SAE INTERNATIONAL
Innovations in Mobility
October 29–31, 2019 | Novi, MI

Prognostics & Vehicle Health Management in the Automotive Industry

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Health-Ready Components / IVHM – Session IIM416-1

31 October 2019

Defining terms…

Diagnosis:

Process of determining the root cause of a problem once a failure has occurred …that is, what part replacement(s) or repair action is necessary to fix the problem (today's world in automotive)

Prognosis:

Process of predicting the onset of a potential failure mode BEFORE the failure has occurred …while the component is still operating within specs & with sufficient advance notice to avoid the problem (RUL)

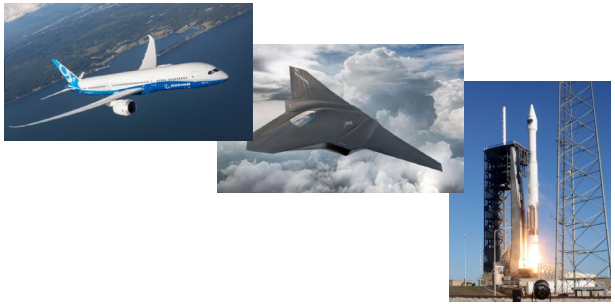
Caveat: This distinction is *very* significant technically but is mostly lost on the public

RUL = Remaining Useful Life

Critical Importance of Setting Clear Goals

Lessons learned from Boeing*

- Commercial Aircraft vs.
- Military Aircraft vs.
- Spacecraft



GM Mfging Applications

- Goal: Predict coming *machine failures* to reduce downtime and increase factory throughput
- Great history files in this domain

GM Vehicle Applications

- Goal: Improve the "*customer experience*"
- Cost & time savings nice too but these are 2nd-ary benefits
- Getting the *right* data is hard!

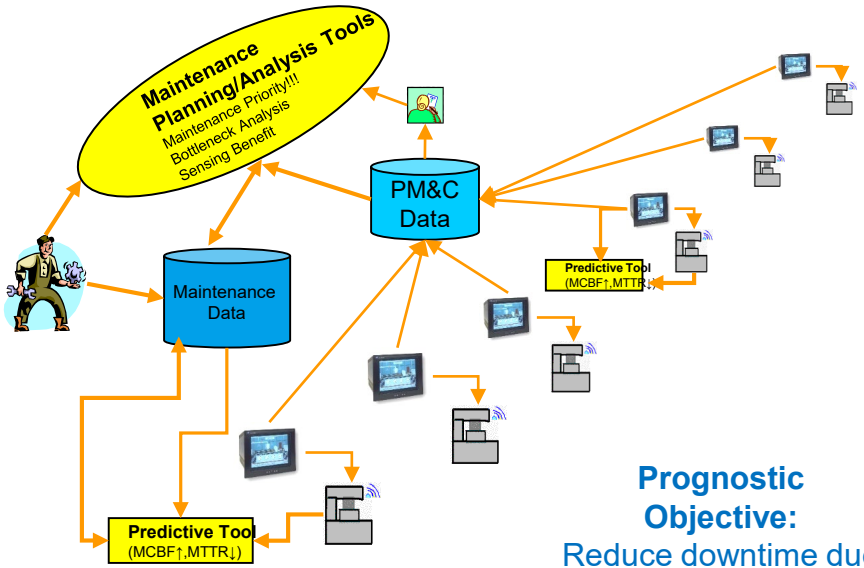
Proactive Alerts

* Source: **Keith Sellers**

Prognostics has proven *extremely* successful in aerospace, communications, IT, wind farms & even automotive…

This technology works!

- GM had huge success using prognostics in assembly plants 15 yrs ago ➔
- A key to success is understanding your primary objective

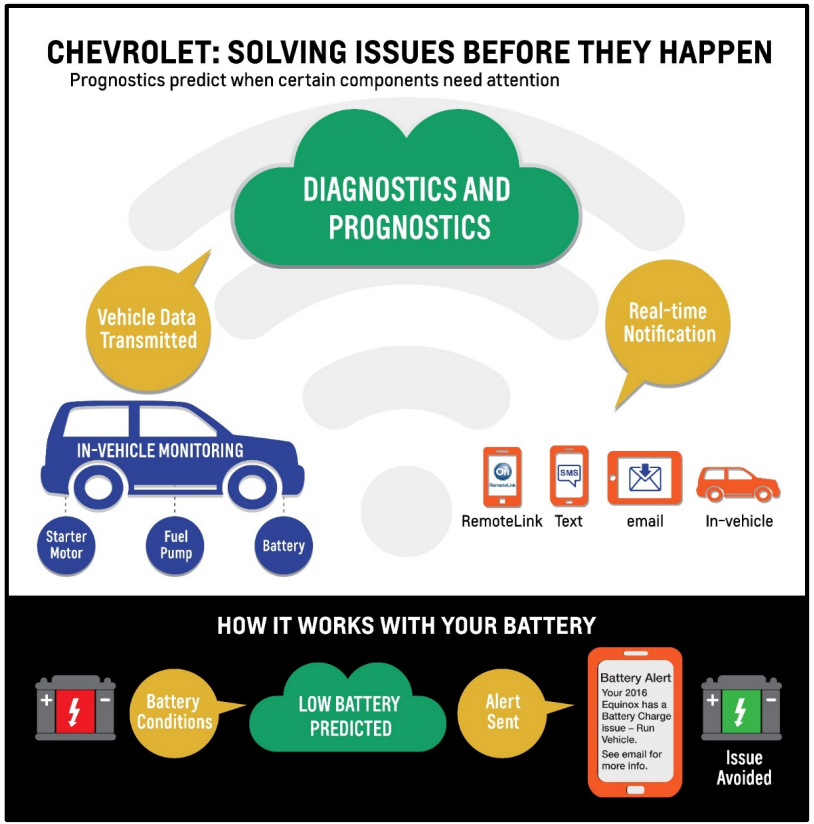


Prognostic Objective:
Reduce downtime due to unplanned maintenance (i.e., which machines will break next?)

Source: "Issues and Opportunities in Automotive PHM", S. W. Holland, PHM Society Conference, St. Petersburg, FL, October 2019

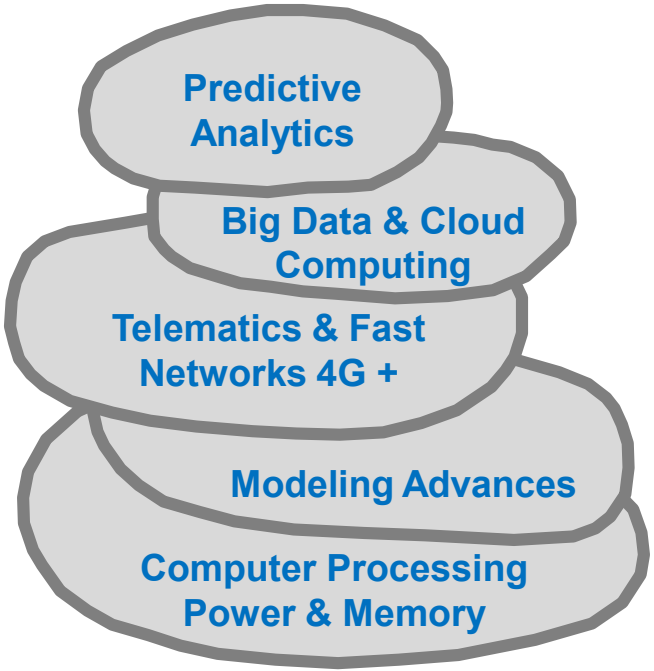
Launch of GM OnStar “Proactive Alerts”

CES 1/4/15:



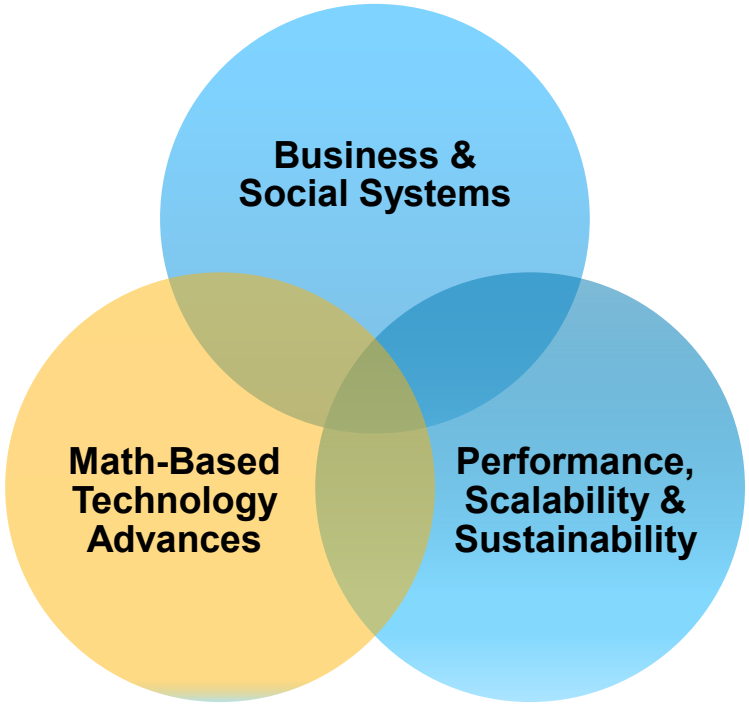
Source: “Issues and Opportunities in Automotive PHM”, S. W. Holland, PHM Society Conference, St. Petersburg, FL, October 2019

Foundations ➔ Technology advances have opened the door for a new paradigm in automotive diagnostics



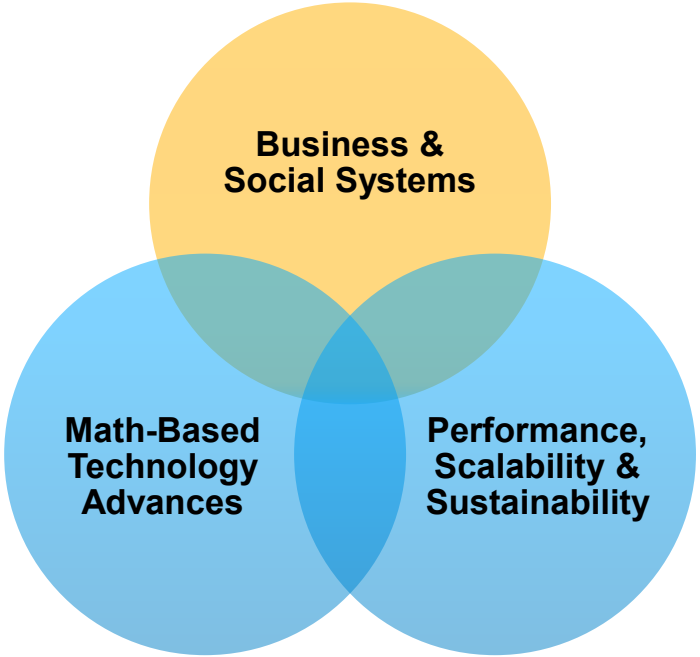
- Prognostics was enabled by stacking up a series of technology advances
- ***…but*** business & social systems will need attention
- ***…but*** we also need better real-time performance, scalability & sustainability

Foundations of Prognostic Systems:
Math-Based Technology Advances



- **GM's Math-Based Approach (c.1991)**
  - Math Model is the Master! ("Digital Thread")
  - GE's "Digital Twin" concept (c.2002)
- **Analytic Method Sophistication**
  1. Descriptive
  2. Predictive (Prognosis)
  3. Prescriptive
- **Combining Physics-Based & Data-Driven Modeling**
- **Targeting High Reliability**
  - If you aren't extremely confident, you dare not use the predictions

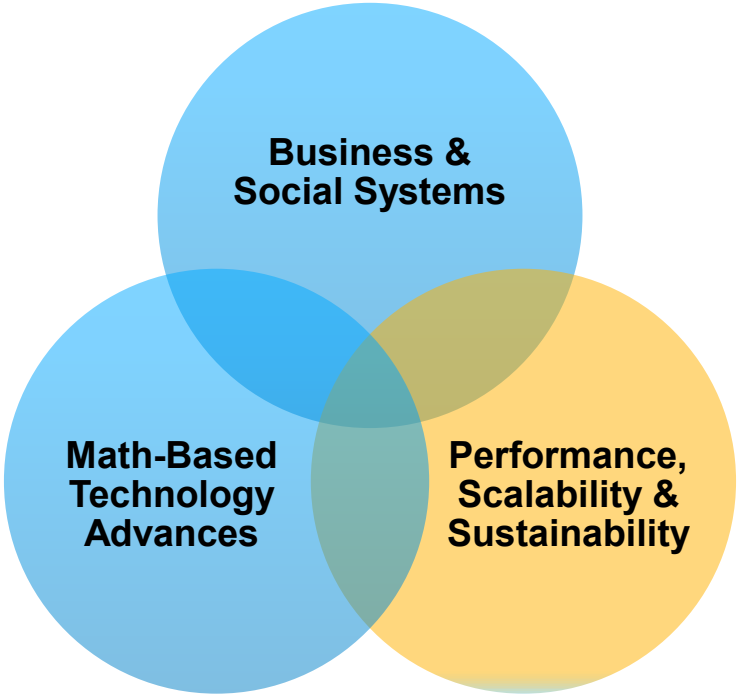
Foundations of Prognostic Systems:
Business & Social Systems



- **Business & Social Relationships are critical to success**
  - Prognostics cannot be implemented effectively as an afterthought
  - Traditional product design organizations control budget allocation and resources
- **In the same way that OBD reached full stride when the design community realized they needed to work with the OBD community*, so will it be true for the Prognostics community**

* John Van Gilder, GM OBD

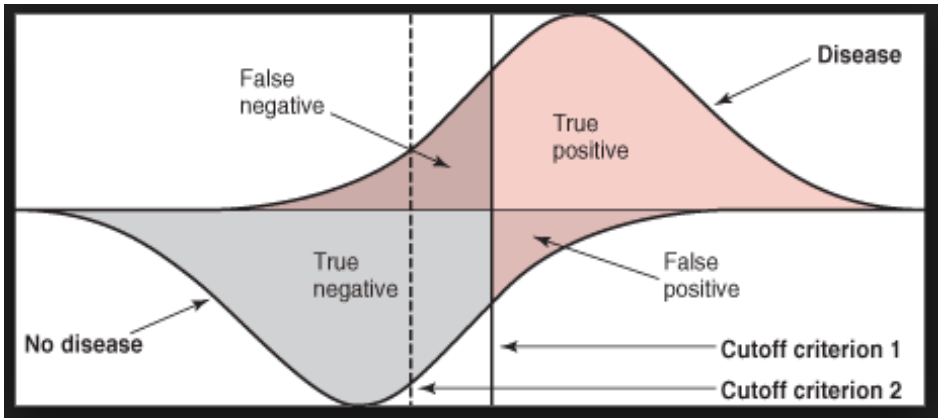
Foundations of Prognostic Systems:
Performance, Scalability & Sustainability



- Advances in computer hardware and software are improving performance but high transaction rate & data volume can be challenging
- Commercial applications must scale to large numbers of vehicles
- The technical processes for supporting/maintaining prognostics must be sustainable over time

Some Important Lessons Learned

1. **Establishing ground truth for component failures is problematic**
   - ✓ SMEs tend to be the ultimate arbitrators
2. **No Trouble Found doesn't mean "no trouble found"**
   - ✓ See next slide
3. **It is extremely difficult to catch live failures in the field**
4. **If you don't try to do prognostics, you are accepting 100% false negatives**



NTF Offers Insights into the Real World

- **Auto industry uses NTF for "No Trouble Found" & Aero industry uses similar NFF for "No Fault Found"**
- **Rates often exceed 50% (sometimes >90%)**
- **NMF for "Not My Fault" might be a better name since real reason could be:**
  1) Testing machine/procedure in service bay or at supplier doesn't capture all field failure modes
  2) Testing environment doesn't reflect actual operating environment (temp, pressure, humidity, vibration, etc.)
  3) Wiring/connection problems in vehicle such as communication or power/ground issues
  4) Cooperating module(s) not performing as expected
  5) Purchasing Buyer negotiated a spec waiver for a lower price which allows supplier to limit warranty exposure
  6) …or component actually has no problems!

Selected VHM Benefits in Automotive

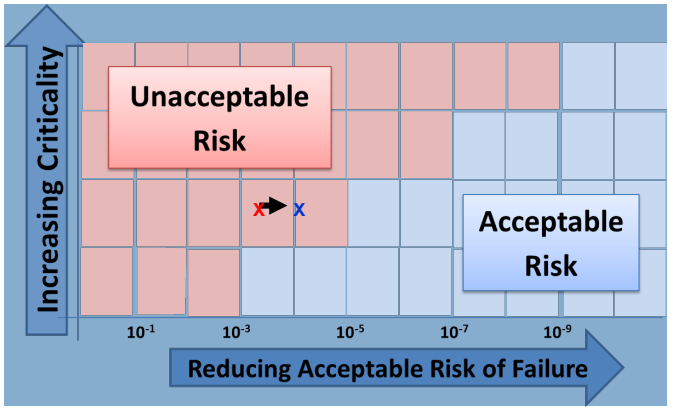
- **Improved customer ownership experience**
  - ✓ Transforming failures into routine maintenance
  - ✓ Why “perceived” reliability is so important
- **Reduced warranty costs**
  - ✓ Avoiding repeat visits
  - ✓ Reacting before major failures happen
  - ✓ Targeted recall campaigns
- **Enhanced availability/uptime for manufacturing and fleets**
  - ✓ Reliability indirectly leads to enhanced safety

Benefit ➔ Prognostics can dramatically improve customer perception

“The customer is king”

1. Prognostic alerts as seen by customers are akin to normal maintenance events and are NOT seen as failures!!!
   – this results in a 10-20x reduction in negative impact

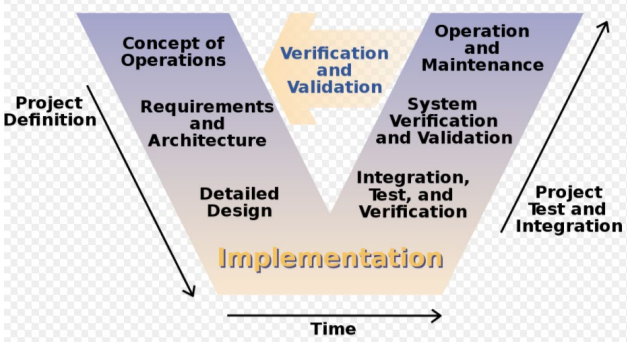
2. While there is no substitute for “designed-in” reliability, consider that achieving just 90% prognostic coverage yields a 10-fold “perceived reliability gain ➔
   – note periodic maintenance analogy to prognostics



Source: Ken Pipe, SAE HM-1, April 2014

Benefit ➔ Enablers for prognostics also yield other important benefits

- **Engineering design**
  - Enhanced FME[C]A
  - Understanding precursors (parameters, relationships/models)
- **Validation process**
  - Faster turnaround, better data from the field
- **Service & Support**
  - Reacting before small problems get big
  - Value in knowing what is working well in addition to problem indicators
- **Warranty management**
  - Narrowing recall actions
  - Prioritizing recall actions



Caution: Prognostics technology still immature

- **VHM technology is impressive but the field remains *immature***
  - It has proven value in some aspects of automotive for enhancing availability & reliability
  - Indirectly, this has benefits for *vehicle safety* but care must be taken to nurture the technology
  - Excessive regulations too early might put future VHM advances at risk

- **VHM software is not mature enough to be used within emission or safety control systems (or flight controls in the case of aerospace)**
  - Said differently, VHM outputs should *not* be used as emission or safety system *inputs* because…
  - An approach to deal with this situation is to extract only portions necessary from the VHM software and embed just that into the control system (subject to all necessary requirements & care)

Role for Standards

- **Data is increasingly becoming *"the"* critical asset**
  - But even with big data, it can be difficult to use
  - We must rise from **Data ➔Information ➔Insight ➔Action**
- **PHM/VHM/IVHM* encompasses both the traditional paradigm of diagnostics and the new paradigm of prognostics**
- **SAE JA6268™ lays out a future vision of how suppliers and OEMs can collaborate to mutual advantage to speed VHM implementation**
- **Industry Consortia provides a complimentary mechanism to go beyond what standards alone can accomplish**

HRCS
Health Ready Components and Systems
A Program of SAE ITC

* PHM, VHM, IVHM used somewhat interchangeably

SAE JA6268™: Automotive suppliers to play an increasingly important role in cost-effective prognostics implementations

SURFACE VEHICLE/AEROSPACE RECOMMENDED PRACTICE	JA6268™	APR2018
	Issued 2018-04	
Design & Run-Time Information Exchange for Health-Ready Components		

RATIONALE

This Surface Vehicle & Aerospace Recommended Practice was created to help reduce existing barriers to the successful implementation of Integrated Vehicle Health Management (IVHM) technology into the aerospace and automotive sectors by introducing health-ready components. Health-ready components are augmented either to monitor and report their own health or, alternatively, ones where the supplier provides the integrator sufficient information to accurately assess the component's health via a higher-level system on the vehicle. The principal motivation for health-ready components is to facilitate enhanced IVHM functionality in supplier-provided components that better meet the needs of end users and government regulators in a cost-effective manner. Underlying this motivation is the assumption that market forces will drive the need to achieve IVHM's benefits, which will in turn drive new requirements that suppliers must ultimately meet. This recommended practice has two primary objectives: (1) to encourage the introduction of a much greater degree of IVHM functionality in future vehicles at a much lower cost, and (2) to address legitimate intellectual property concerns by providing recommended IVHM design-time and run-time data specification and information exchange alternatives in an effort to help unlock the potential of IVHM.

https://www.sae.org/standards/content/ja6268_201804/

What is a “Health-Ready Component”?

- Health-ready components are supplier-provided components or subsystems which have been augmented to monitor and report their own health or…
- Alternatively, those where the supplier provides the integrator sufficient information to accurately assess the component’s health via a higher-level system on the vehicle (or combination of both)
- Information sharing should be machine-readable or math-based
- *This is key to unlocking the potential of VHM!*

Why is JA6268™ important to Industry?

- **Motivation is to facilitate & speed the integration of IVHM functionality for supplier-provided components to meet needs of**
  - ✓ OEMs,
  - ✓ end users/fleets and
  - ✓ government regulators

- **Also to lower costs & address legitimate IP concerns**

- **Market forces will ultimately drive industry-wide application of IVHM and new health-ready requirements that suppliers must ultimately meet**

SAE's IVHM Capability Levels

SAE Level	Vehicle Health Capability	Narrative Description	Participation in Repair Actions	Key Data Resources	Availability of Logged &/or Real-Time Data	Use of Supporting Models	IVHM System Characteristics
Manual Diagnosis & Repair Process performed by Technician							
0	Limited On-Vehicle Warning Indicators	Service actions for scheduled maintenance or when Operator notices problems or is alerted by indicator lights or simple gages.	**Operator/Driver & Service Tech**	On-Vehicle Measurements & Observation	N/A	Paper-based Manuals	Only Manual Diagnostic Tools & No Condition-Based Services
1	Enhanced Diagnostics Using Scan Tools	Service techs gain added diagnostic insight using automated scanners to extract vehicle operating parameters & diagnostic codes	Operator/Driver & Service Tech	**On-Vehicle & Service Bay/ Depot Tools**	Logged Diagnostic Codes & Parameters available to Service Tech	Paper-based Manuals	On-Board Diagnostics Available
2	Telematics Providing Real-Time Data	Service techs gain real-time vehicle data via remote monitoring of vehicle to more completely capture issues	Operator/Driver, Service Tech & Remote Support Center Advisor	On-Vehicle, Service Bay / Depot & Cloud Data	**Telematic Data Available to Service Tech with Diagnostics Info**	Paper-based Manuals	On-Board & Remote Data Available
Diagnosis & Repair Augmented by Prognosis & Predictive Analytics							
3	Component Level Proactive Alerts	Operator and service techs are provided with component health status (R/Y/G) before problem occurs . Limited condition-based maintenance	Operator/Driver, Service Tech & Cloud-Based Services	On-Vehicle, Service Bay & Cloud Data	Telematic Data Available to Service Tech with Diagnostics Info	**Addition of Component-Level Health Models**	Component-Level Health Predictions
4	Integrated Vehicle Health Mgmt.	Operator and service techs are provided with system or vehicle level health indicators before problems occur with remaining useful life estimated. Condition-based maintenance	Operator/Driver, Service Tech & Cloud-Based Services	On-Vehicle, Service Bay & Cloud Data	Telematic Data Available to Service Tech with Diagnostics Info	Addition of Vehicle-Level Health Models	**Vehicle-Level Health Management**
5	Self-Adaptive Health Mgmt.	Self-adaptive control to extend vehicle operation and enhance safety in presence of potential or actual failures	Operator/Driver, Service Tech & Cloud-Based Services	On-Vehicle, Service Bay & Cloud Data	Telematic Data Available to Service Tech with Diagnostics Info	Addition of Vehicle-Level Health Models	**IVHM Capability Integrated into Vehicle Controls**

https://www.sae.org/servlets/works/committeeResources.do?resourceID=659064

Automotive Application Insights

1. **Prognostics is strongly indicated wherever you find high levels of ECS content (electronics, controls & software)**
2. **Prognostics is best focused on critical systems but high accuracy is required**
3. **Routine maintenance applications [Managed Maintenance] can be useful & enjoy *much lower* accuracy requirements**
4. **High duty cycle applications tend to be dominated by need for availability/uptime**
   - ✓ Manufacturing
   - ✓ Fleets (trucking, cars)

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