The 8\textsuperscript{th} Annual Conference of the PHM Society

Panel Discussion on:

Fielded Systems

6-Oct-2016, 1:15-3:00 PM MDT
Introducing Today’s Panel

Chair:
  – Andy Hess, Hess PHM Group

Panelists:
  – Steve Holland, General Motors
  – Tim Felke, Honeywell
  – Pete Carini, UTC
  – Gary Larivee GDLS-C
Steve Holland

- Currently, Research Fellow, Vehicle Health Management at GM Global R&D
- 40+ years of experience at GM in R&D and Manufacturing Eng./Robotics
- Chief Technologist: applying PHM technologies to GM vehicles (10 yrs)
- Previously R&D Director: application of PHM to improve GM plant throughput (4 yrs)
- Bachelors/EE from Kettering & Masters/CS from Stanford
- PHM Board of Directors & Member of PHM International Scientific Committee
- SAE Member: HM-1 IVHM Standards & IVHM Steering Committee
- Professional Engineer & IEEE Fellow

steven.w.holland@gm.com
## IVHM Capability Levels for Aerospace/Automotive

### Manual Diagnosis & Repair Process performed by Technician

<table>
<thead>
<tr>
<th>SAE Level</th>
<th>Vehicle Health Capability</th>
<th>Narrative Description</th>
<th>Participation in Repair Actions</th>
<th>Key Data Resources</th>
<th>Availability of Logged &amp;/or Real-Time Data</th>
<th>Use of Supporting Models</th>
<th>IVHM System Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Limited On-Vehicle Warning Indicators</td>
<td>Service actions for scheduled maintenance or when Operator notices problems or is alerted by indicator lights or simple gages.</td>
<td>Operator/Driver &amp; Service Tech</td>
<td>On-Vehicle Measurements &amp; Observation</td>
<td>N/A</td>
<td>Paper-based Manuals</td>
<td>Only Manual Diagnostic Tools &amp; No Condition-Based Services</td>
</tr>
<tr>
<td>1</td>
<td>Enhanced Diagnostics Using Scan Tools</td>
<td>Service techs gain added diagnostic insight using automated scanners to extract vehicle operating parameters &amp; diagnostic codes</td>
<td>Operator/Driver &amp; Service Bay/Depot Tools</td>
<td>Logged Diagnostic Codes &amp; Parameters available to Service Tech</td>
<td></td>
<td>Paper-based Manuals</td>
<td>On-Board Diagnostics Available</td>
</tr>
<tr>
<td>2</td>
<td>Telematics Providing Real-Time Data</td>
<td>Service techs gain real-time vehicle data via remote monitoring of vehicle to more completely capture issues</td>
<td>Operator/Driver, Service Tech &amp; Remote Support Center Advisor</td>
<td>On-Vehicle, Service Bay / Depot &amp; Cloud Data</td>
<td>Telematic Data Available to Service Tech with Diagnostics Info</td>
<td>Paper-based Manuals</td>
<td>On-Board &amp; Remote Data Available</td>
</tr>
</tbody>
</table>

### Diagnosis & Repair Augmented by Prognosis & Predictive Analytics

<table>
<thead>
<tr>
<th>SAE Level</th>
<th>Vehicle Health Mgmt.</th>
<th>Narrative Description</th>
<th>Participation in Repair Actions</th>
<th>Key Data Resources</th>
<th>Availability of Logged &amp;/or Real-Time Data</th>
<th>Use of Supporting Models</th>
<th>IVHM System Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Component Level Proactive Alerts</td>
<td>Operator and service techs are provided with component health status (R/Y/G) before problem occurs. Limited condition-based maintenance</td>
<td>Operator/Driver, Service Tech &amp; Cloud-Based Services</td>
<td>On-Vehicle, Service Bay &amp; Cloud Data</td>
<td>Telematic Data Available to Service Tech with Diagnostics Info</td>
<td>Addition of Component-Level Health Models</td>
<td>Component-Level Health Predictions</td>
</tr>
</tbody>
</table>
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 components are expected to be added in future model years. “This is a new chapter in our pursuit to provide customers with the highest 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 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 problem 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 potential issues before the plane arrives, Chevrolet takes the guesswork out of certain types of car trouble, predicting problems before they happen and redefining what routine maintenance means.

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.”
- 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
- Introducing OnStar™ Proactive Alerts - a new customer care service
CHEVROLET: SOLVING ISSUES BEFORE THEY HAPPEN

OnStar Proactive Alerts predict when certain components need attention

VEHICLE DATA TRANSMITTED

DIAGNOSTICS + PROGNOSTICS

REAL-TIME NOTIFICATION

IN-VEHICLE MONITORING

STARTER MOTOR

FUEL PUMP

BATTERY

HOW IT WORKS WITH YOUR BATTERY

VEHICLE BATTERY

BATTERY CONDITIONS SENT

LOW BATTERY PREDICTED

ALERT SENT

ISSUE AVOIDED

TEXT

EMAIL

IN-VEHICLE
Where are we today on OnStar™ Proactive Alerts?

– 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

– Currently cover three critical components
  • battery, starter, fuel pump

– Will be extended to more GM vehicle programs and cover other critical vehicle components over time
Tim Felke

• 30+ years of experience in Condition Based Maintenance (CBM) and Integrated Vehicle Health Management (IVHM)
• Currently; Engineering Fellow, Honeywell IVHM Systems
• Previously;
  – Senior Technical Manager for Honeywell’s Common IVHM Architecture
  – Technical Lead for Deployment of IVHM in Automotive Applications
  – Data Architect for US Army’s Platform-Soldier, Mission Readiness System
  – Technical Lead for Diagnostics and Fault Model Development of Central Maintenance Computer (CMC) for Boeing 777 and 787 Aircraft

tim.felke@Honeywell.com
Honeywell Integrated Vehicle Health Management (IVHM) History

- Flight Control Maintenance Diagnostics System
- Platform Soldier Mission Readiness System
- Primus Epic® Central Maintenance & Aircraft Condition Monitoring
- Zing™ Vehicle Diagnostics
- 777 Central Maintenance & Aircraft Condition Monitoring
- 787 Crew Information & Maintenance System
- Health & Usage Monitoring (HUMS)
- CEV Orion Systems Management & Abort Determination
- Automotive – Integrated Vehicle Health Management (IVHM)
Honeywell Fielded Systems: Central Maintenance Computing Systems

777: Monitors 85% of AC systems
- 80% Reduced NFFs
- 50% Reduced Repair Turn Time
- >99% Dispatch reliability

787: 65,000 parameters monitored
- 150 systems, 1100 ECUs
- Advanced Diagnostic Modeling
- 30% DMC savings projected vs. 767-300
- Includes Cyber Security Features

Business and Regional Jets
- 15 Major OEMs
- Nose to Tail Coverage for CMCF and ACMF
Honeywell Fielded Systems: Helo Health & Usage Monitoring

Vibration Monitoring and Analytics: Rotor Track and Balance

- 95% reduction in aborts for vibration
- $102M in IVHM savings over 26 months
- Readiness Increased by 5-8%
- Class A mishaps reduced 9-12%
- Parts Costs per FH Reduced 12-22%
- Maintenance reduced by over 2950 mh

HUMS = Safety, Lower Cost, Higher Readiness
Honeywell Fielded Systems: Auxiliary Power Unit Trend Monitoring

APU Health Prediction
- 4500 APUs Monitored
- On-wing time: 75% improvement
- Eliminate maintenance inspections
- Web-based tool gathers APU sensor data
- Real-time, in-flight data transmission
- $1.2M annual maintenance cost savings/vehicle
Honeywell Fielded Systems: Automotive Model Based Diagnostics

Adapting IVHM for Ground Vehicles

- Low cost diagnostic modeling
- Deal with high variation
- Improve Diagnostic Accuracy
- Reduced NTFs
- Reduce Intermittent Faults

Warranty Cost Savings (Projected)

- 50% reduction in unnecessary repairs
- $100M+ annual warranty cost savings
Honeywell IVHM System Overview

Configurable Data Recorders
Software Libraries Provide Intelligent Data Collection

Analytics
Analytics for Fleet, Quality and Material Anomaly Detection and Cause Analysis

Diagnostics
Support for Service Bay Technician

Prognostics
Graphical Fault Visualization

Guided Diagnostics
Interactive Diagnostic Work Plans

Trending & Prognostic Alerts

Field Feedback / Learning Loop

Knowledge Management System

Data Recording Specifications
Integrated Reference Models
Calibration Files
Configuration Files

October 2016 Annual Conference of the PHM Society 2016
Dealing with Fleet Variation: Problem Statement

• Sources of Variation
  – Market / Usage Driven Product Variation
  – Evolution of Requirements (Regulatory, Safety, Efficiency, Customer Preference)
  – Versions: Evolution of Implementations (to address new requirements, reduce cost, improve reliability)
  – Variants: Introduction of new system / part as an alternative to an old one.

• Effects of Variation on Asset
  – Changes to BOM, Failure Modes, Functions and expected Symptoms
  – Changes to Failure Occurrence Rates
  – Changes to Failure / Symptom CoOccurrence Rates
  – Changes to Parametric Reporting Messages
  – Changes to Fault Reporting Messages

• Effects of Variation on IVHM System
  – Changes to IO and Decode Functions
  – Changes to Fault Detection Algorithm Parameters and Trip Points
  – Changes to Fault Isolation Logic
  – Changes to Fault Prediction Algorithm Parameters and Trip Points
  – Changes to Maintenance Procedures
  – Changes to Logistics and Parts Management
Dealing with Fleet Variation: Solution Summary

- Minimize Changes to Software, Have Variation Handled by the Reference Model
- Maximize Use of Design Data in Model Integration Process
- Produce Separate Reference Models for Each Major Variant (e.g., Model-Year)
- Use Effectivity Tags within Reference Model to Encode Minor Variation within a Major Variant (e.g., Service Bulletins, Part Changes, etc.)

Component Models (Re-Usable), Include:
- Processing Model
- Fault Model
- Advisory Model

Interface Models (Re-Usable)

Design Data (Per Program)

Model Integration Processes

- IRM is Produced for Each Major Platform Variant
- Includes Effectivity Information to Ensure Accurate Results

BOM, Schematics, FMEA, ICD’s, UML, Models, Algorithms, etc.

October 2016
Annual Conference of the PHM Society 2016
UTC Aerospace Systems

HUMS History

1990

- V-22
- H-60B HIDS, A-109 Rega, CH-53E EOA

2000

- KT-1
- H-60B, CH-53E, S-92, UH-1Y/AH1-Z, MH-60, UH-60A/L

2010

- V-22 Refresh
- VSLED
- MPU
- IVHMU
- VIGOR
- RSIM

HUMS Functions

- Parametric Data Recording
- Rotor Tuning
- Shaft Balancing
- Vibration Diagnostics
- Mechanical Diagnostics
- Event Detection
- Exceedance Detection
- Operational Usage
- Regime Recognition

Over 25 years experience with over 2000 systems delivered

HUMS History
In the first one-year deployment of 38 aircraft equipped with UTC Aerospace Systems HUMS in an Army battalion, the battalion executed 27% more missions than a non-equipped sister battalion with the same mission profile. The HUMS-equipped battalion set a new Army record for the most missions accomplished in a one-year period, never missing or aborting a mission due to mechanical problems.

The U.S. Army recognized a reduction in Non-Mission Capability Maintenance rates of 10% for aircraft deployed into combat operations.

**Maintenance Reductions**

<table>
<thead>
<tr>
<th></th>
<th>Unscheduled MMH/FH</th>
<th>Mission Aborts MMH/FH</th>
<th>Total MMH/FH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitored</td>
<td>-52%*</td>
<td>-48%*</td>
<td>-17%*</td>
</tr>
<tr>
<td>Unmonitored</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Actual data from U.S. Army Deployed UH-60 Black Hawk helicopters
Everything works as designed until it is tested. At the point where it is tested, it fails as designed.

We should not seek to “pass the test” but rather aspire to “fail to break” the system.

It is by exposing the flaws and limitations in a system that we can improve the systems we build.
CBM – US Army Stryker
THE THINGS THAT HELP PREDICT ARE LOOKING AT THE TITLE, COVER AND CHARACTERS, ALSO READING THE FIRST PART OF THE BOOK.
GDLS Lessons Learned

Cost of Entry

- Average miles / hours driving and at idle
- Average speed attained while vehicles in use
- Average fuel consumption while driving and at idle

- PVT testing maintains approx. 60% engine load for duration of day - In theatre engine load rarely exceeds 60%
- PVT test requires constant vehicle movement - In theatre vehicle is idle ~ 70% of mission
CBM Driven Investigations – 28 OEF
Condition Indicators Lead to Preventive Maintenance
**GDLS Analysis Findings:**

**Vehicle Usage**

- Vehicle data showing hot shutdown event.
- Vehicle data showing immediate electrical power shutdown.