October 2015

Onboard Health & Performance Monitoring

Amsted Rail

Agenda

Onboard Health & Performance Monitoring

- IONX remote monitoring platform
- Onboard weighing system
- Hand brake monitoring system
- End of car systems:
  - Impact detection
  - Cushion unit health
- Bearing condition monitoring:
  - Temperature based
  - Vibration based
- Bogie performance monitoring
- Wheel fault detection

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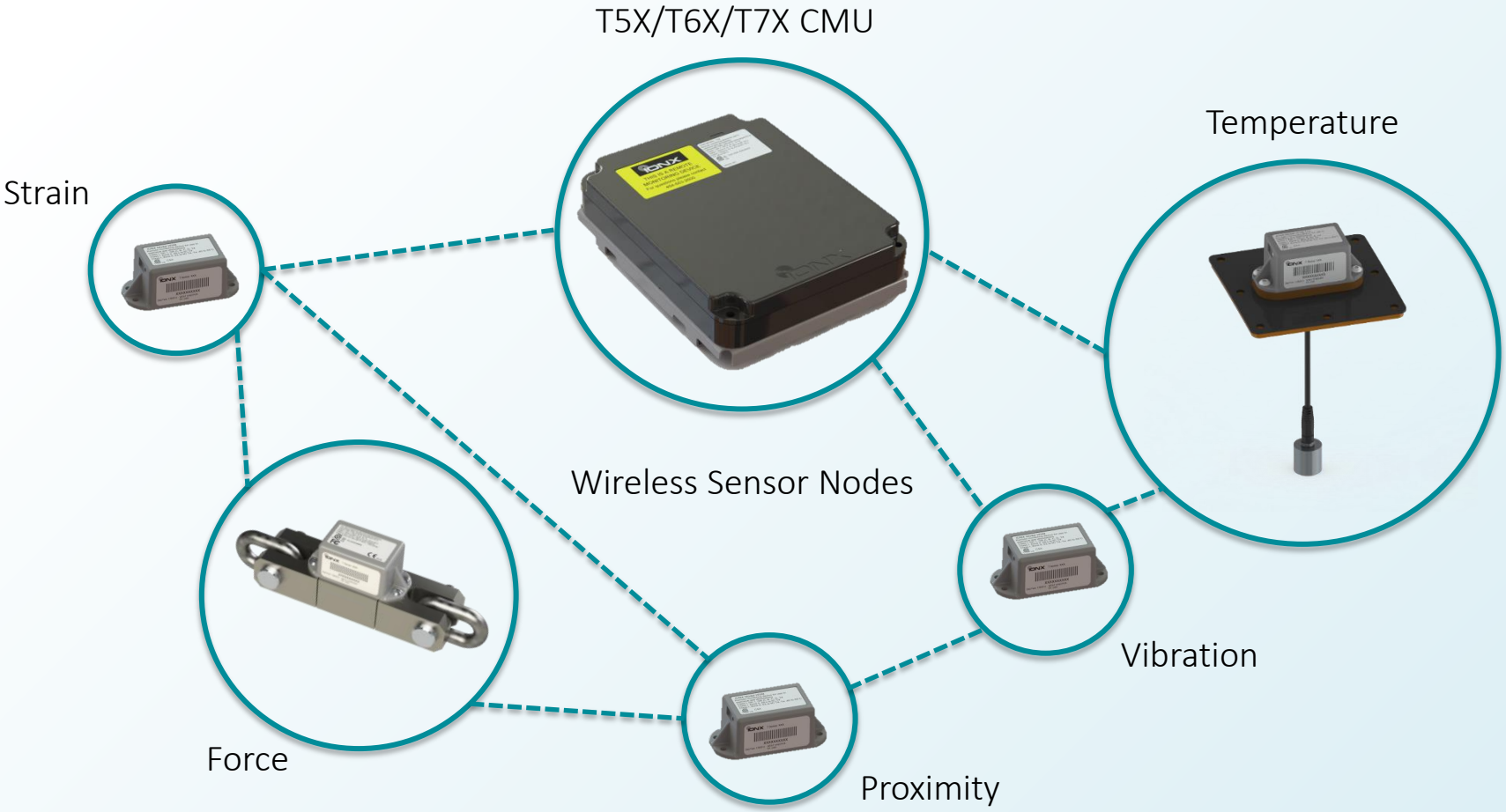
IONX Remote Monitoring System: Overview



Onboard Weighing System: Overview

Goal:

- Design a 1% accurate onboard weighing system

Key Requirements:

- Standalone system per car – no wires
- Bluetooth interface for local monitoring
- Integrate into Amsted Rail truck system (“smart” component)

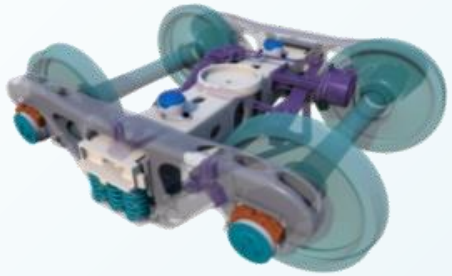
Approach:

- Integrate transducers into truck system and calibrate

Onboard Weighing System: System Overview

A-End OWS Truck

B-End OWS Truck



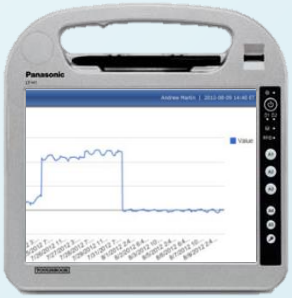
Raw Transducer Readings

Wireless Sensor Nodes

Transmit Readings

Convert raw data to A- and B- truck payload

Bluetooth or cellular connection



Net Payload displayed on tablet/PC

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Onboard Weighing System: Performance

Lab Results:

- Accuracy better than **0.5%** during calibration cycles in load frame

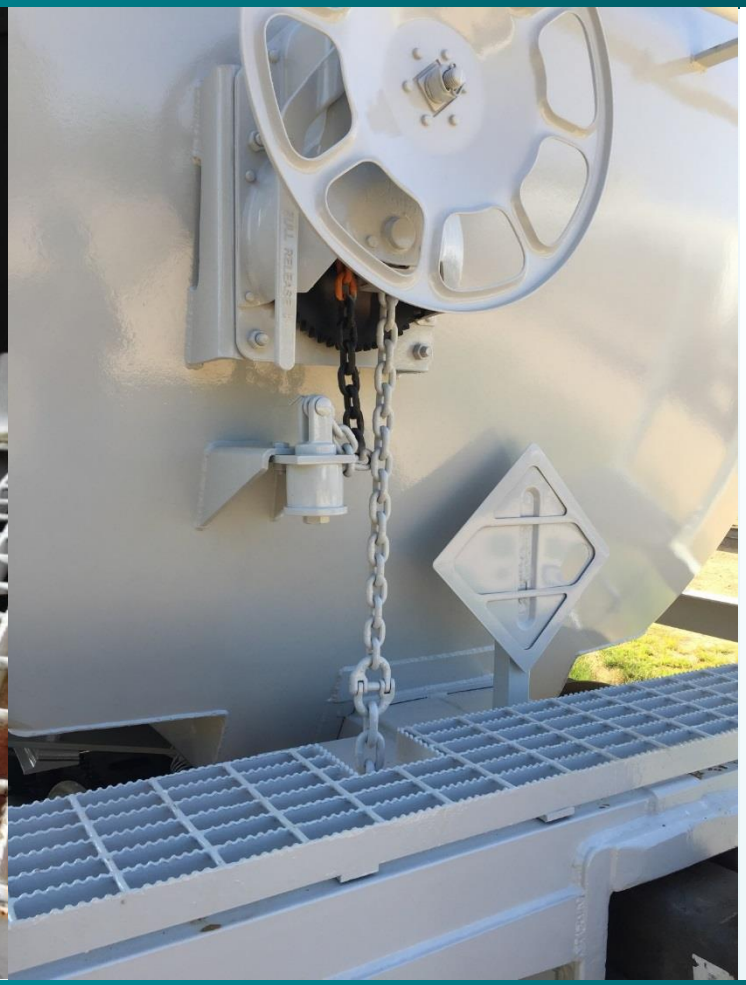
Field Results:

- Payload readings compared to track scale readings
- Average accuracy of **3.1%**
- Six (6) tank cars in service for **853** days to date

Next Steps:

- Second generation hardware deployed in tank car field trial (September 2015)

Hand Brake Sensor: Overview



Goal:

- Develop a hand brake force monitoring system

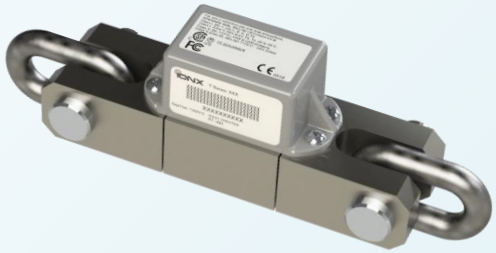
Key Requirements:

- Compatibility with existing hand brake systems/chain
- Accurate and reliable operation from -40 to 85 degrees Celsius

Approach:

- Strain-based custom transducer design
- Provide chain tension readings/alerts

Hand Brake Sensor: Performance



Specifications:

- Accuracy better than **1.0%** from **-40** to **85** degrees Celsius
- Survived **4,500** cycles (application and full release)
- Breaking strength of **39,000** Lbf
- Capable of batch calibration

Hand Brake Sensor: Application

End of Car Systems: Impact Detection

Goal:

- Estimate struck coupler force during coupling events

Approach:

- Indirect - correlate peak car body acceleration and peak impact force
- Direct - instrument coupling system (force measuring coupler)

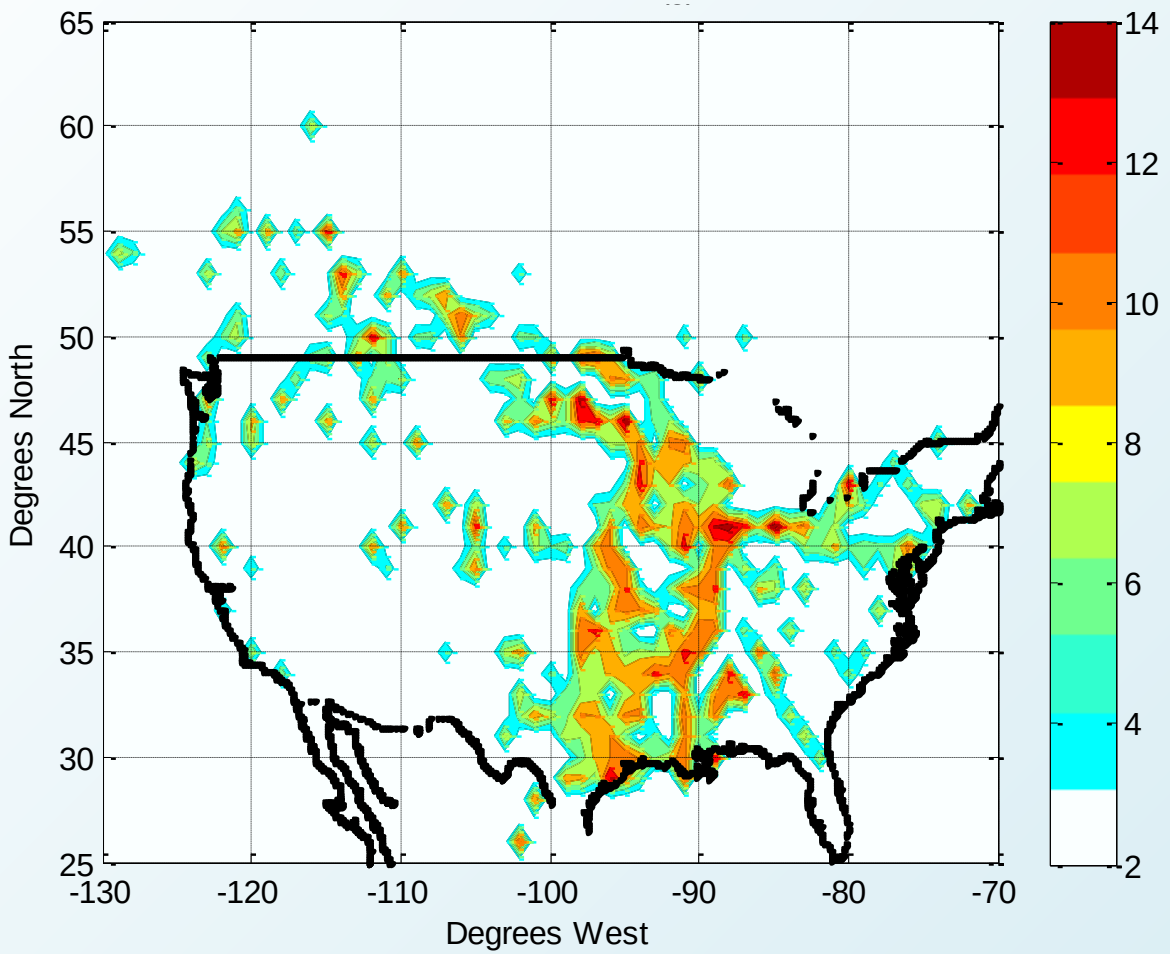
Progress:

- Accuracy better than **± 150 kips** achieved using IONX T-series device with built-in accelerometer
- Accuracy better than **± 100 kips** achieved with instrumented coupler concept

End of Car Systems: Impact Detection

Field Data Analysis:

- Heat map identifies locations of overspeed impacts
- Of **1,933 cars** monitored, **14** have seen input forces of **1 million pounds** or more
- 1 million pounds is equivalent to **13 g's** on an empty car



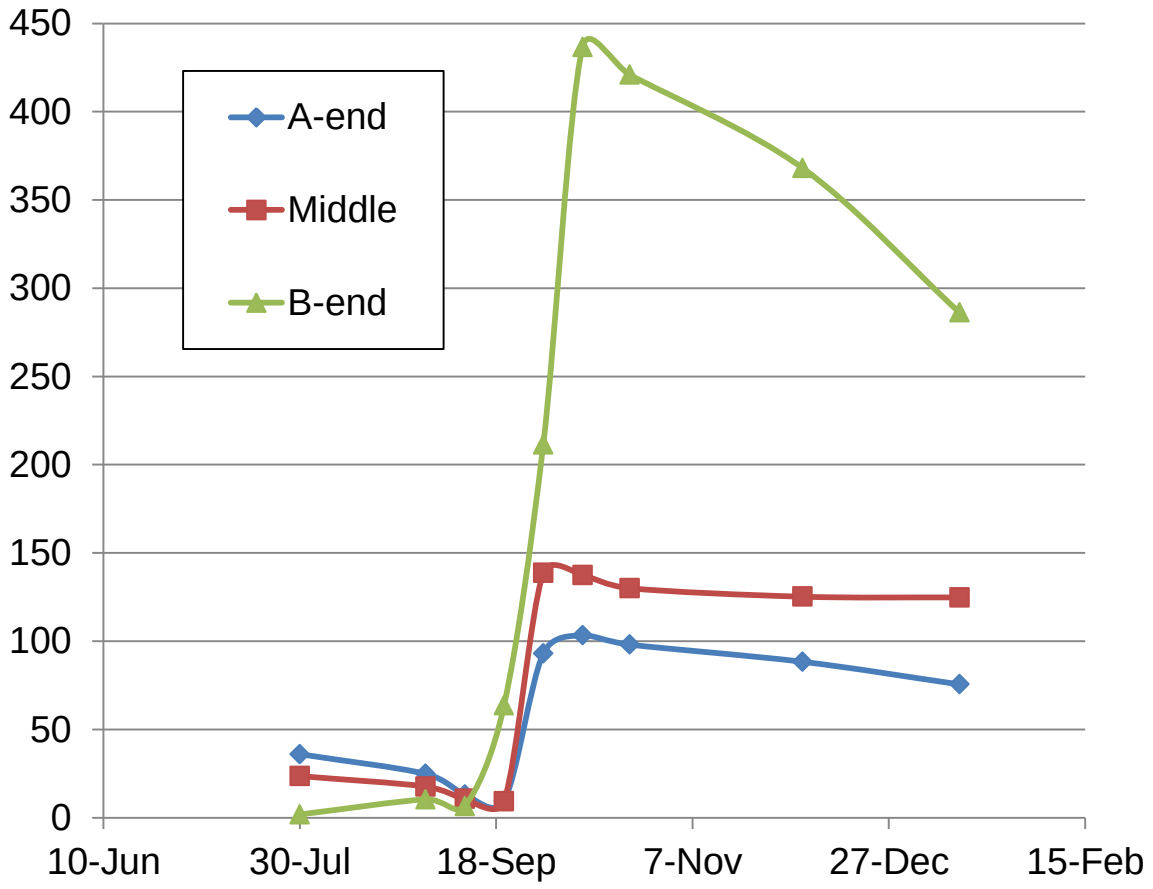
End of Car Systems: Cushion Unit Health Monitoring

Goal:

- Estimate cushion unit ‘health’ using carbody acceleration data

Progress:

- T4S placed on car to monitor cushion unit health
- Known condition of draft system based on inspection:
  - A-end: minor wear
  - B-end: wear and minor leakage
- Calculated statistics from acceleration data indicate damage



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Bearing Condition Monitoring: Overview

Goal:

- Detect and diagnose bearing defects using onboard sensors

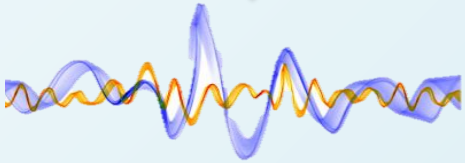
Approach:

- Temperature-based on roller bearing adapter
- Vibration-based on roller bearing adapter
  - “Features” extracted from time domain vibration data
  - Pattern recognition & machine learning used to classify bearing

Temperature and/or vibration data

Wireless Sensor Node

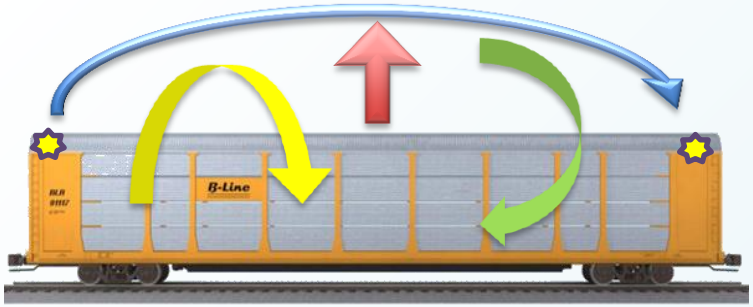
Extract features from raw data

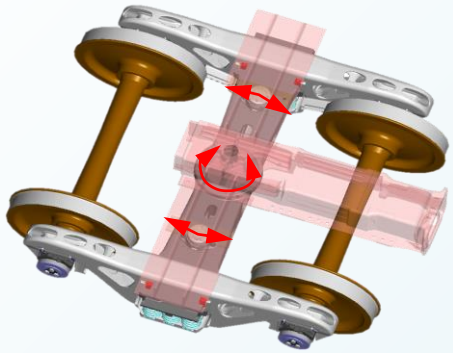


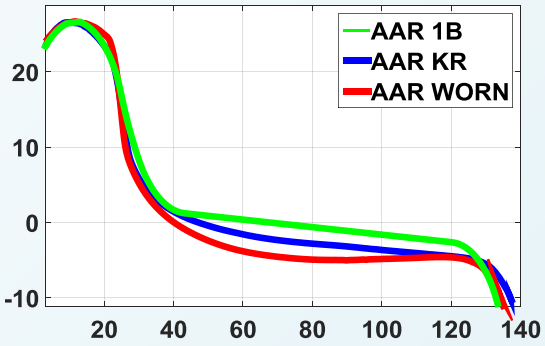
Classify bearing

Inner raceway spall

Bogie Performance & Condition Monitoring: Overview







Goal:

- Measure bogie performance and condition using onboard sensors

Concept Studies:

- Body mounted sensors:
  - Measures roll, pitch, yaw, and bounce
- Truck mounted sensors:
  - Measures single truck response
  - Can detect worn wheels, worn wedges, or side bearings

TTCI Testing:

- Acceleration data collected during hunting acceptance tests with different levels of wheel wear

Bogie Performance & Condition Monitoring: Overview

Test speeds [mph] for each wheel profile

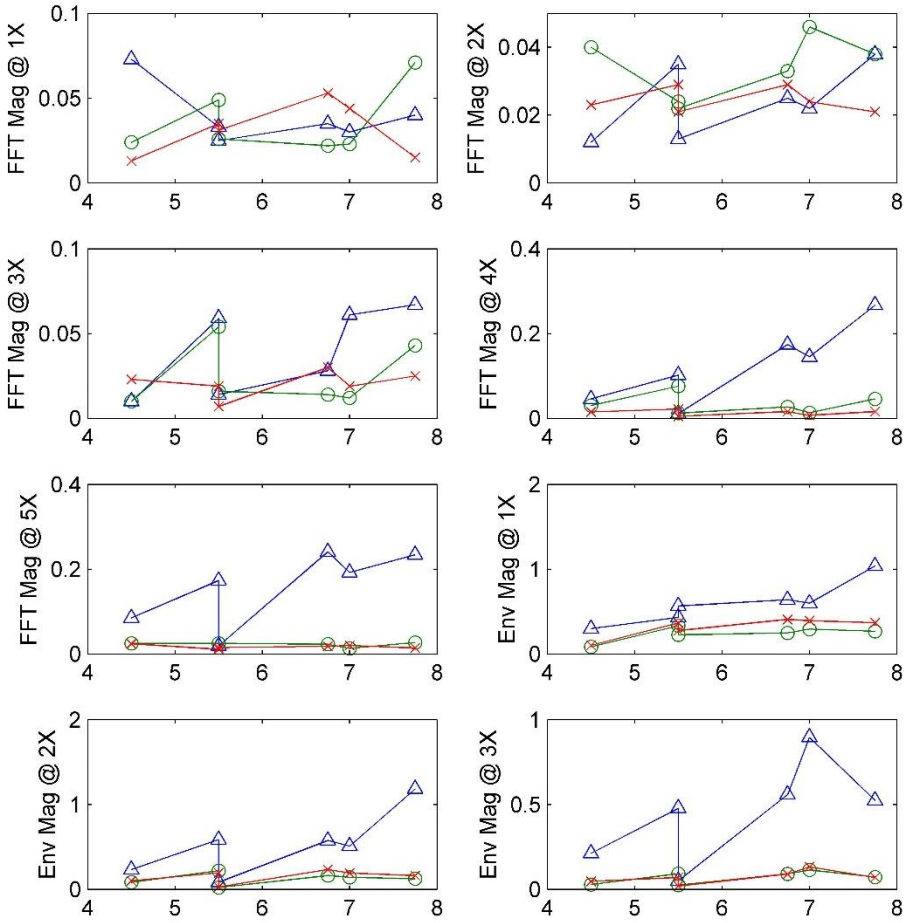
AAR 1B	KR	BNSF
40	30	40
50	40	50
60	50	55
65	60	60
67	62	62
70	64	64
72*		67
75		70

* Red color indicates speeds at which hunting occurred.

Algorithm & Results:

- 'Features' extracted from raw vibration waveforms
  - Time domain
  - Frequency domain
- Features ranked according to mutual information (MI)
- Classifier trained using training set
- Classifier utilized with 'fresh' data
  - Accuracy of **90%** demonstrated

Wheel Fault Detection: Overview



Goals:

- Detect & diagnose wheel defects using onboard sensors

Approach:

- Vibration-based on roller bearing adapter

Progress:

- Field data with high kip wheels used for analysis
- ‘Features’ extracted from acceleration signal
- Machine learning used to “classify” data
- Accuracy of **70%** achieved with single feature and up to **100%** with multiple features

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