Vehicle Health Management

- Everything wears out over time
- Customer’s life is disrupted, when his/her vehicle needs repair unexpectedly
- The solution - Vehicle Health Management (VHM)
  - Alert before failure happens
  - Transform an emergency repair to planned maintenance
  - Enhance ownership experience - a delight to customers
Diagnostics and Prognostics

• The diagnostic solution is to detect vehicle faults and isolate the root cause
  ➢ On-board diagnostics (OBD)
  ➢ 1996 OBD-II specification is mandatory for all cars in US

• The prognostic solution is to predict the failure and estimate the remaining useful life.
  ➢ Developing an accurate and reliable production solution is challenging
Mobile-cellular subscriptions approaching 7B, the number of people on the earth

3B use the Internet

Facebook has over 1.4 billion active users globally; 85% are mobile users

90% of the world’s data has been created in the last two years – 2.5 quintillion bytes of data created every day!

Introducing OnStar™ Proactive Alerts…
OnStar™ PROACTIVE ALERTS– A New Customer Care Service
Chevrolet Opens New Chapter for Driver Assurance

Customers will soon drive vehicles that can predict future service needs.

DETROIT – Chevrolet is using advanced connected vehicle technology to give customers an unprecedented level of assurance in their vehicles later this year. This industry-leading prognostic technology can predict and notify drivers when certain components need attention – in many cases before vehicle performance is impacted.

The predictive technology is initially focused on the battery, starter motor and fuel pump, all critical to starting and keeping a vehicle running. Additional vehicle parts and components are expected to be added in future model years.

“This is a new chapter in our pursuit to provide customers with convenience and the best overall service in the industry,” said Alicia Boler-Davis, General Motors senior vice president, Global Connected Customer Experience. “Using our innovative OnStar 4G LTE connectivity platform, we can actively monitor vehicle component health and notify our customers if covered vehicle components need attention. Nobody else in the industry is offering this.”

Building on the 15-year history of connected vehicle technology through OnStar, the prognostic service relies on OnStar 4G LTE to provide data streams from sensors within the vehicle. When a customer has enrolled their properly equipped vehicle in this service, the data is sent to OnStar’s secure servers and proprietary algorithms are applied to assess whether certain conditions could impact vehicle performance. When indicated, notifications are sent to the customer via email, text message, in-vehicle alerts or through the OnStar RemoteLink smartphone app.

This service is expected to be available on select 2016 Chevrolet Equinox, Tahoe, Suburban, Corvette, Silverado and Silverado HD models equipped with certain powertrains, followed by more Chevrolet vehicles throughout the 2016 model year.

Prognostic capability is the latest advancement in a suite of services that will keep Chevrolet customers informed from the first day of ownership through many years into the future.
Chevrolet Now Offers Customers Ability to ‘See’ the Future

Industry-first OnStar Proactive Alerts set to redefine routine maintenance

DETROIT – What if the company that built your car or truck could warn you about a potential issue before you were stranded on the side of the road? Chevrolet is the only automaker to offer this predictive technology with a new industry-first OnStar service called Proactive Alerts.

Similar to how Boeing 787s can send in-flight messages to ground crews alerting them of parts needing diagnosis and inspection before the plane arrives, Chevrolet takes the guesswork out of certain types of car trouble, predicting problems before they happen and relegating potential roadside breakdowns into routine maintenance. Could the end of the dreaded “check engine” light be next?

Owners of the 2016 Chevy Silverado, Tahoe, Suburban, Corvette and Equinox can now opt-in for OnStar Proactive Alerts, which monitor the health of the vehicle’s starter motor, fuel pump and 12-volt battery. If one of these components is wearing out or if certain faults are detected, OnStar will notify drivers through in-vehicle notifications, and an email or text message based on customer preference.

“Chevrolet already offers the most dependable, longest-lasting full-size pickups on the road, and now we are taking an important step towards the day when you will never be stranded or have certain unexpected repairs on your vehicle,” said Steve Holland, chief technologist for Vehicle Health Management at General Motors.

Predicting the future health of a vehicle component requires sophisticated systems analyzing and refining billions of pieces of data to isolate problems and determine the likelihood of a developing issue.

Proactive Alerts works by collecting a small batch of data each time the vehicle is started and monitoring it on an ongoing basis. This enables identification of vehicles that may have an affected part, significantly reducing the number of customers inconvenienced by a potential repair.

“Accuracy is the key to our prediction algorithms,” Holland said. “We want to be able to tell dealer service departments so they can spend less time testing for a condition we have already diagnosed. They can replace the necessary part quicker and minimize the amount of time a customer’s vehicle is at the dealership.”

Proactive Alerts is offered with all OnStar service plans on eligible models, including the OnStar Basic Plan that comes standard for five years on new Chevrolet vehicles. In the future, plans are in place for Proactive Alerts to monitor additional vehicle components and expand to other Chevrolet models.

Of the components for which Proactive Alerts is initially offered, customers most likely would get an alert about their 12-volt battery. A typical lead-acid battery can lose 3 percent of its charge per month, but a low state of charge may require nothing more than the customer going for a drive to recharge the battery – instead of unnecessarily replacing it. However, Proactive Alerts also can spot short circuits and high resistance that can result in premature battery failure.

“A few companies are doing limited in-vehicle diagnostics, but none have yet demonstrated the capability of accurately predicting a component’s life expectancy,” said Paul Krajewski, director of the Vehicle Systems Laboratory in General Motors R&D. “As we keep expanding the parts of the vehicle we cover, we hope to continuously enhance our customers’ experience, saving them time and money.”
Current Status for OnStar™ PROACTIVE ALERTS Service

- Launched on
  - 2016 Chevrolet Equinox
  - 2016 Chevrolet Tahoe
  - 2016 Chevrolet Suburban
  - 2016 Chevrolet Corvette
  - 2016 Chevrolet Silverado
  - 2016 GMC Terrain
  - 2016 GMC Yukon
  - 2016 GMC Sierra
  - 2016 Cadillac Escalade
- Being extended to more GM vehicle programs over time
- Currently cover three critical components
  - battery, starter, fuel pump
Framework for OnStar™ PROACTIVE ALERTS Service

Vehicle engineering data is collected with customer consent and free opt-in.
How did We Get Here?

• The challenges
  - Prediction uncertainties due to many impacting factors: usage variations, part to part variations, environmental variations
  - Low false positive and low false negative

• The opportunities
  - Wireless communication
  - Onboard sensor
  - Cloud computing

• The approach
  - Combination of physical model and big data
Physical-Model based Algorithm Generation

- Study failure modes and model physics of failure
- Identify fault signatures and failure precursors
- Estimate model parameters
- Validate concept on benches and test vehicles

Lead Acid Battery
(Plate Surface Scanning Electron Microscopy)

Equivalent thermal circuit model battery

Electric Motor

Equivalent electrical circuit model for battery

Particle filter based battery life estimation
Big-Data Based Algorithm Refinement and Calibration

- Correlate field data from 1,000,000+ vehicles with warranty analysis and engineering assessment
- Refine failure precursors to address corner cases
- Iteratively calibrate algorithm parameters

Data visualization

Results from Kernel-SVM-based feature ranking

Membership Function for Fuzzy decision tree
A Validation Case Study
Battery SOC Estimation Enhancement

- Battery State of Charge (SOC) is estimated using two approaches
  - OCV-SOC mapping
  - Coulomb counting

- \[ \text{SOC}_{\text{running}} = \text{SOC}_0 + \frac{n}{c_R} \int_{t_0}^{t} I \, dt \]

- Large discrepancies are identified from Data
  - If the SOC is under-estimated, the charging resistance may be over-estimated, which will result in a false alarm.
  - If the SOC is over-estimated, the low SOC cases are failed to predict.

MY2012 GMC Yukon

20% 23%
Identify the Root Cause

- The parasitic load current is not accurately measured

- Acid Stratification cause SOC over-estimated
  - Uneven electrolyte density results in unequal SOC, and unequal current distribution in the battery, which makes the battery degradation faster.

- Surface Charge may cause SOC over-estimated
  - The electro-chemical charging reaction occurs on the plate surface, and the diffusion process is slow comparing to the reaction.

Illustration of acid stratification for lead acid batteries [9].
1. Identify confirmed SOC
2. Estimate ignition off current
3. Estimate SOC estimation using ignition on current and ignition off current

\[ SOC_{est}(k) = SOC_{est}(k-1) + \frac{1}{C_{norm}} \int \rho \cdot I_{on} \cdot dt + \frac{1}{C_{norm}} I_{off} \cdot \Delta t_{off} \]
• The new algorithm can reduce the number of points with large estimation error from 11% to 1%.

• For low SOC points, it can reduce the number of points with large estimation error from 20% to 4.8%.
Future Opportunity

Electronic Explosion

- Rear-Passenger Flat-Panel Displays
- Command System with PCMCIA Slot
- GPS Navigation
- DVD Player
- LED Lamp Cluster
- Head-Up Displays
- Dashboard-Instrument Cluster
- Telematic System
- Climate Control
- Electronic Power-Roof System
- Radar Sensor
- Transmission Control
- Collision Avoidance
- Adaptive Cruise Control
- HID Headlamp
- Memory Seat/Mirror/Steer
- Air-Bag Control and Satellite Crash Sensors
- Active Steering
- Tire-Pressure-Monitoring System (TPMS)
- Body Control
- Suspension Control
- Power Windows
- Remote Keyless Entry
- Seat Massage/HVAC
- Adaptive Brake Lights
- Electronic Returnless Fuel System
- Parking Sensors
- Rear-View Camera
- Battery Management
- Power Seats
- Throttle Control
- Engine Control Unit
- Folding Door Mirrors
- Electrochromic Rear-View Mirrors
- Car Radio
- Anti-Lock-Braking System/Electronic-Stability Program
- Starter
The VHM Approach Revisited

1. Identify failure modes
2. Identify precursors and impact factors of failures
3. Develop prognostics algorithms
4. Calibrate algorithm parameters
5. Evaluate the performance
6. Go to 1

Can we automate or semi-automate the steps?
- Failure precursor identification
- Algorithm adaptation with limited number of fault instances
- Automatic calibration
- Performance evaluation with automatic labeling
GM’s new car-sharing service

Provide customers access to highly personalized, on-demand services.

Initially launching at U-Michigan, Ann Arbor

- Rideshare
  AM / PM Commutes
  Weekends

- Grocery Delivery
  Scheduled in Advance
  Early Evenings Result in Surge

- Food Delivery
  Lunch / Dinner Hours
  Sundays

- Package Delivery
  Scheduled in Advance
  Holidays Result in Surge
MAVEN MEMBERS HAVE DRIVEN

- 79% CAR SHARING
- 13M+ RIDE SHARING RIDES GIVEN*
- 90% OF RESERVING MEMBERS ARE MILLENNIALS

MAVEN HAS ROLLED OUT IN 17 CITIES ACROSS NORTH AMERICA

MAVEN MEMBERS HAVE DRIVEN ENOUGH MILES TO GO AROUND THE WORLD 10,280 TIMES

CHEVROLET BOLT EV
- MILES DRIVEN: 20M+
- ELECTRIC VEHICLE MILES DRIVEN
- GALLONS OF GASOLINE SAVED*: 800K+

ACROSS OUR BRANDS
- CADILLAC ATS
- CHEVROLET MALIBU
- GMC YUKON

*estimate
GM Super Cruise

On MY 2018 Cadillac CT6 for semi-autonomous highway driving, which permits hands-free operation of the vehicle.

Super Cruise works with Adaptive Cruise Control (ACC), which controls acceleration and braking while it is enabled and operating.

Super Cruise support services through OnStar®, along with precision LiDAR mapping, work with in-car cameras, radar sensors, and GPS to detect every curve and hill on the road ahead.

Super Cruise will be available on all Cadillac models, with the rollout beginning in 2020.

D&P will be more critical in autonomous vehicles than the conventional vehicles.
Intelligent Transportation in the Next Decade (2025)

- Automated Highway Driving
- Partial / Full Urban Driving
- Extensive V2V (and V2P) capability
- Acceleration of Intelligent Infrastructure
- High-Volume / High-Speed Integrated Connectivity
- Efficiency / Electrification
- Shared Mobility
- Full VHM Coverage