Achieving Autonomous Driving in the Bus Industry

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1 Overview

Autonomous Driving is creating a revolution within the metro bus industry, offering significant opportunities to reduce costs, improve operational efficiencies, and modernize public transportation.
One of the primary objectives for Autonomous Buses is to increase vehicle utilization by reducing and potentially eliminating the dependency on human drivers
However, despite significant investments in Autonomous Bus platforms, many municipalities seem no closer to achieving reliable, predictable autonomous operations than before they started.
In this session, we will explore some of the challenges implementing Autonomous Driving in the bus industry, and share some insider tips that can help ultimately achieve the Autonomous metro bus

2 Challenges in the Bus Industry

Tremendous technology change underway in the metro bus market:
Electrification, Hydrogen Fuel Cells, Hybrid Powertrains, and mixed fleets
Autonomous driving is often integrated with this technology change
New technologies are driving higher maintenance costs and total cost of ownership for the municipalities
New technology powertrains typically deliver lower travel distance and higher variability of distance per charge
Metro bus companies are constrained by publicly-funded budgets

3 How are these Challenges being met?

Advanced EV Route simulations & Machine Learning
Platooning and satellite bus barns
Charging strategies: sequencing, positioning of charging stations
Advanced Predictive Maintenance solutions
New Revenue Streams to offset increased Maintenance costs

4 The Expectation: Deliver the Passengers on Time

Ultimately, the metro bus companies are expected to meet their ultimate purpose:
Deliver passengers to their respective destinations on time, every time
To meet their primary objective, and to deal with the technology challenges and ultimately achieve Autonomous driving, the metro bus industry must relying on advanced telematics, remote diagnostics
Without the driver providing notifications, autonomous buses are fully reliant on telematics, remote diagnostics, and predictive maintenance ensure predictable, reliable, and cost-effective transportation
Predictive Maintenance is quickly becoming **the leverage item** to achieving autonomous driving in the metro bus industry

5 Customer Innovation Study: Metro St. Louis

Situation Analysis

- Metro St Louis used to invest money just to replace parts and keep the buses running
- Their buses operated at industry average performance levels

4000 miles between failure
Average lifecycle of 12 years

- Primarily operated in a reactionary mode
- To meet their performance and cost targets, Metro St. Louis developed a new maintenance program that they called the "K Plan."

- **Needed a Proactive Approach for improved Fleet Maintenance**

Picture 1. Metro Bus Fleet

Innovation Strategy

- By partnering with LHP Engineering, Metro St. Louis is able to gather data from over 2/3rd of its fleet of buses and analyze that data to successfully predict failure of parts
- Some processing of the data includes taking snapshots of the 330 different data points every 10 seconds
- Able to run algorithms, such as pattern recognition, to monitor usage rates and fault codes

Patterns match up to the events where a part actually broke down
Predict where a part failure would happen

Leverage Data and Analytics to Measure Everything

Business Impact

- Metro STL reduced parts and labor cost by 50%
- The average Mean Time Between Failures (MTBF) of buses was 4,000 miles. Today with the K Plan, the MTBF has been improved to 21,000 miles
- Metro STL estimates that with the LHP solution on the Smart Bus, the MTBF can be further extended to 30,000-35,000 miles
- The life cycle of a bus expanded from industry average of 12 years to 15 years and from 500,000 miles to 800,000 miles

- **Achieving Autonomy means achieving Predictive Maintenance**

Picture 2. Project Results

Predictive Maintenance: Transmission Failure

- Remote diagnostics comparative analysis of Oil temperature shows greater volatility in advance of failure
- Comparing multiple buses on the same route, for Bus #2 also notice increasing temperature lap over lap on the same route, starting with lap 12 and increasing with each consecutive lap until failure on lap 15
- We start seeing irregularities within the gearbox oil pressure readings shortly before the failure occurred
- Machine Learning predicted potential transmission failure within 3 laps

- **Maintenance was alerted, actions taken to replace bus without impacting passengers, and prior to engine failure**

Table 1. Gearbox Temperatures

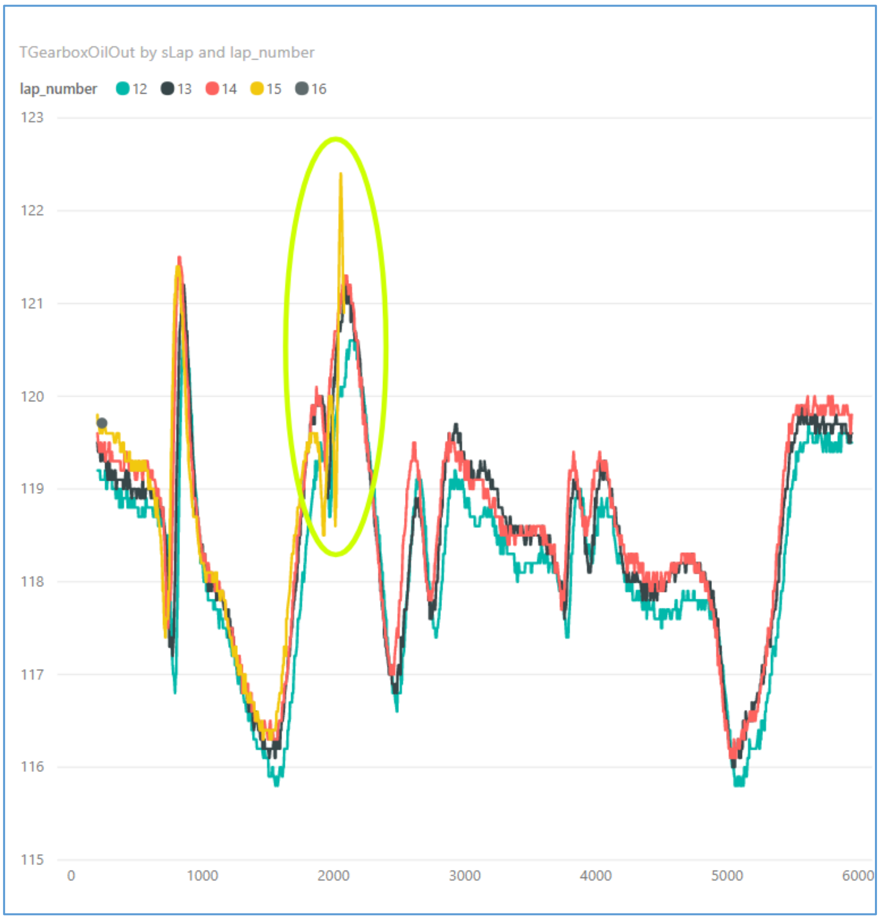

Table 2. Vehicle Tracking System

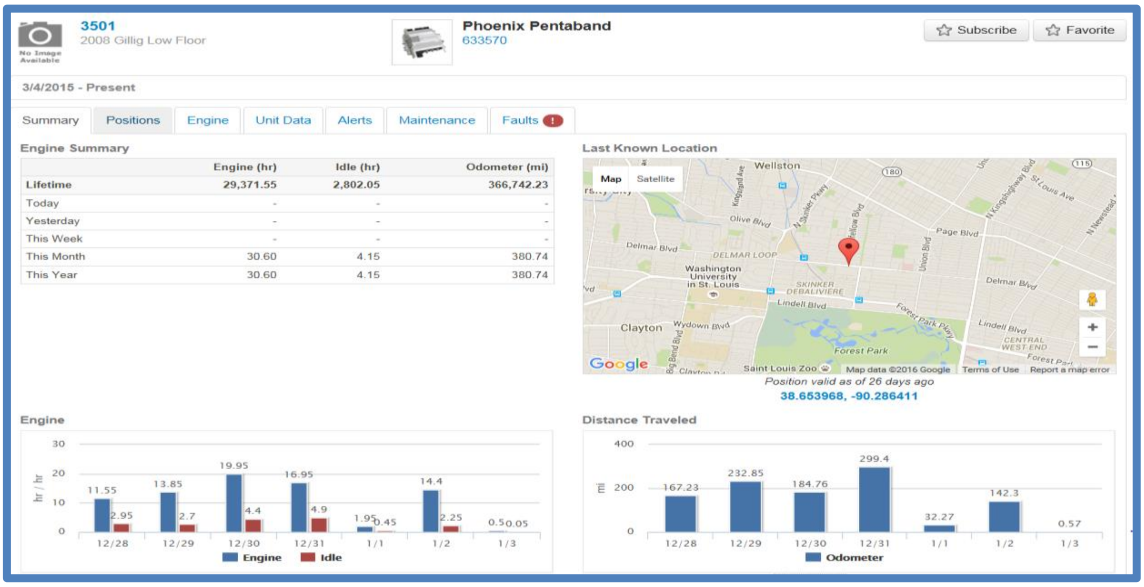

Table 2. Real-Time Dashboard

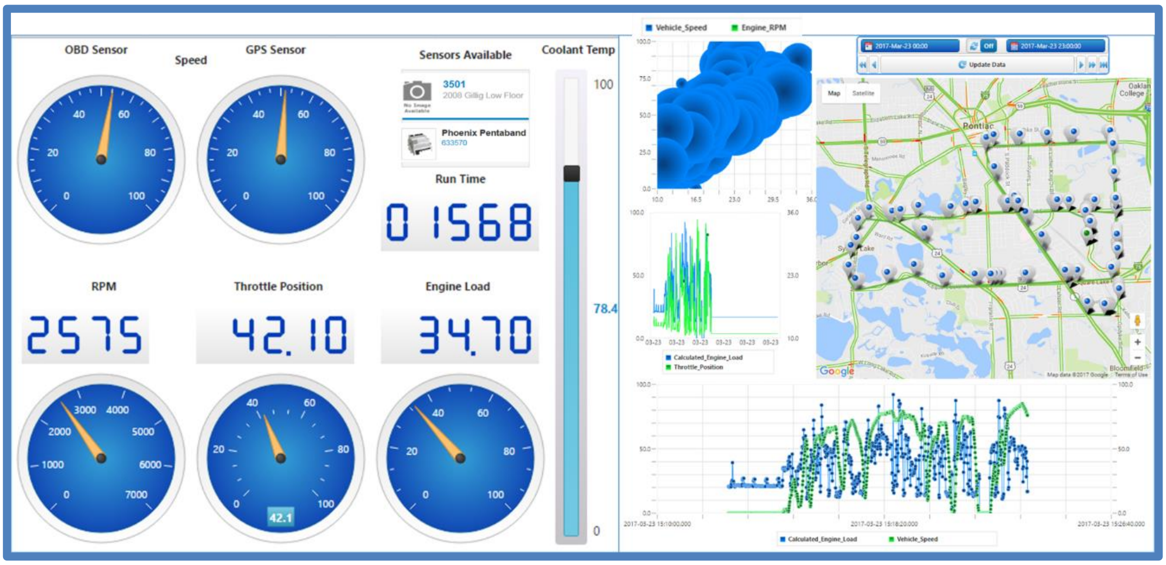

Table 3. Engine Diagnostics

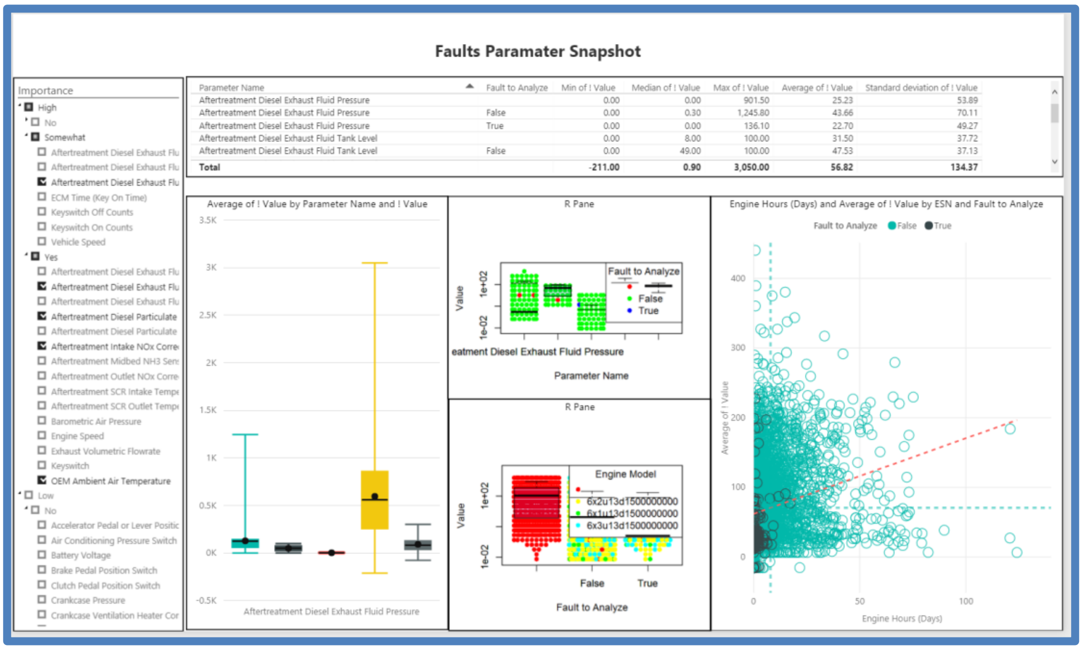

Table 4. Comparative Analysis

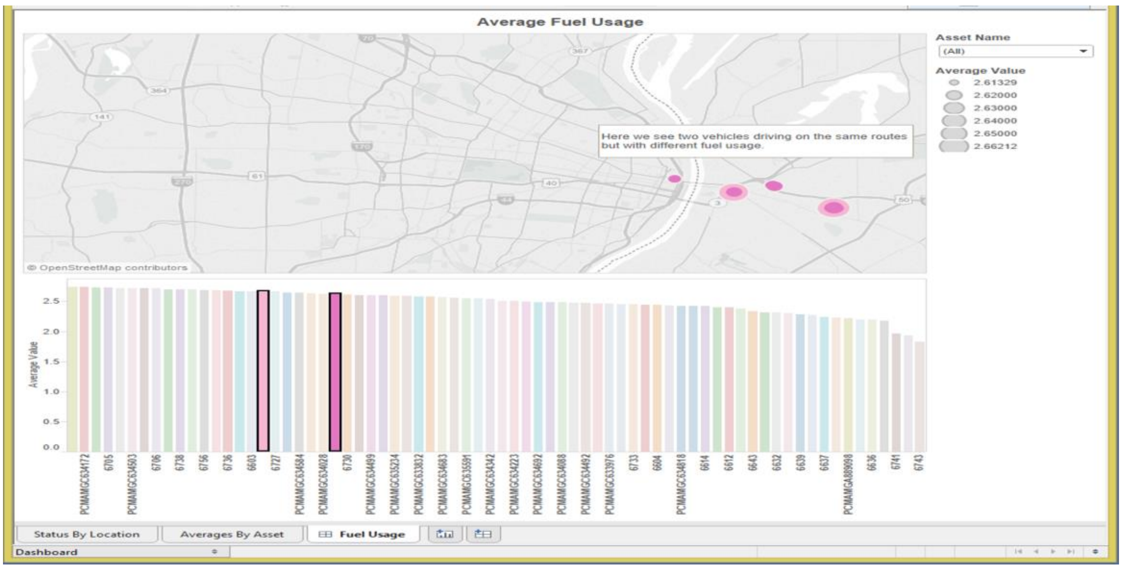

Table 4. Lead-Lag Analysis

Picture 3. Bus Maintenance

6 Insider Tips to achieve Predictive Maintenance in the Bus Industry

Tip #1: Do the Analysis

The Challenge: Getting started with Predictive Maintenance

- Too many Predictive Maintenance initiatives immediately focus on the biggest, most expensive, and/or most impactful equipment or components of critical assets
- Too much time spent connecting to machines and adding new sensors
- Large, expensive machines rarely fail due to major component failures
- More often it is the low cost, nuisance items that consume maintenance time and cost

Hoses, bearings, chip collection, weld tips, filters….

- **Understanding where you are spending time, cost, resources will be key to identifying where to start, and help drive quick-wins early in the program**

Tip #2: The Predictive Maintenance Maturity Curve

The Challenge: Getting started with Predictive Maintenance

- **Data Analytics**: what is the asset already telling us?
- **Remote Monitoring**: is the asset operating or not?
- **Asset Utilization**: how is the asset performing?
- **Remote Diagnostics**: why is the asset performing as it is?
- **Predictive Maintenance**: when will the asset fail?
- **Fully Autonomous**: automated response to change

Focus your early efforts on the with the machines you know the best, using existing data sources before adding new systems

Tip #3: The Data is not in the Bus

The Challenge: How much data is needed?

- The typical Predictive Maintenance sales pitch is pretty much the same: Plug the ECU and sensors into some new system, and you will be able to predict maintenance!
- If it was that easy, your team would have already figured that out years before
- Our Controls Engineers would have already incorporated the data into the machine programming
- The Lead-Lag analysis required to predict maintenance requires data far beyond the ECU

Quality, delivery, rework, temperature, ground vibrations, crew loading, operator training, etc.

The data you need to predict maintenance is all the other data related to the operations, and how they correlate to the machine performance

Tip #4: How do you Predict Maintenance?

The Challenge: Achieving Predictive Maintenance

- There seems to be endless vendors who have never managed operations or forecasted maintenance are now selling Predictive Maintenance solutions.
- How can these vendors be any more knowledgeable than the operators and technicians?
- How will more sensors help improve current maintenance forecasting?
- What data do you need that your techs do not already have?
- How do you predict maintenance today?

- **Model the Predictive Maintenance program after how you predict maintenance today as an improvement initiative, not as a replacement.**

Tip #5: You don't implement Predictive Maintenance

The Challenge: Achieving Predictive Maintenance

- Too much hype and too much money being spent on packaged, pre-built solutions.

The Bat Computer, The X Platform, the Scientific-Sounding-First-Name-System

- Achieving predictive maintenance requires strong analytical capabilities and the ability to integrate data across multiple domains.
- Expect gaps in connectivity and device measurement that defy packaged IT systems
- Packaged systems rarely (if ever) reflect the actual maintenance shop

- **Predictive Maintenance is the maturity level of a business process that is developed over time, by building on small successes, achieved by working together**

7 Conclusions

- Autonomous Driving is creating a revolution within the metro bus industry
- Tremendous technology change underway in the metro bus market
- Autonomous driving is often integrated with the technology change
- Predictive Maintenance is quickly becoming ***the leverage item*** to achieving autonomous driving in the metro bus industry
- Predictive Maintenance is the maturity level of a business process that is developed over time, by building on small successes, achieved by working together