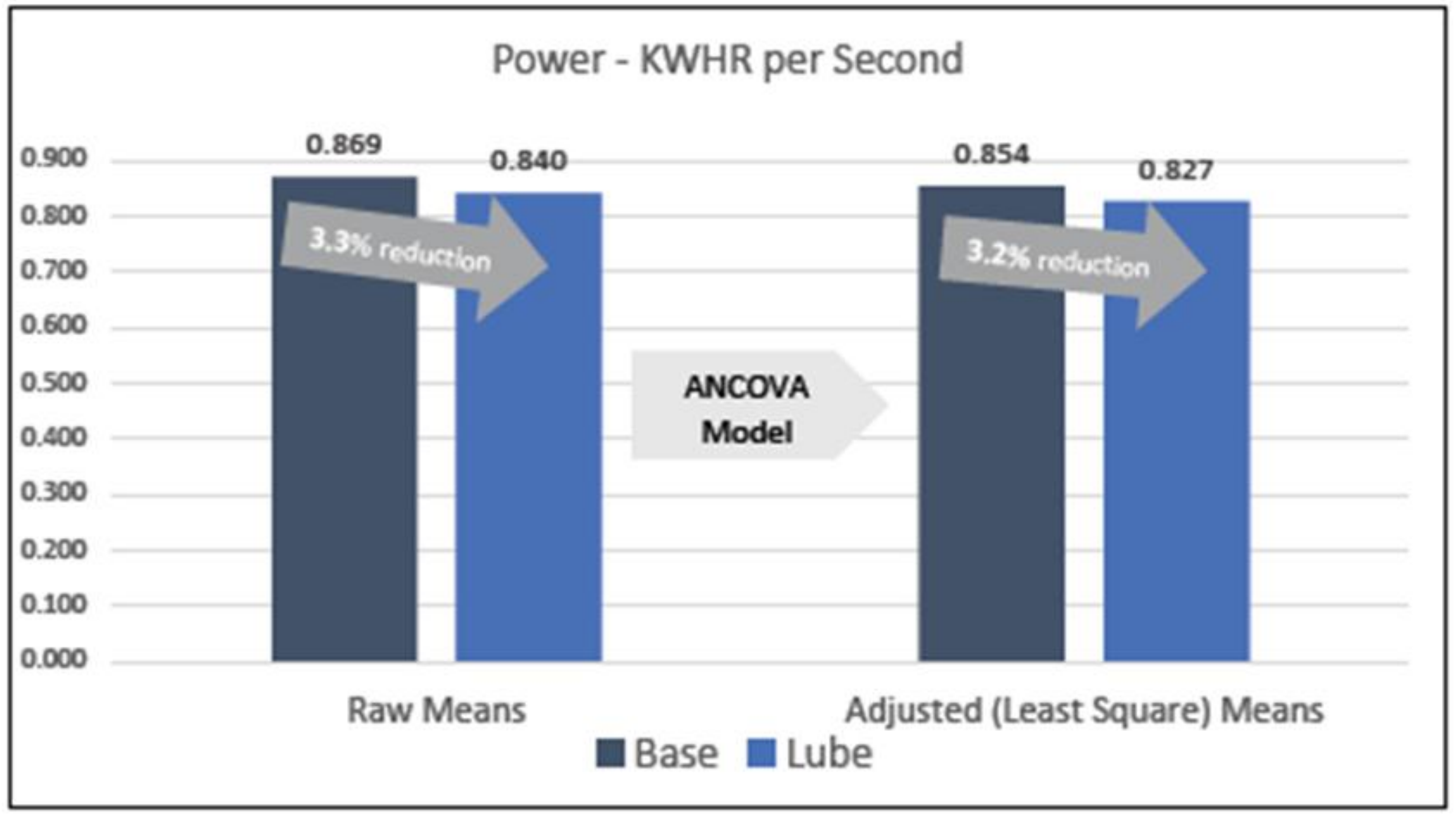
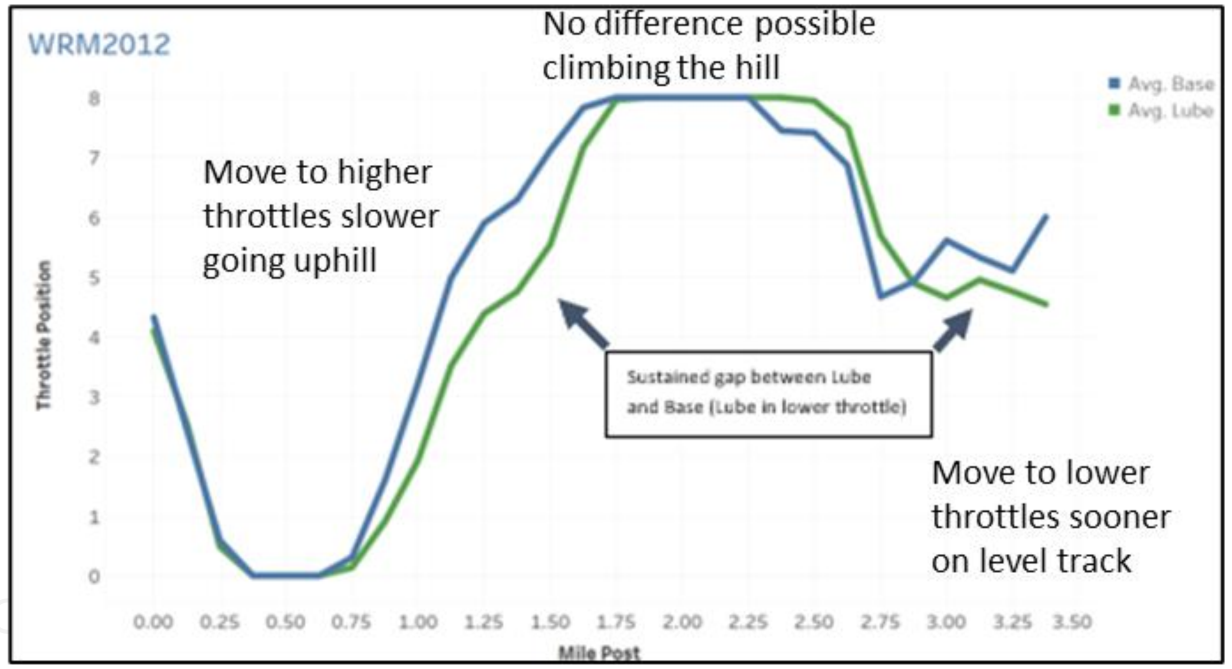


Figure 9 – Comparison of Means, Base versus Lubricated



Energy savings increases as the degree of curvature increases due to flanging

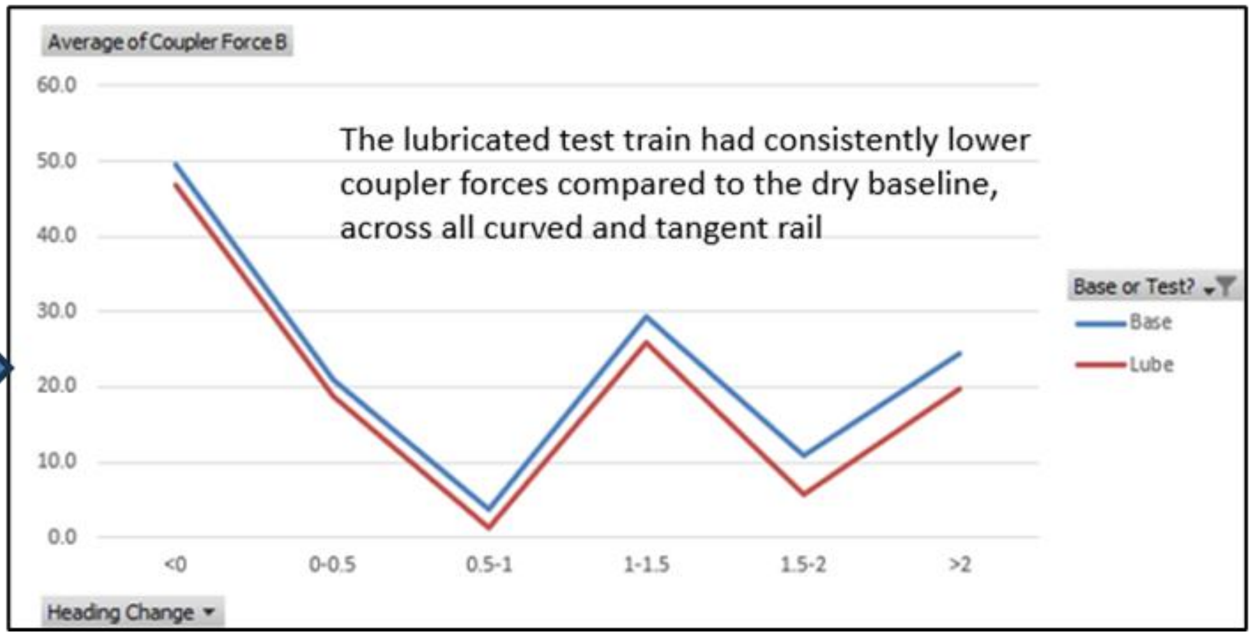
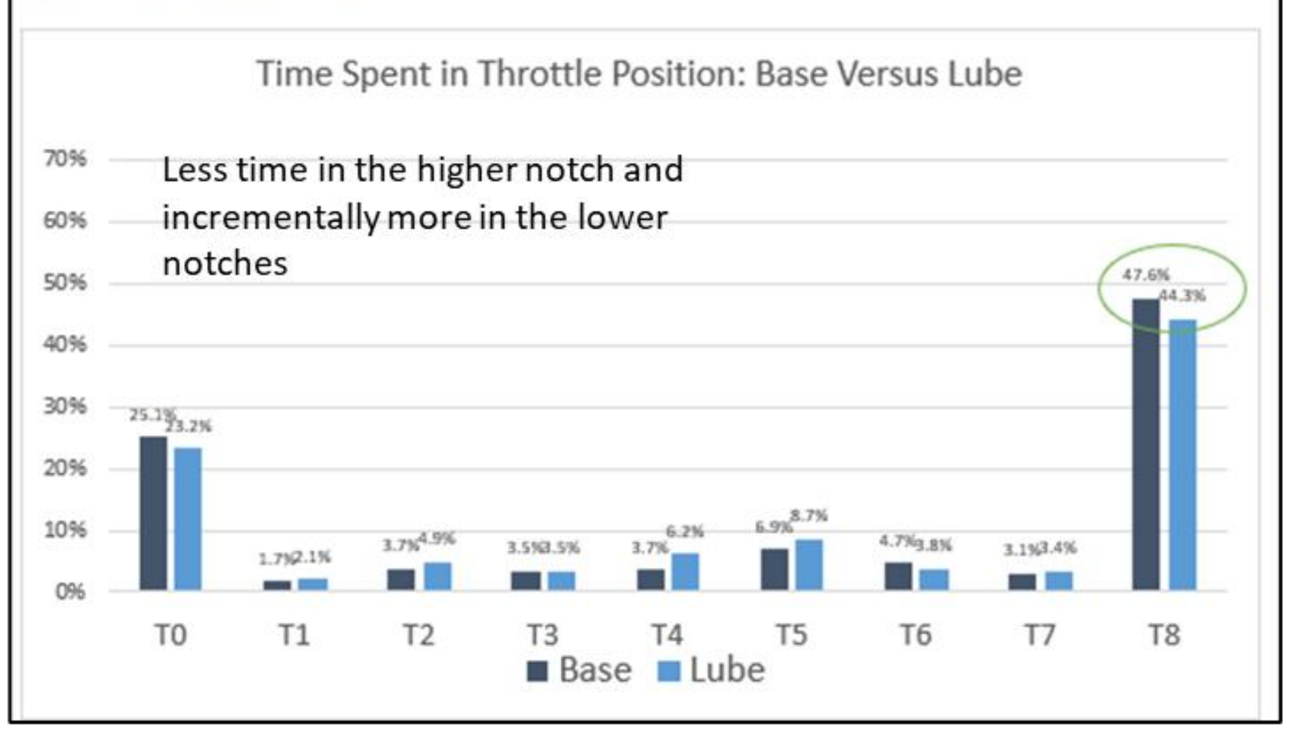


Figure 5 - Time Spent in Throttle Position



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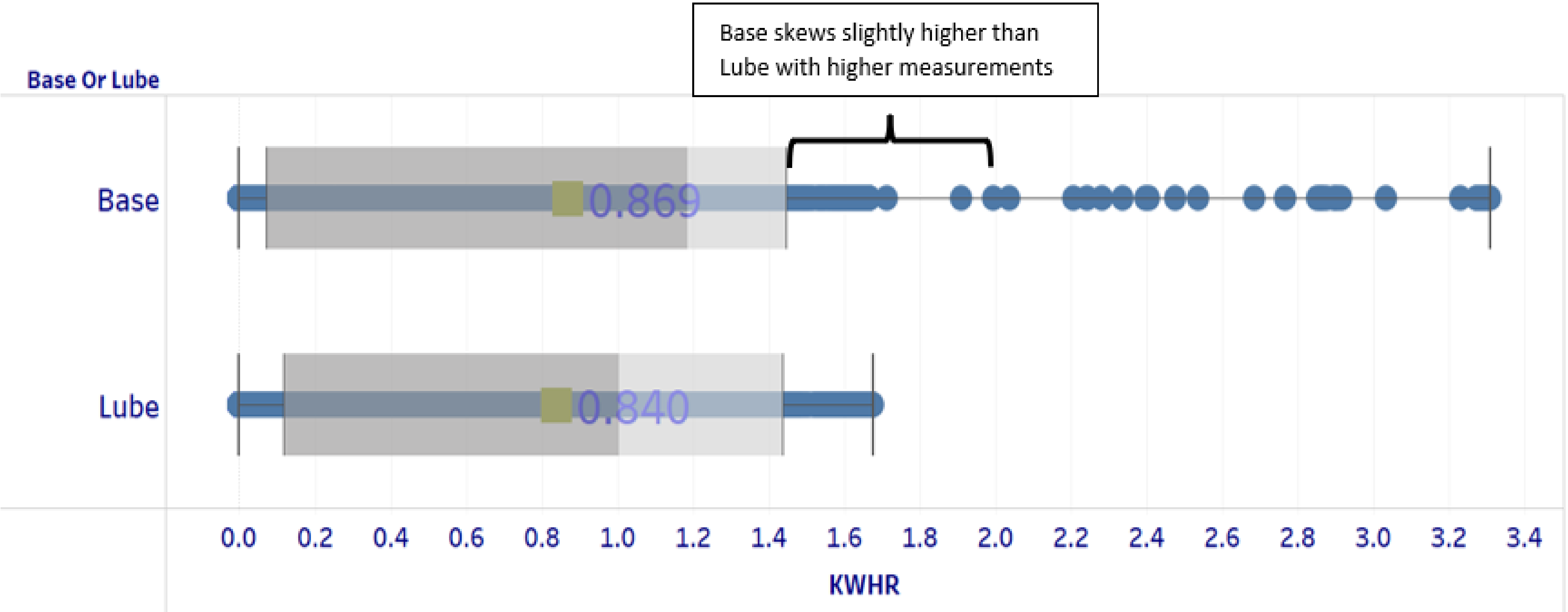
UNDERSTANDING VARIATION IS KEY

"The central problem in management and leadership is failure to understand the information in variation." — W. Edwards Deming

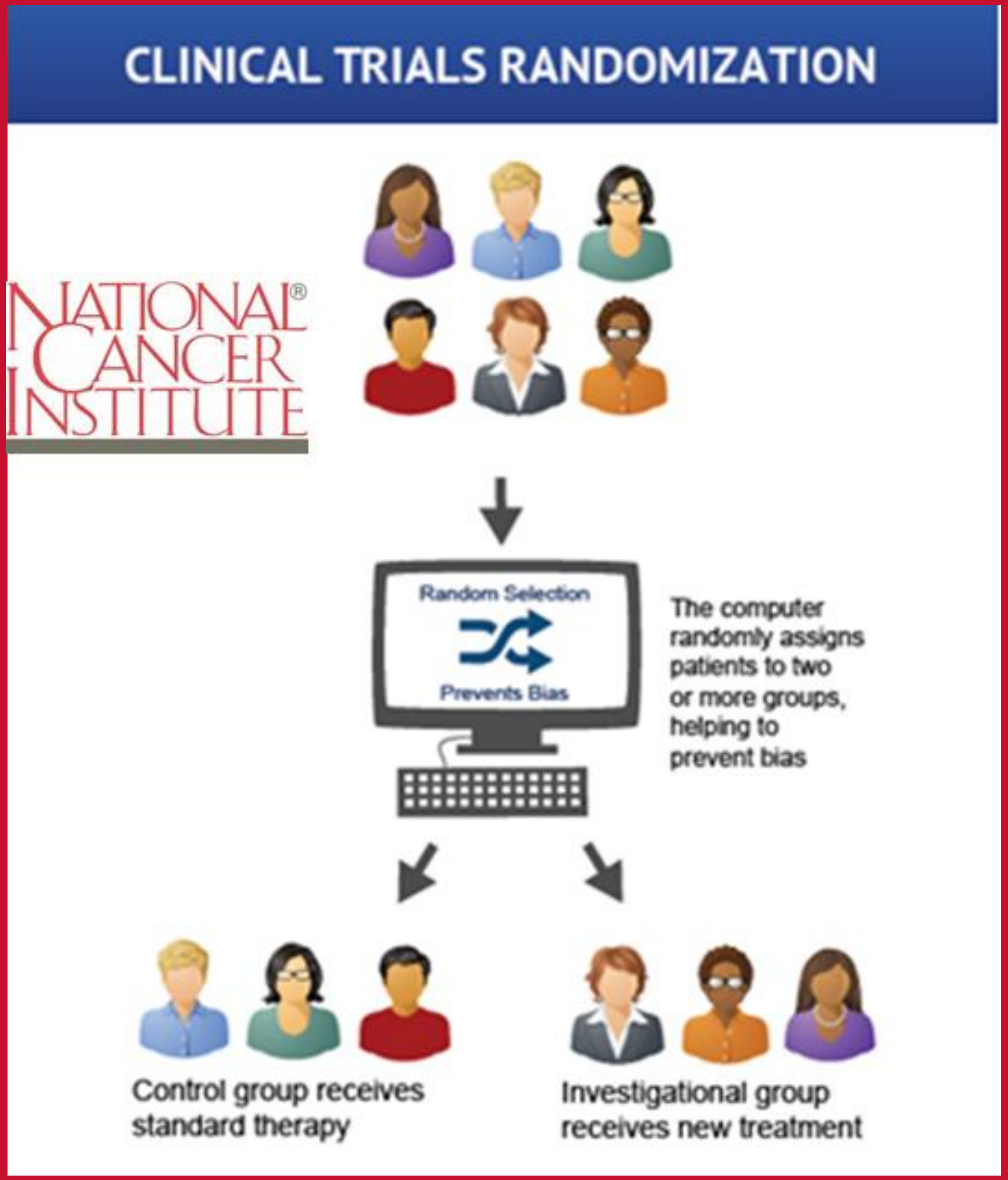


Condition	Number of Observations	Mean	Standard Deviation
Base	8,681	0.869	0.659
Lube	11955	0.840	0.636

Standard Deviation is a measure of spread. Base has a greater range of energy measurements values.

COMPARISON TO CLINICAL TRIALS

Design and Analysis of Experiments



- Patients are randomly assigned to “investigational” and “control” groups.
- This reduces bias up-front
- Investigational group gets the “treatment” (stick lube)
- Control group gets “standard therapy” (base condition)
- Statistical models are used to analyze the outcomes.

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WHY NOT COMPARE RAW MEANS BETWEEN TEST AND CONTROL?

Pitfalls mitigated using statistical tools

- Looking at raw means alone, in a univariate sense, **does not account for other ancillary factors** that may also be driving the difference of the means.
- Statistical modeling using multivariate methods allow us to quantify those ancillary factors and **adjust the means** accordingly to have a more balanced comparison.
- Statistical models can assign a **degree of confidence** that the true effect (energy savings) is non-zero.
- Means are a single number – a point estimate. Statistical modeling can provide an estimate of the range of **potential outcomes**.

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ANalysis of COVAriance Model (ANCOVA)

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Linear Mixed Effect Model

$$\mathrm{KWHR}_{ij} = \beta_0 + \beta_1 \cdot \mathrm{TestCondition}_i + \beta_2 \cdot \mathrm{Curvature}_{ij} + \beta_3 \cdot \mathrm{ElevationChange}_{ij} + \beta_4 \cdot \mathrm{TestTrack}_j + \epsilon_{ij}$$

Lube versus Base (control).

We need this to compute the least square (adjusted) means

Covariates that account for other, non-lube variation in KWHR.

These are used to make the adjustments to the Least Square Means ("all other things being equal").

The coefficients vary across test tracks (WRM loop versus Transit Test Track). Thus, these the "random effects"

Fixed effect indicator for the test track: WRM Loop vs. Transit Test Track

ϵ_{ij}: residual error, assumed $\epsilon_{ij} \sim \mathcal{N}(0, \sigma^2)$

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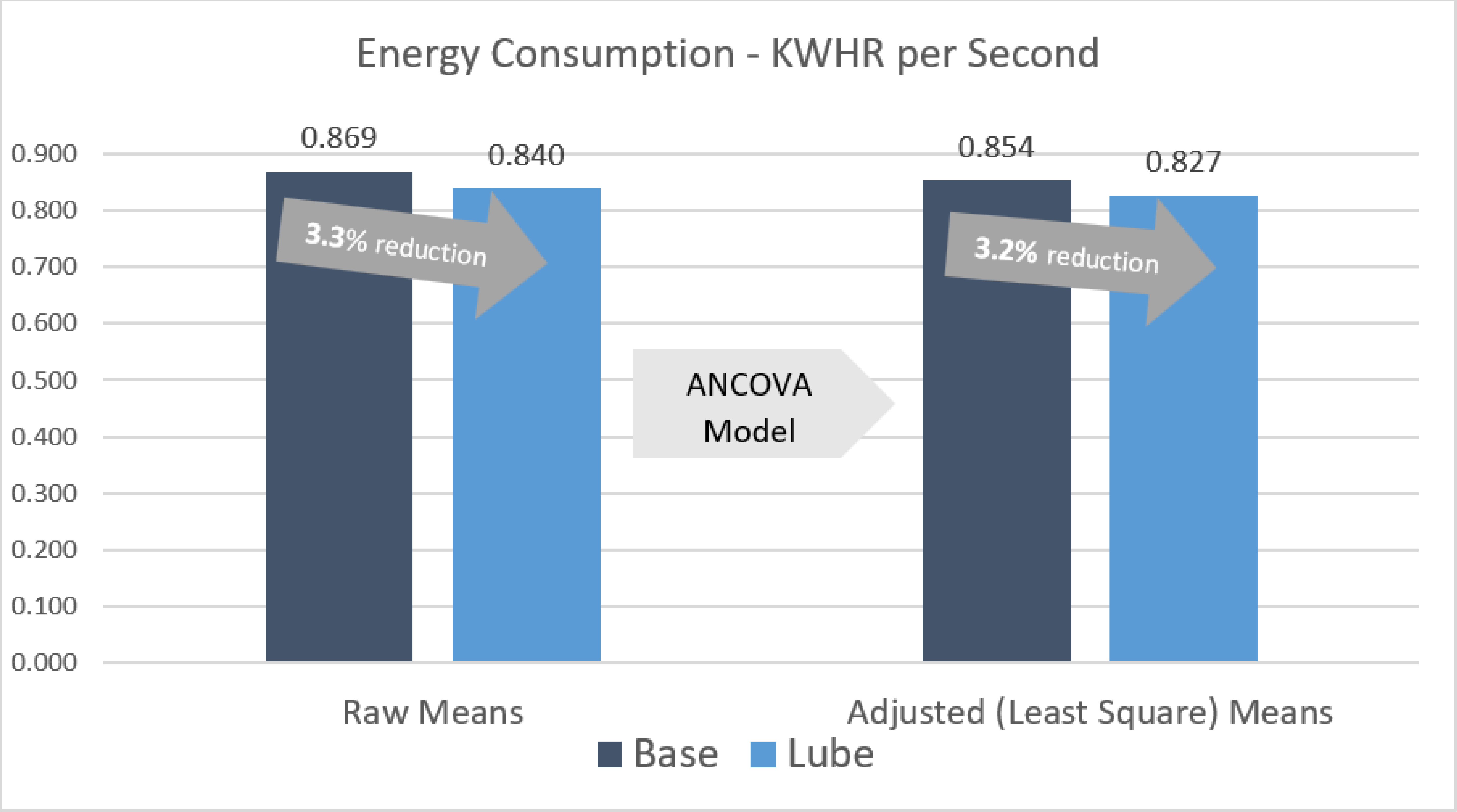
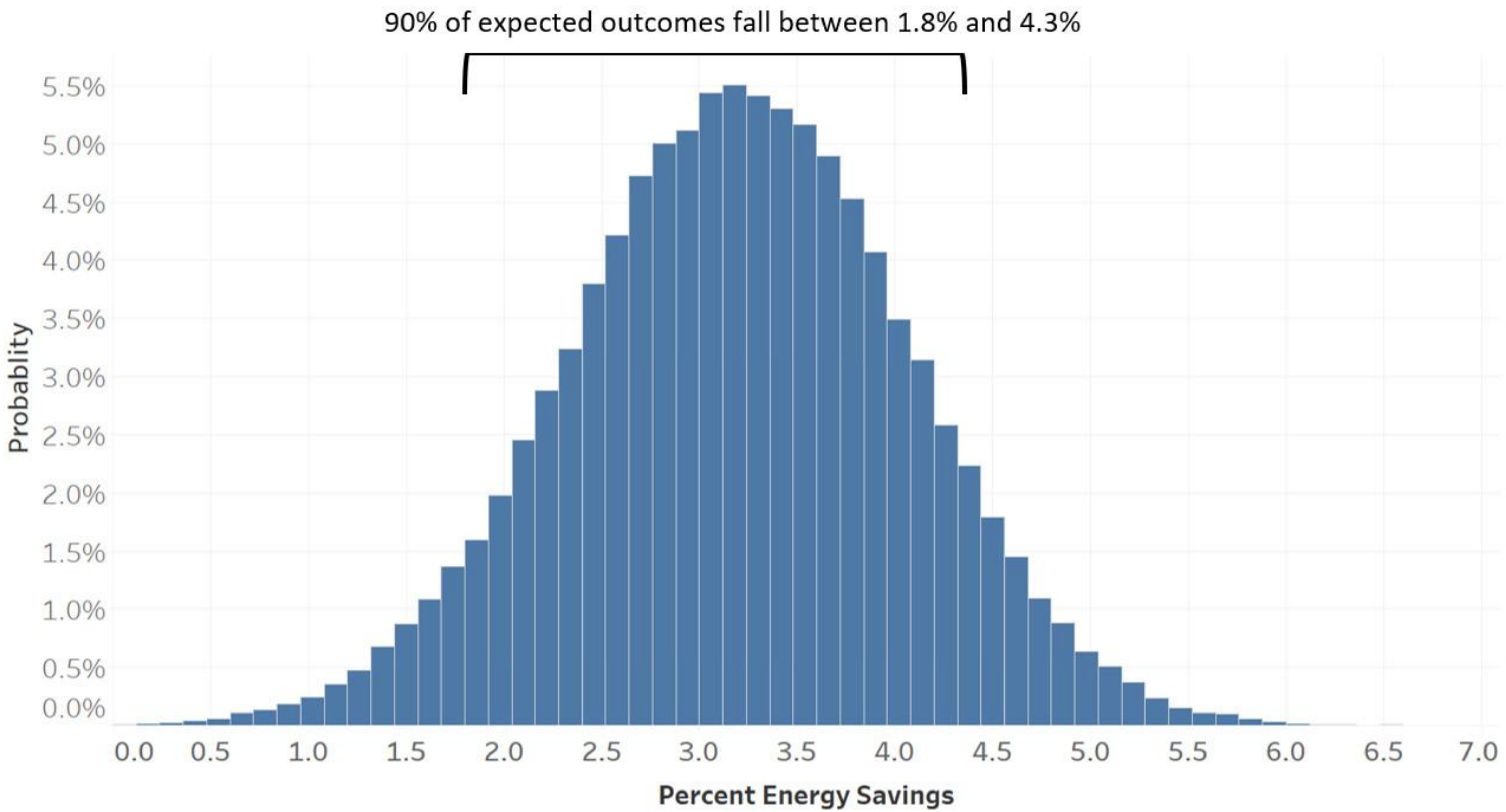
ANCOVA RESULTS



UNDERTANDING A RANGE OF OUTCOMES

Monte Carlo Analysis



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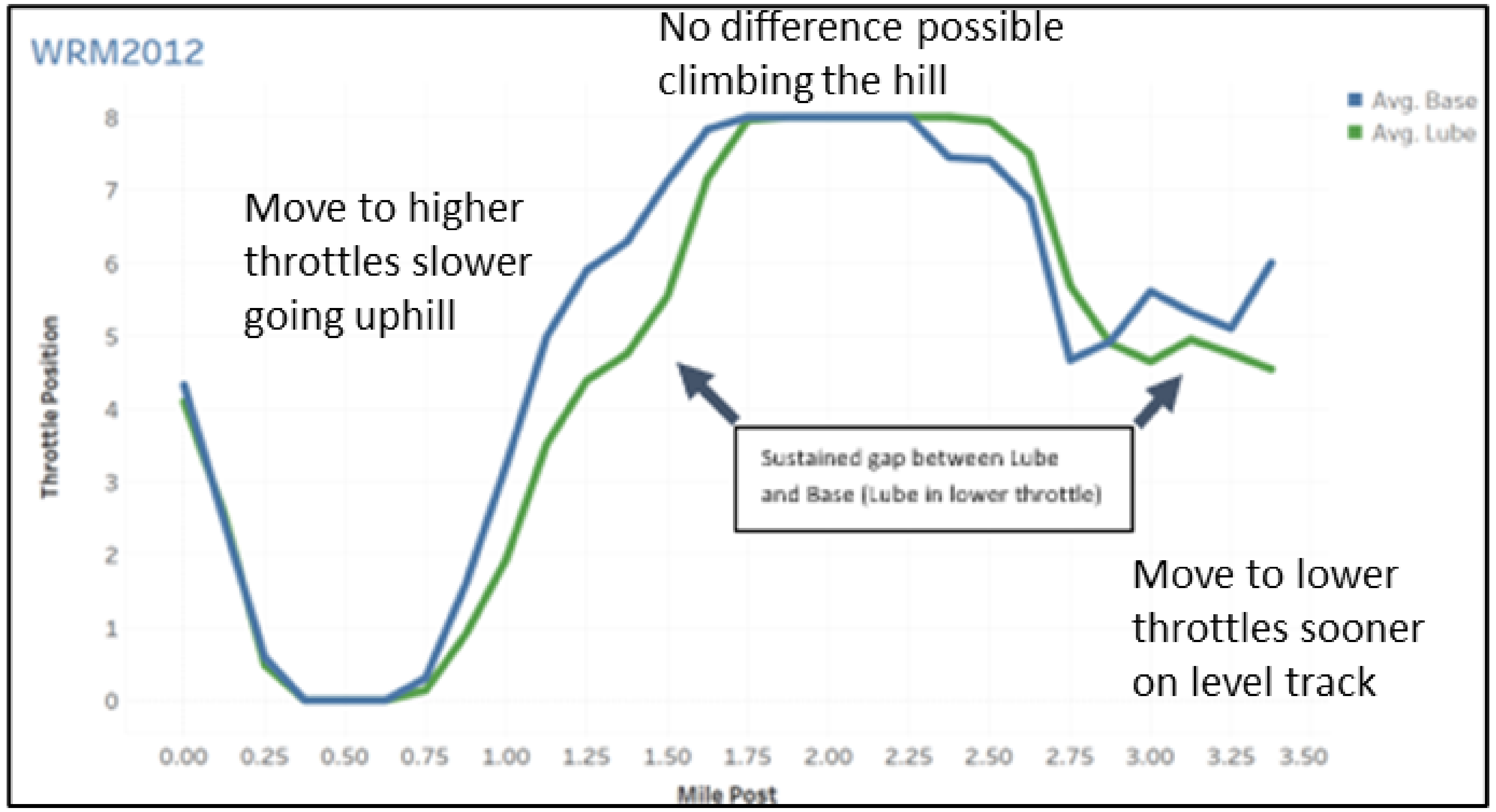
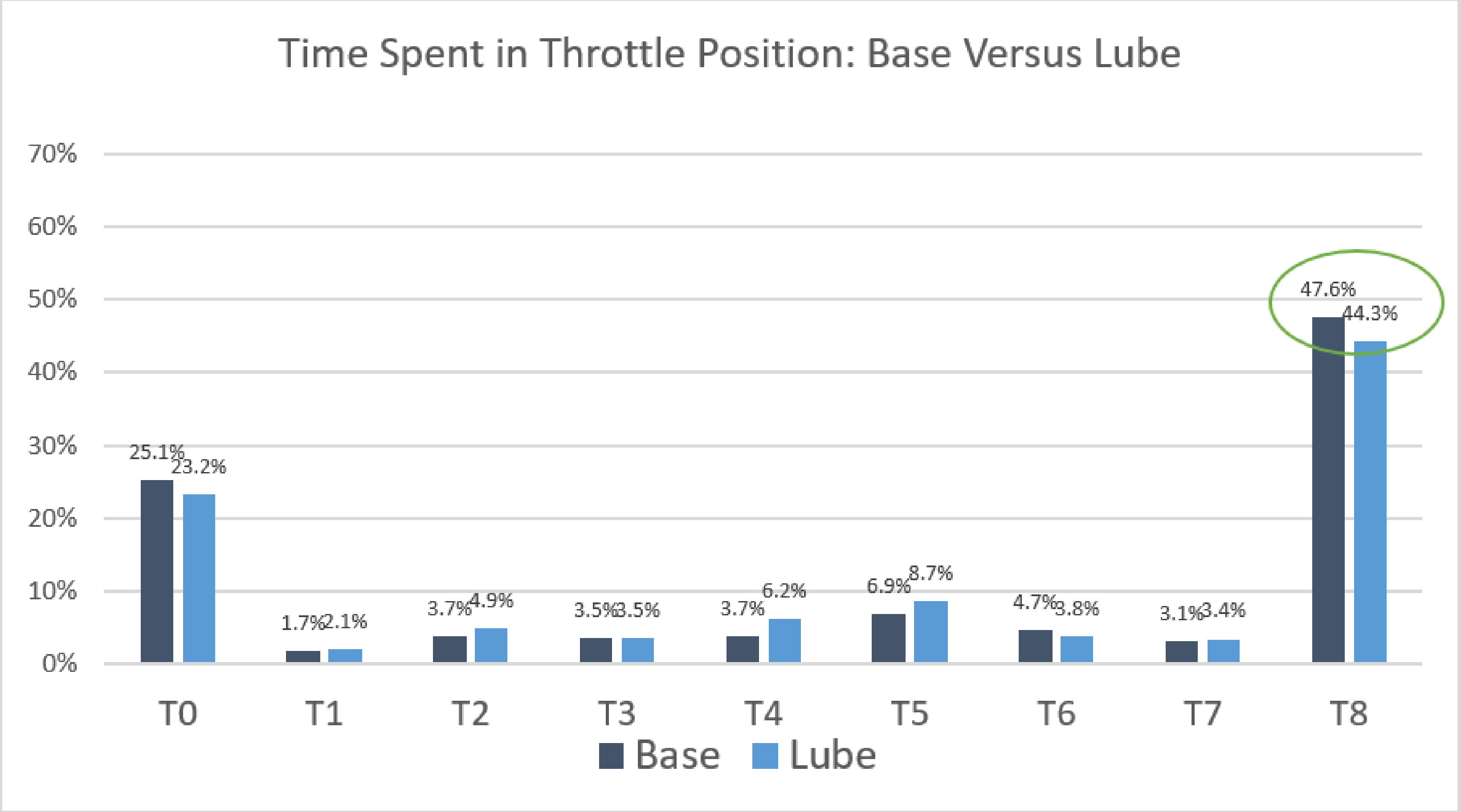
ADDITIONAL EVIDENCE





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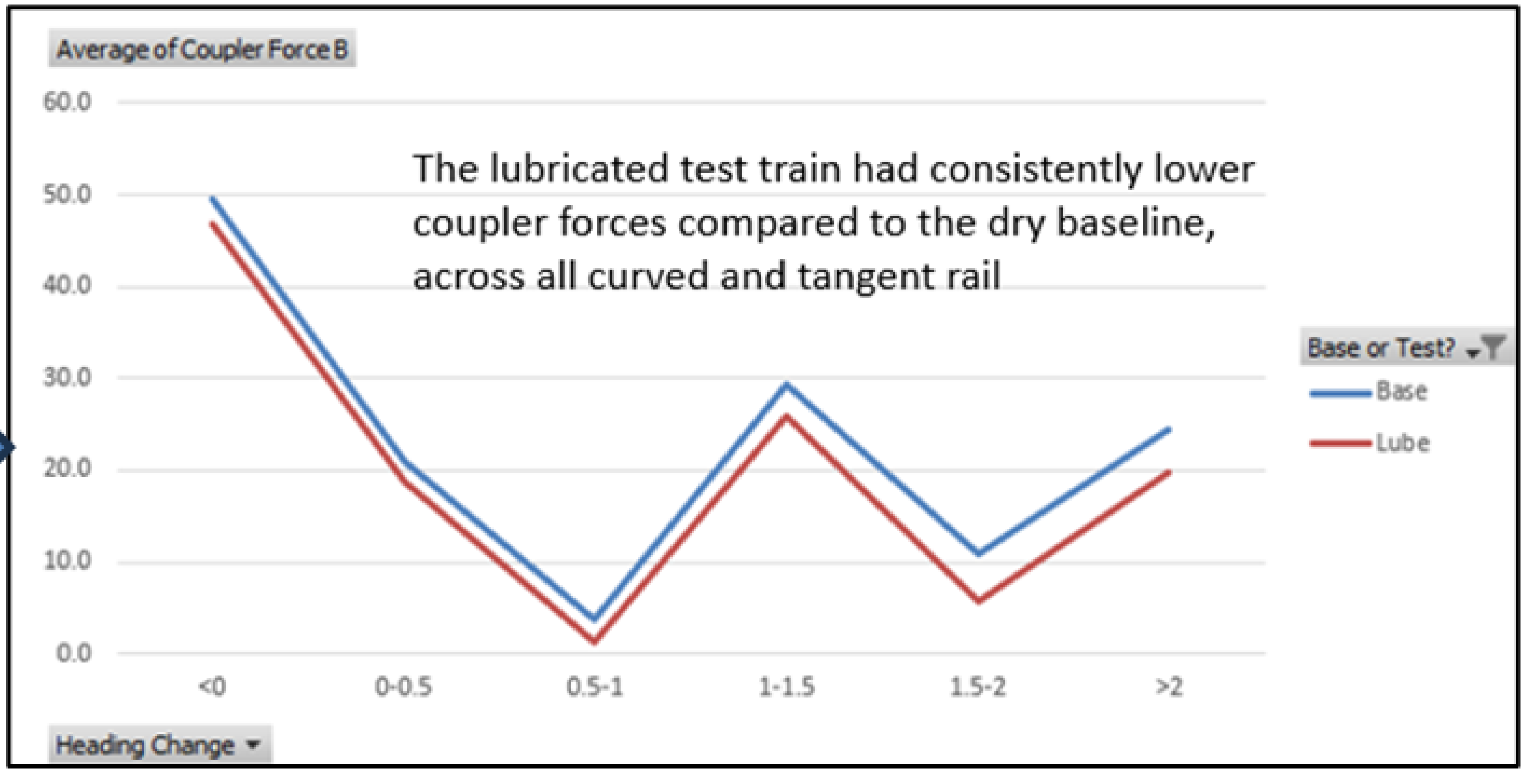
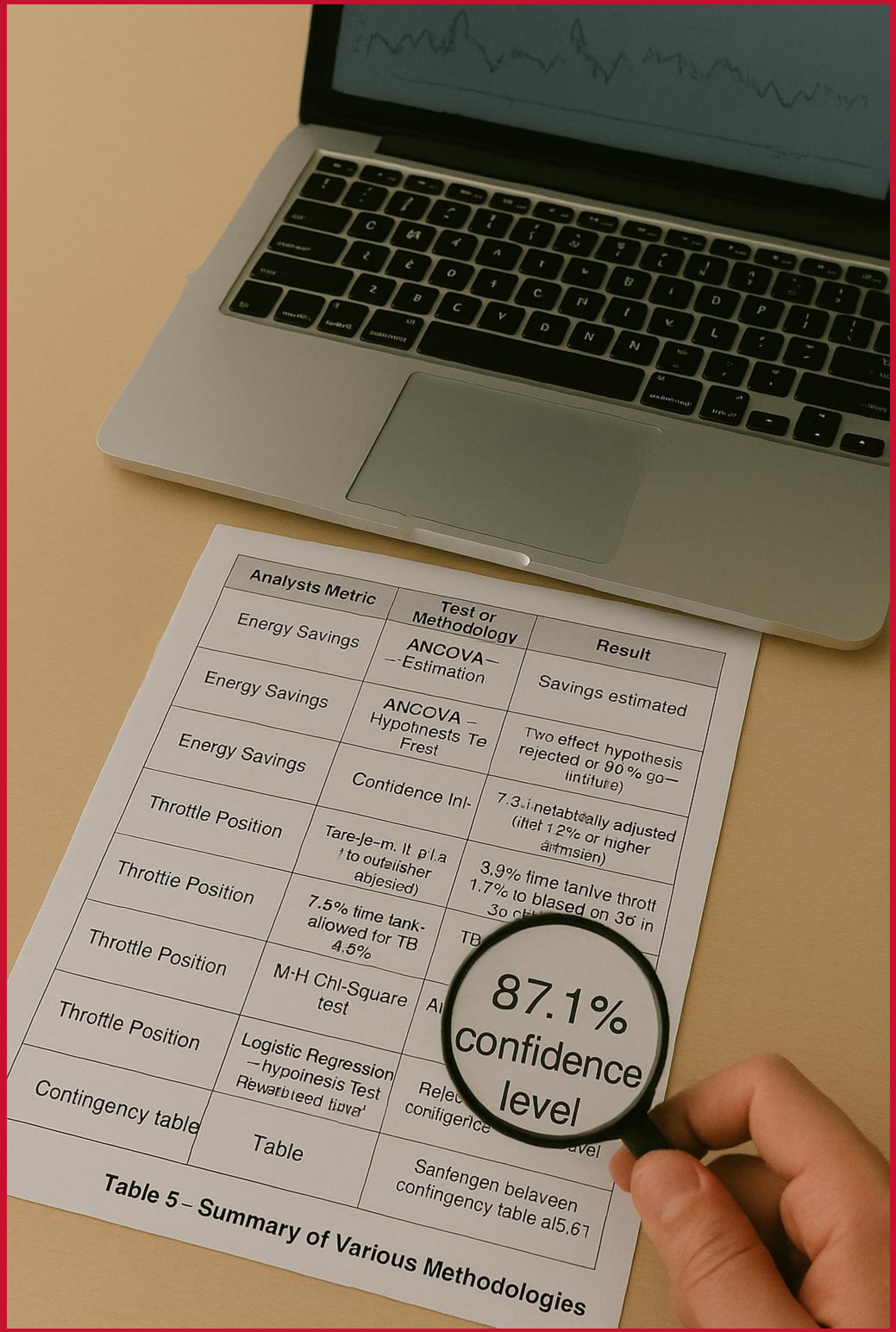


A Battery of Statistical Tests to Build Evidence



Analysis Metric	Test or Methodology	Result
Energy Savings	ANCOVA - Estimation	Savings estimated to be 3.2%
Energy Savings	ANCOVA– Hypothesis Test (t-test)	"No effect" hypothesis rejected at 99% confidence level
Energy Savings	Simple two-sample t-test	"No effect" hypothesis rejected at 99% confidence level
Energy Savings	Confidence Intervals	90% of expected outcomes are within 1.8% and 4.3%
Throttle Position	Simple statistics and visualization	7.1% less time spent in T8 (not statistically adjusted) More time spent in T4 and T5
Throttle Position	M-H Chi-Square test	Time spent in each throttle position, taken as a whole, is statistically different at the 90.1% confidence level
Throttle Position	Simple two-sample t-test	Average throttle position is statistically different at the 90.0% confidence level
Throttle Position	Logistic Regression - Estimation	Odds of being in T8 reduced by 4.8%
Throttle Position	Logistic Regression – Hypothesis Test (Wald Chi-Square)	"No effect" hypothesis on T8 reduction rejected at 87.1% confidence level.
Throttle Position	Visualizations	Visible gap between Lube and Base along the track mileage

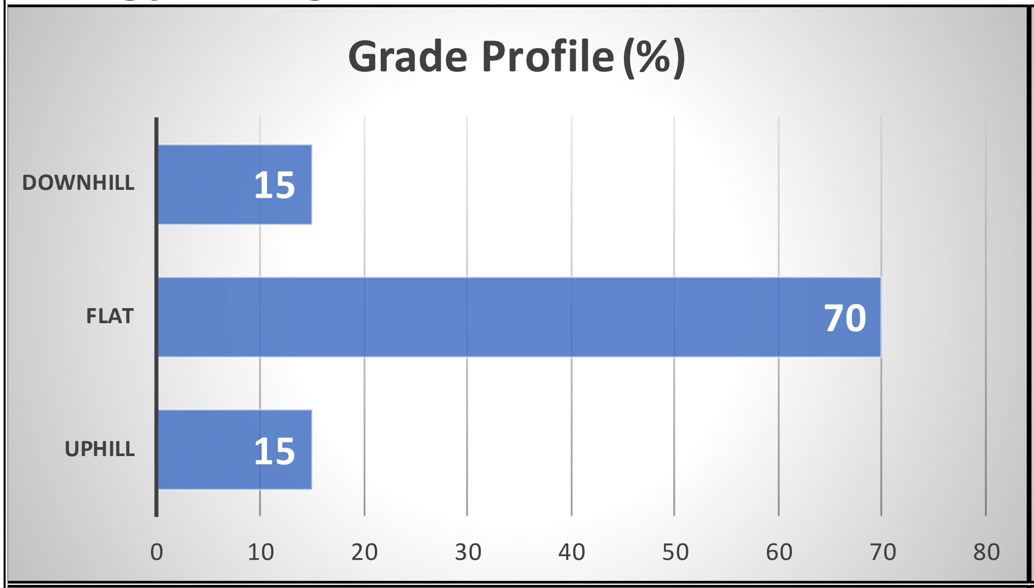
Table 5 – Summary of Various Methodologies Applied

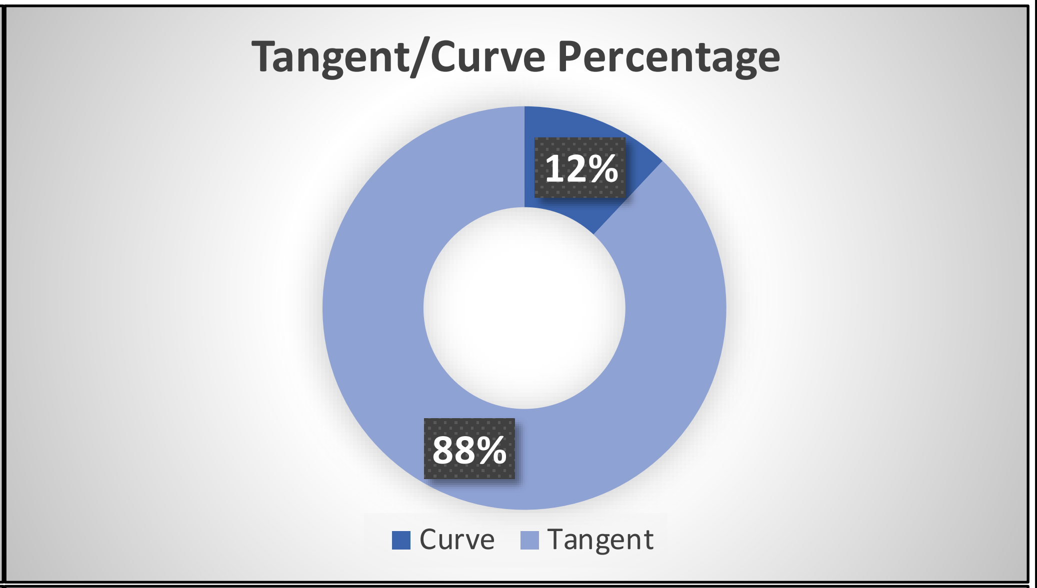
PROJECTING TEST FACILITY RESULTS BY RAILROAD

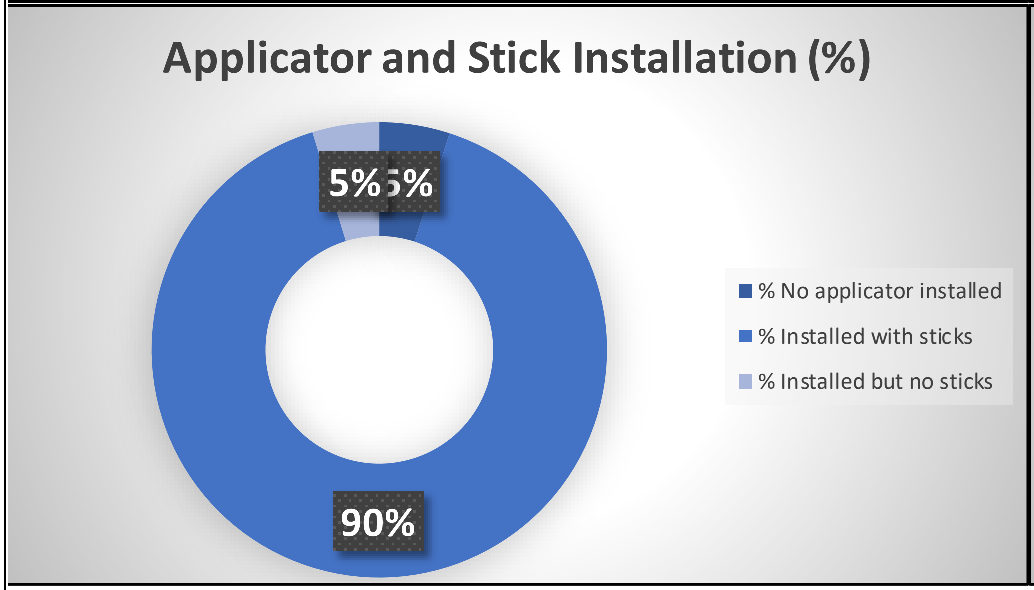
PROJECTING TTC / MxV RESULTS

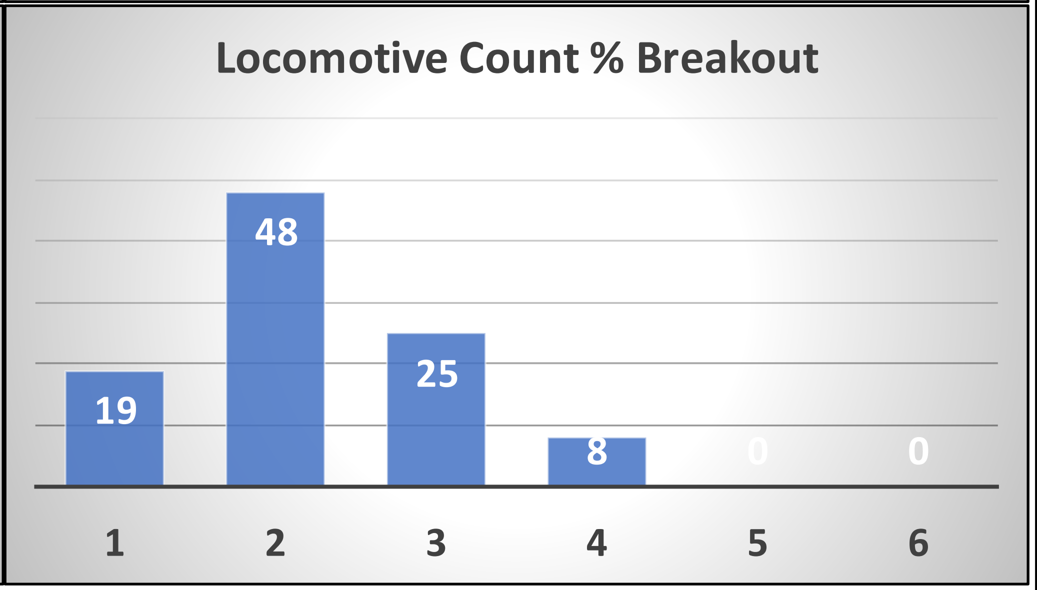
Based on a Railroad's Profile

Energy Savings









Train Length

Feet	Equivalent Cars
8100	113

Total % Savings
2.4

Velocity Benefit

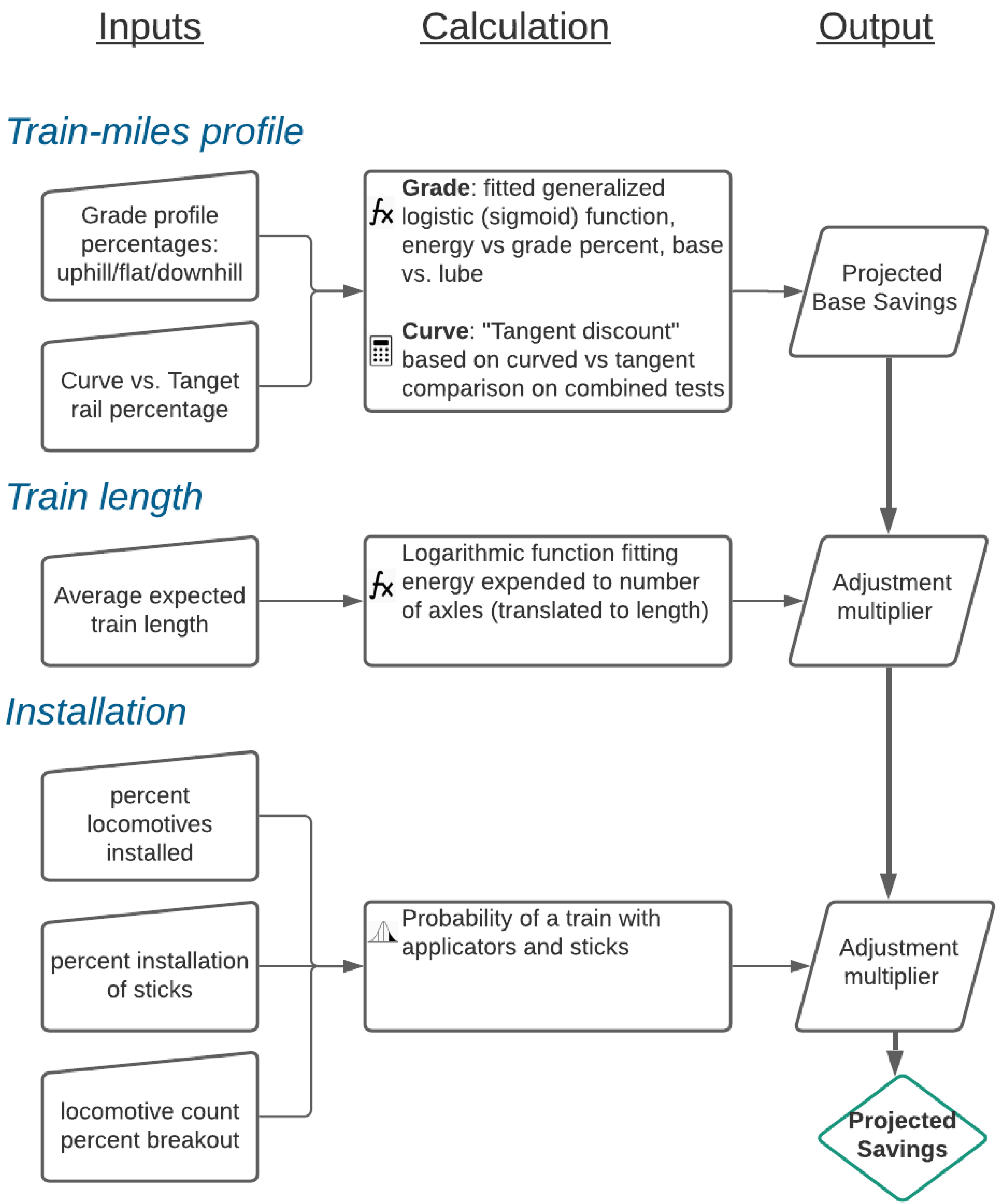
Throttle Profile

% Time in T8	40
% Time in Idle/DB	40

% Velocity Improvement
0.29

PROJECTION MODEL

Based on a Railroad's Profile



FUEL MEASUREMENT RELIABILITY

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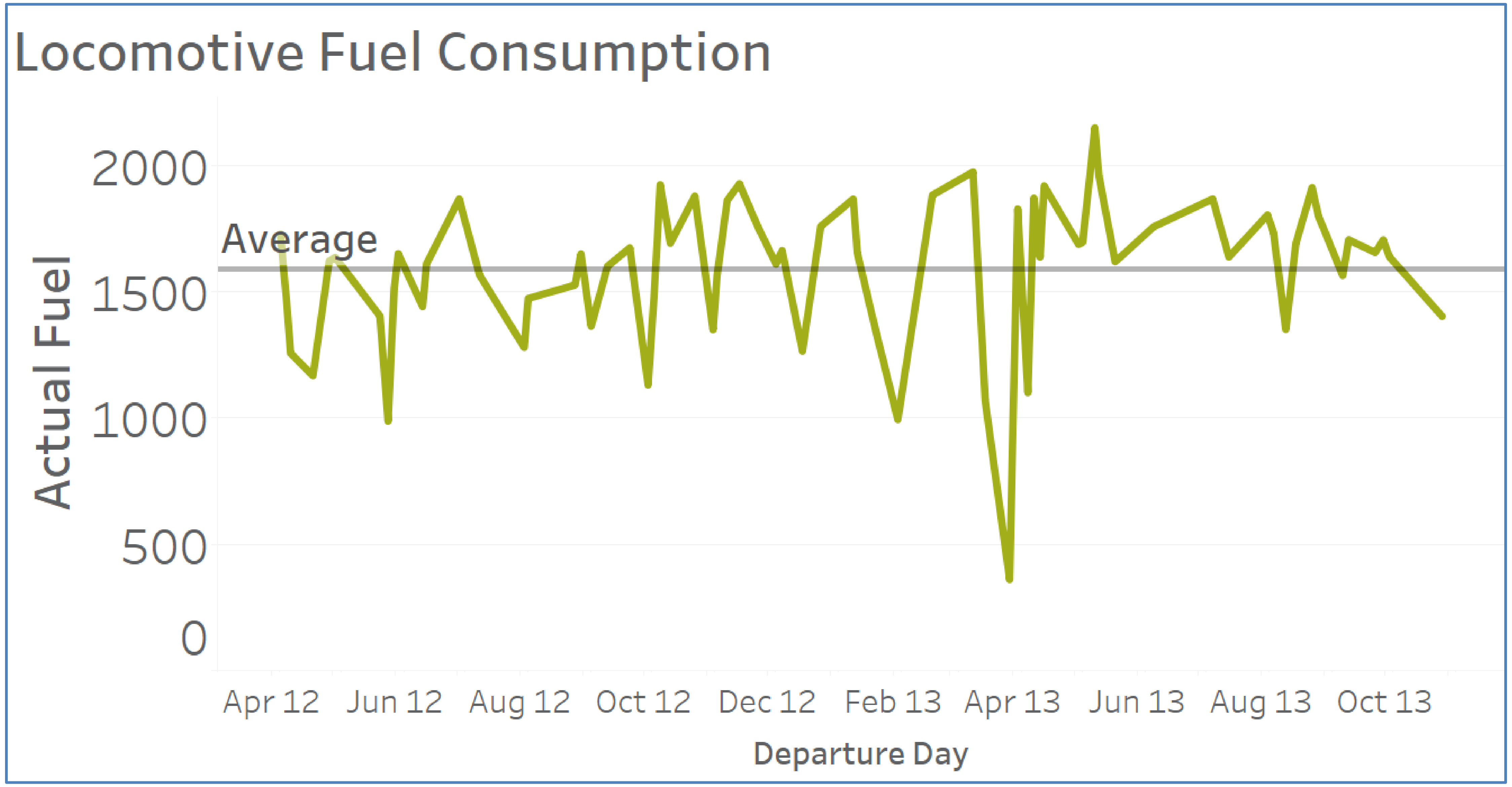
FUEL MEASUREMENT DATA CAN BE NOISY

- Same origin-destination
- Same locomotive count
- Same horsepower
- Similar number of cars / tonnage (loaded coal)
- Same engineer



CREATING A RELIABLE FUEL METRIC

Raw Measurement → **Business Rules** → **Statistical Imputation** → **Model Combination**

Raw Measurement

Wi-Tronix

Event Recorder (Notch)

Business Rules

- Identification of "bad" records for each measurement type
- Statistical outlier detection
- Rules for combining data

Statistical Imputation

Formal statistical methods to replace "bad" records with data- and model-based estimates

Model Combination

- Final estimate based on "jury of opinion" of the models.
- Rigorous methods, such as *Bayesian Model Averaging* (data-determined weighting)

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COMPOSITE FUEL METRIC FEATURES AND BENEFTS

- Consistency and reliability
- Highly automated
- Includes both human expertise and statistical modeling and algorithms

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- Reduces variation allowing for the ability to tease out fuel technology savings in the 2% range
- Incorporates into existing data warehouse, dashboards and Tableau / PowerBI reports
- Enables “what-if” scenarios such as testing technology X on Subdivision Y to calculate length of test and provide a realistic % savings rate

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CONCLUSIONS FOR THE RAIL INDUSTRY

- Railroads are challenged to stay on their SBTi emissions reduction glideslopes
- Many available technologies exist that are not widely adopted due to uncertainty on fuel savings
- Locomotive wheel flange stick lubrication offers both fuel savings and wheel / rail reduction benefits
- A rigorous statistical approach is needed to prove fuel savings with a high degree of certainty
- Pooled testing / funding efforts for Pueblo testing is recommended to only have to prove it once
- Don’t fall into the trap of “we can’t prove it, so it must not save fuel or reduce wheel/rail wear”

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