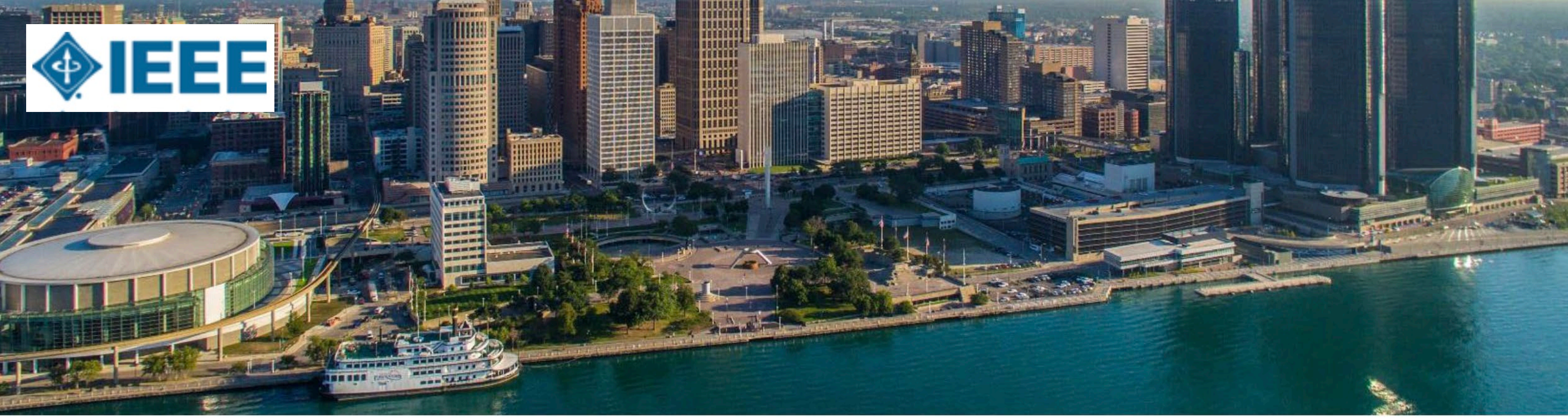


Automotive PHM & the Role for Health-Ready Components

Steven W. Holland, PE, IEEE Fellow, PHM Fellow

2021 IEEE International Conference on Prognostics and Health Management
7-9 June 2021 – Detroit, MI, USA

VHM Innovations, LLC

210531

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**:

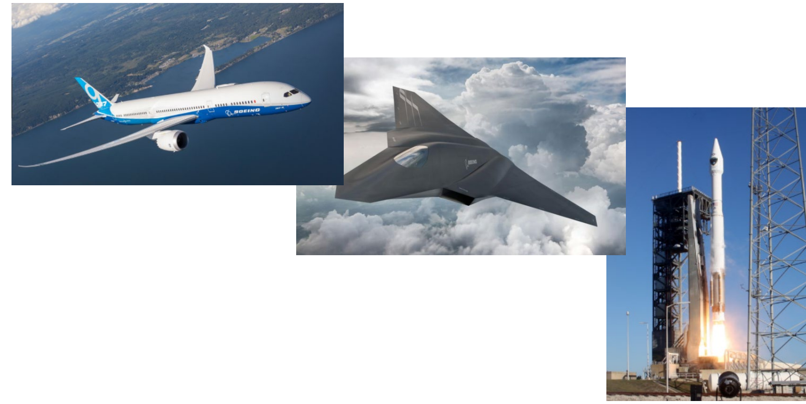
  Process of predicting the onset of a potential failure mode BEFORE the failure has occurred …while the component is still operating within specs & with sufficient advance notice to avoid the problem (RUL)

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

RUL = Remaining Useful Life

IEEE

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

Proactive Alerts

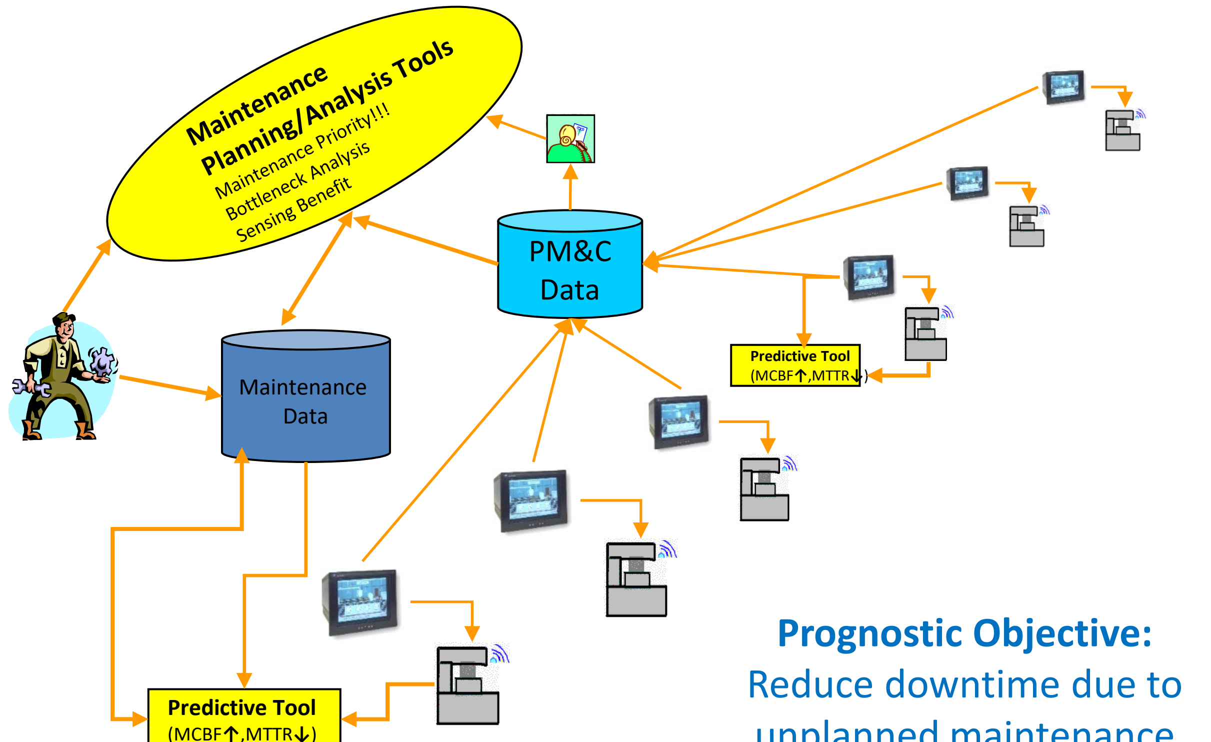
GM Vehicle Applications
- Goal: Improve the "*customer experience*"
- Cost & time savings nice too but these are 2nd-ary benefits
- Getting the *right* data is hard!

* 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 20 yrs ago ➔
- A key to success is understanding & focusing on your primary objective

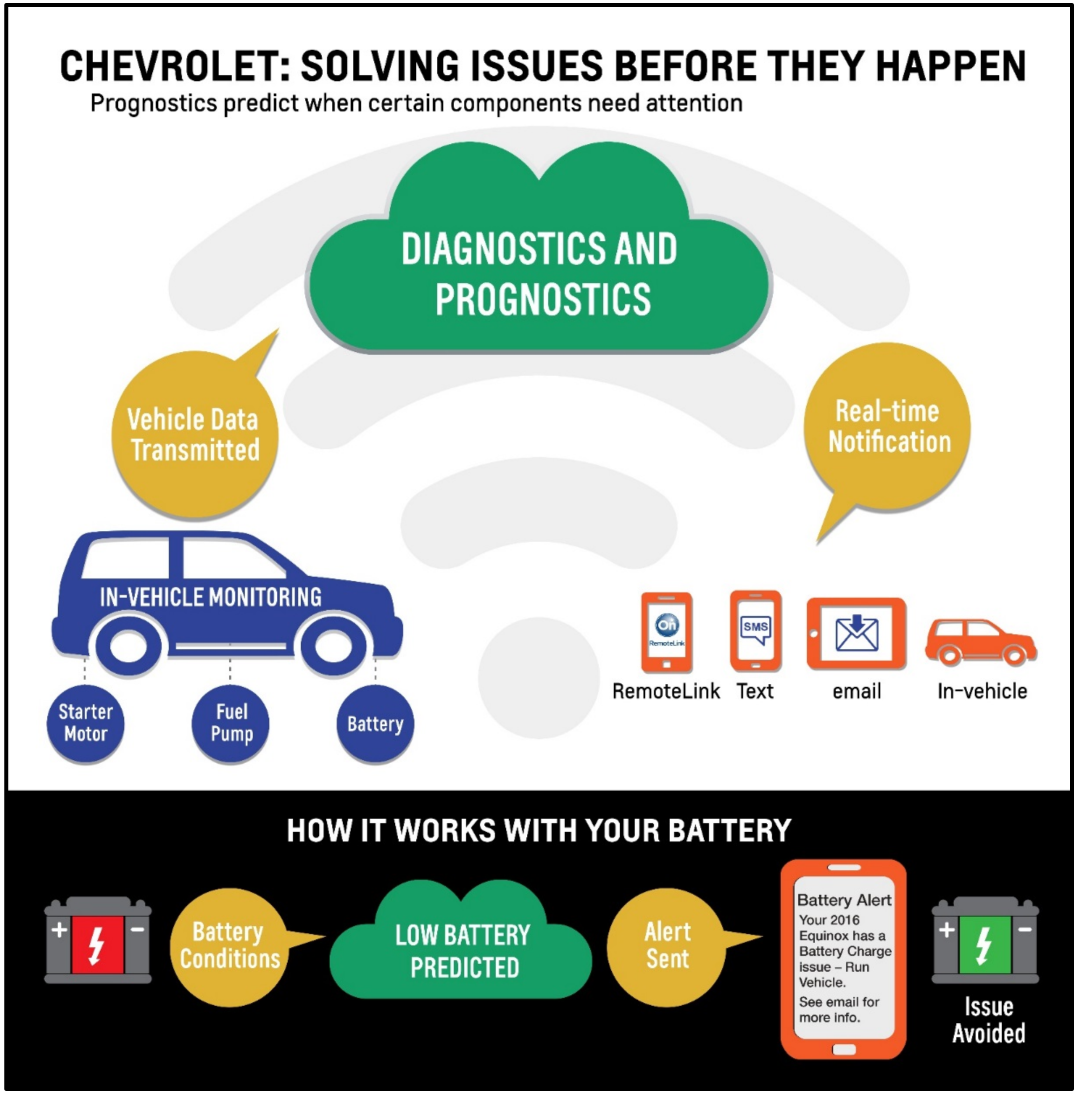


Prognostic Objective:
Reduce downtime due to unplanned maintenance (i.e., which machines will break next?)

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

Automotive News Service Insight (2016)

FIXED OPS JOURNAL

BEING PROACTIVE

General Motors innovation could rewrite service business

RICHARD TRUETT
Fixed Ops Journal

Imagine a customer arriving at a dealership's service drive with the diagnostic work completed, the faulty part identified and the warranty repair approved before a service writer even greets the driver.

You don't have to imagine it. It's happening.

This spring, General Motors quietly introduced a new feature for its OnStar connected car technology called Proactive Alerts. The program's goal, says Steve Holland, GM's chief technologist for vehicle health management, is to detect and correct a potential vehicle-stopping issue before the check-engine light comes on.

critical systems in the vehicle," Holland says, "things that have a lot of electrical content."

Once a problem is detected that requires service, the driver has about two weeks to schedule a service appointment, Holland adds.

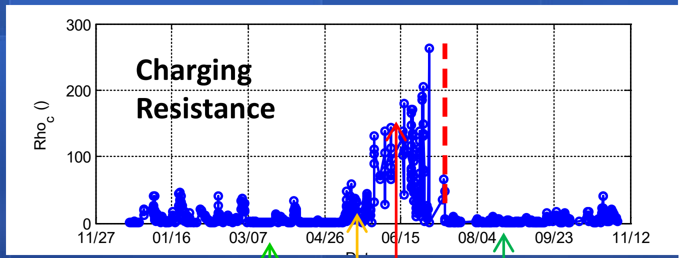
"That's early enough so that the customer has time to deal with it before they suffer the inconvenience of having a problem while they are driving," he says. "We don't know the precise time [the component will stop working], but we do know that it needs to be taken care of, and if left unserviced, that it is going to fail."

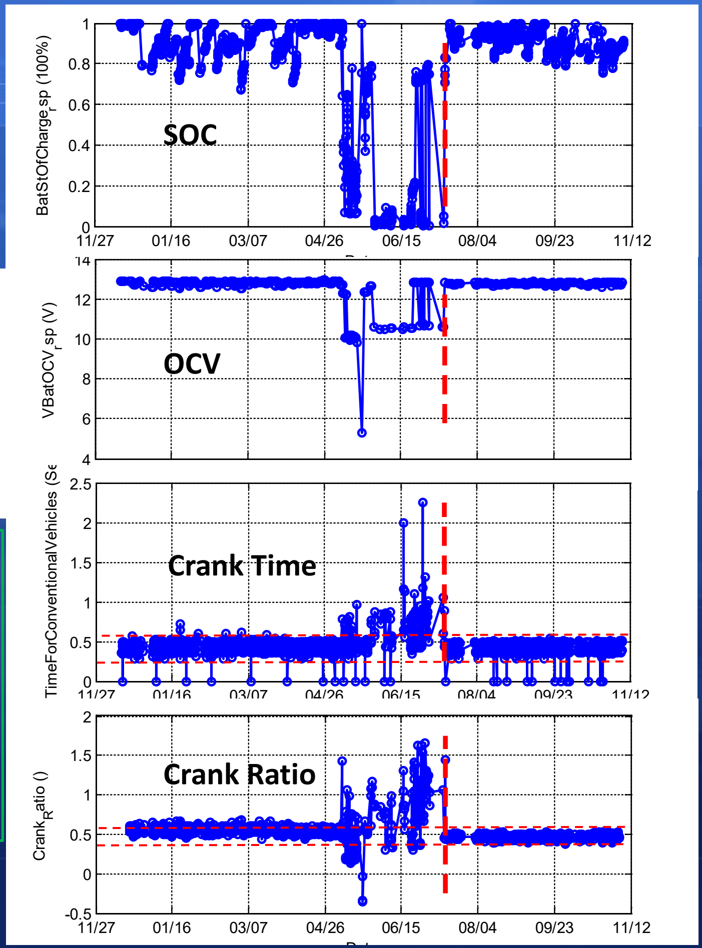
> "There are a lot of similar services, but no one offers the depth or breadth of services that OnStar offers."
> **DAVE SULLIVAN**, analyst, AutoPacific

Case Study – Predicted "Battery Short" in Field

(OBSERVATION of Single Vehicle over a 1-year time window)

Model	Equinox FWD
Warranty	Bat Replace|7/13|No Start
VHM Alert	Bat Replace Short|5/26





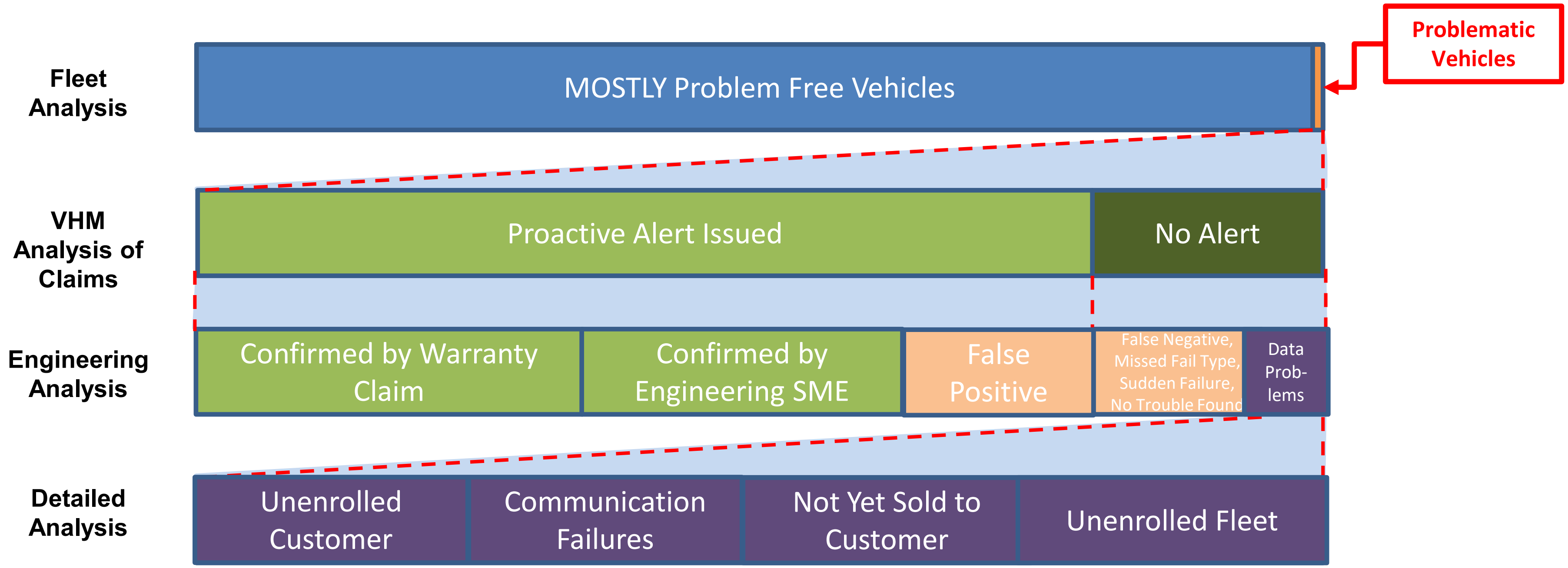
VHM Decisions

G	2/8	12:06:08 PM	No Action	Green
	2/8	5:23:40 PM	No Action	Green
Y	5/13	12:33:42 PM	Inspect Cr…	Yellow
	5/13	2:26:42 PM	Inspect Cr…	Yellow
R	5/26	8:55:44 PM	Replace B…	Red
	5/28	11:47:22 AM	Replace B…	Red
G	7/16	10:30:30 AM	No Action	Green
	7/16	11:35:34 AM	No Action	Green

VEHICLE HEALTH MANAGEMENT

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

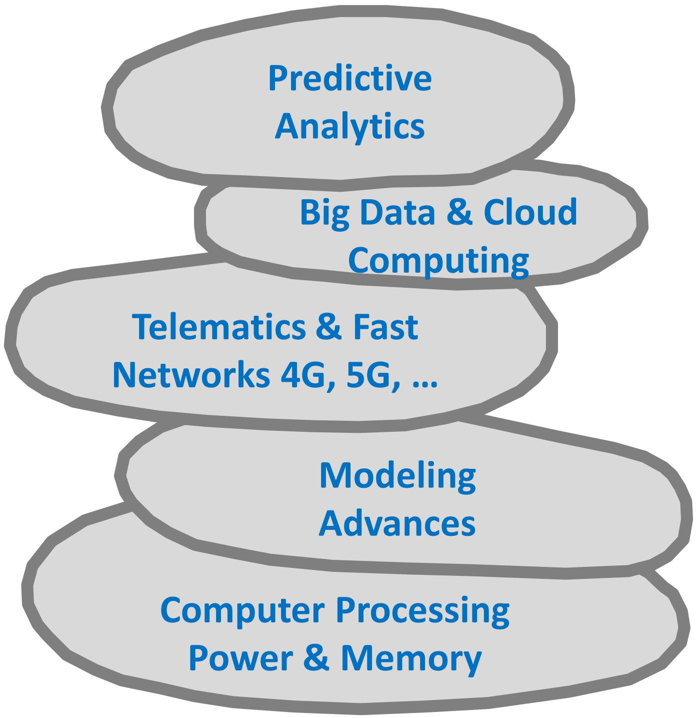
Understanding Field Results can be Nuanced



- Not Shown to Scale
- SME = Subject Matter Expert

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

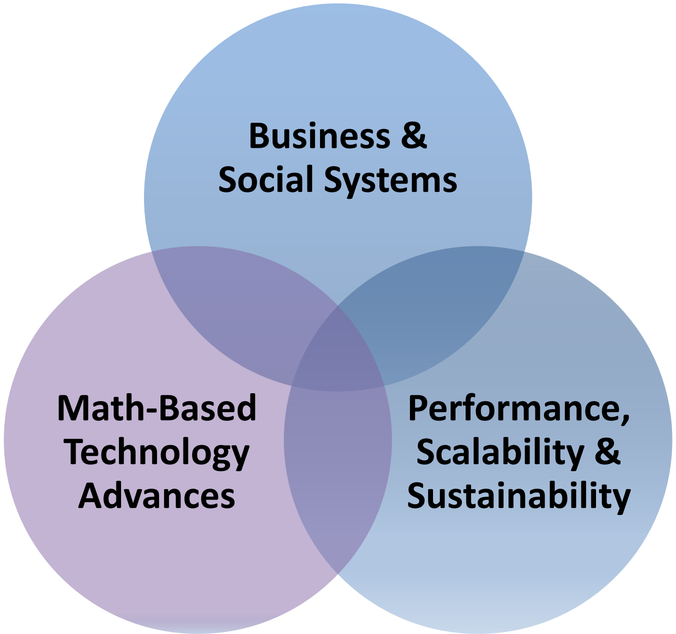
Foundations ➔ Technology advances have opened the door for a new paradigm in automotive diagnostics



- 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:

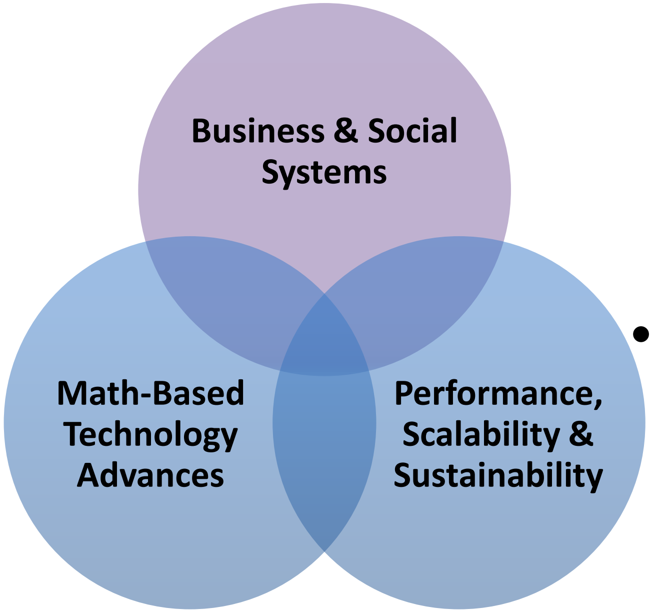
Math-Based Technology Advances



- 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

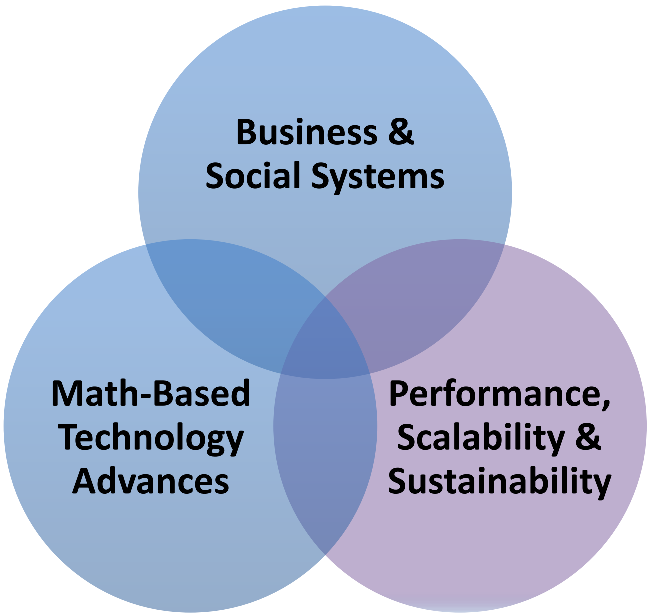


- Business & Social Relationships are critical to success
  - Prognostics cannot be implemented effectively as an afterthought
  - Traditional product design organizations control budget allocation and resources
- In the same way that OBD reached full stride when the design community realized they needed 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
- Commercially successful applications must **scale** to large numbers of vehicles
- The technical processes for supporting/maintaining prognostics must be **sustainable** over time

4 Non-intuitive Lessons to Consider

1. "The real world is HELL"
2. Establishing ground truth for component failures is problematic
3. No Trouble Found doesn't mean "no trouble"
4. Who owns the data?

SAE EDGE Report: Unsettled Technology Opportunities for Vehicle Health Management and the Role for Health-Ready Components; March 2020; http://saemobilus.sae.org/content/EPR2020003/

"The Real World is HELL" - Don Hart, c.1970

- This was a powerful lesson to me early in my career
  - Nothing is as simple as you think

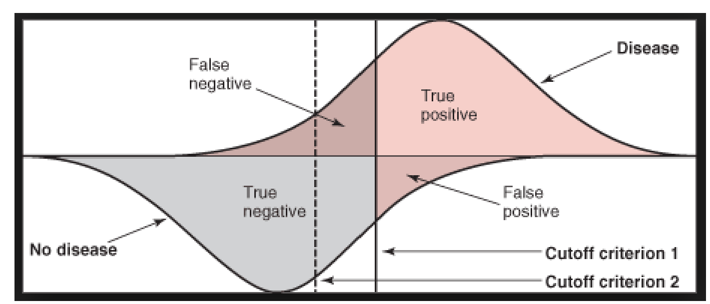
- OnStar Proactive Alerts monitoring starting system for millions of vehicles in NA but…
  - Proper validation can require 100Ks of vehicles
    - You need to identify all the *corner cases* (pathological ex.)
    - Small scale laboratory experiments simply are not adequate!

- Hack: Exploit designed-in structure & canaries

Establishing ground truth is ***not*** easy (False Positives / Negatives)

Machine Learning needs labeled training sets [supervised]

- It is extremely difficult to catch live failures in the field
  - This is generally true across industries
- Ground truth is elusive—is it failed or not?
  - SMEs tend to be the ultimate arbitrators
- "Zero false positives" is *obviously* not a realistic goal
- If you don't try to do prognostics, you are just accepting *100% false negatives*



SME = Subject Matter Experts

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%) leading me to **NMF** as a better mnemonic 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!**

Who owns the PHM data? *

- This may **not** be best question to focus on!
  - PHM data can be very valuable but *only if* it is widely deployed & utilized
  - Better perspective: recast the question in terms of **RISK MGMT:**
    - "What practices w.r.t. PHM data are in the best interests of the end customer?" – this aligns the company's interests [& long term success] with that of its customers

- Selling PHM data may bring some profit (**$**) …while missing more in lost business …& potentially exposing your company to huge risks!

- Thought Experiment: "What if a vehicle manufacturer withholds info [via pricing or other control] which could have a material impact on the health & safety of the public and that becomes known"—how might you estimate the following risks?
  1. **$$** Risk to **Corporate reputation** resulting in loss of sales, or more importantly…
  2. **$$$$** Risk to **Brand Value** and hence Market Cap, or even more importantly…
  3. **$$$$$$** Risk of **legal/governmental penalties** which could crush the company

* SAE HRCS Policy Statement: http://www.sae-itc.com/hrcs

Selected PHM Benefits in Automotive

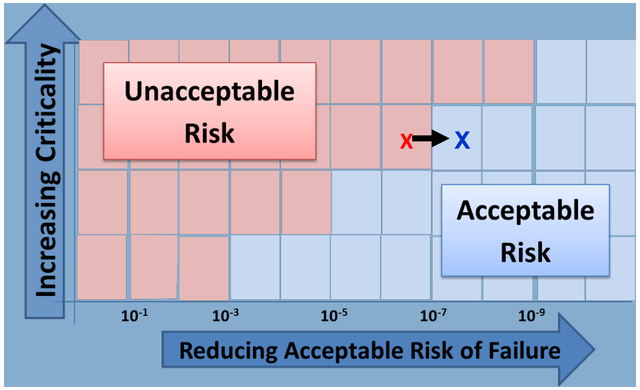
- Improved customer ownership experience
  - Transforming failures into routine maintenance
  - Why "perceived" reliability is so important
- Reduced warranty costs
  - Avoiding repeat visits
  - Reacting before major failures happen
  - Targeted recall campaigns
- Enhanced availability/uptime for manufacturing 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

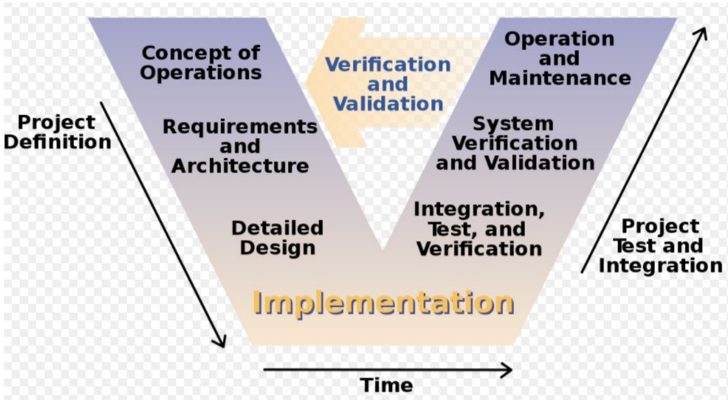
2. While there is no substitute for "designed-in" reliability, consider that achieving just 90% prognostic coverage yields a 10-fold "perceived" reliability gain ➔
   - note periodic maintenance analogy to prognostics



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 remains immature

- PHM 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 PHM advances at risk

- PHM software is not mature enough to be used within emission or safety control systems (or flight controls to give an aerospace analogy)
  - Said differently, PHM outputs should *not* be used as emission or safety system *inputs*
  - An approach to deal with this situation is to extract only portions necessary from the PHM 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 PHM implementation
- Industry Consortia provides a complimentary mechanism to go beyond what standards alone can not accomplish

HRCS
Health Ready Components and Systems
A Program of SAE ITC

* PHM, VHM, IVHM used somewhat interchangeably

SAE JA6268™: Automotive suppliers will play an increasingly important role in the cost-effective implementation of prognostics

SAE INTERNATIONAL

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/

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

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 the IVHM functionality for supplier-provided components to meet the 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

Health Ready Emphasis on Prognostics *

Real-time Functions & Processes	Non-Real-time Functions & Processes
• Fault detection and reporting • Support for Initiated Test functionality and protocols • Performance or degradation reporting • Intermittent fault data capture • Functional availability reporting • On-platform screen and user message generation • Usage monitoring and reporting of usage related data • System mode or state reporting • System configuration reporting • Data recording/logging management	• Diagnostics & Fault isolation: - Nuisance suppression (events which can safely be ignored) - Cascade removal (additional symptoms triggered by one symptom that don't add diagnostic value) - Correlation of loss of function to root cause - Guided troubleshooting and repair • Prognostics • Maintenance planning • Logistics or material planning • Supplemental analytics • Anomaly Detection • Engineering Analysis: - Root Cause Analysis - Precursor Analysis - Fleet Performance Analysis - Design Improvement Analysis • Bench Testing

Red items denote Prognostics emphasis

* SAE JA6268™

SAE ITC Launched the HRCS Consortium

- Unlike **SAE International** which is a 501(c)(3), **SAE ITC** is a 501(c)(6)
  - Members are all companies unlike SAE
- Steve Holland serving as Chairman of HRCS
- Potential to amplify the impact of JA6268™ in unique ways beyond the standards document
- Pilot projects recently completed with American Trucking Association
- HRCS website provides a wealth of info http://www.sae-itc.com/hrcs

HRCS Registry for SAE JA6268™ 3 Registration Stages

Stage 1: *Functional Self Assessment*

Stage 2: *Failure Modes Assessment*

Stage 3: *Detailed Design Assessment*

Note:

- *Stage 1 is intended to provide a provisional registration with a low barrier to entry. All Stage 1 information will be recorded in online HRCS Registry.*
- *Stages 2 & 3 are enhanced by seeking an OEM/ integrator to validate the more detailed supplier-provided assessments. Stage 2 & 3 submissions should be accompanied by Stage 1 info as well to populate registry. Stage 2 & 3 completion will be noted in HRCS Registry but the additional data will not be loaded since it contains potentially proprietary info.*

SAE HRCS Health-Ready Components Registry (Core info) Stage 1, 2, & 3

- Component Name (and known aliases)
- Supplier's catalog reference number (or numbers)
- Suppliers contact information and DUNS number, CAGE Code or other industry standard supplier identifier (if applicable)
- Validation approach can be based upon (a) design-time information, (b) run time information or (c) both design-time and run-time information
- Format of Health Ready info which provides a mathematical model (or mathematical relationships) in a machine-readable format to allow for a proper interpretation and use of specific component parameters
- Integrator/OEM name providing the validation along with their contact information and DUNS number (if applicable)
- Dates validation was completed and date which the validation expires (if applicable)

\+ *Other items to be determined by HRCS SG (all non-proprietary)*

Stage 1-Part A Assesses Health-Readiness using ISO Functional Reference Model*

*(adapted for use) ISO13374-1 (2002). Condition Monitoring and Diagnostics of Machines, Geneva, Switzerland

IVHM Functional Block	Description	IVHM Process Stage
Data Acquisition (DA)	This function collects the sensor data and health state information from the equipment internal monitors, the system data bus or data recorder.	Sense Acquire
Data Manipulation (DM)	This function processes and transforms the sensor data and health state information collected by the DA.	Transfer
State Detection (SD)	This function evaluates equipment state conditions against normal operating profiles and generates normal or abnormal condition indicators.	Analyze
Health Assessment (HA)	This function provides information to determine the current state of health of equipment.	
Prognostics Assessment (PA)	This function provides future state of health, performance life remaining, or remaining useful life (usage) indicators.	
Advisory Generation (AG)	This function provides actionable information to operational and maintenance personnel or external systems.	Act

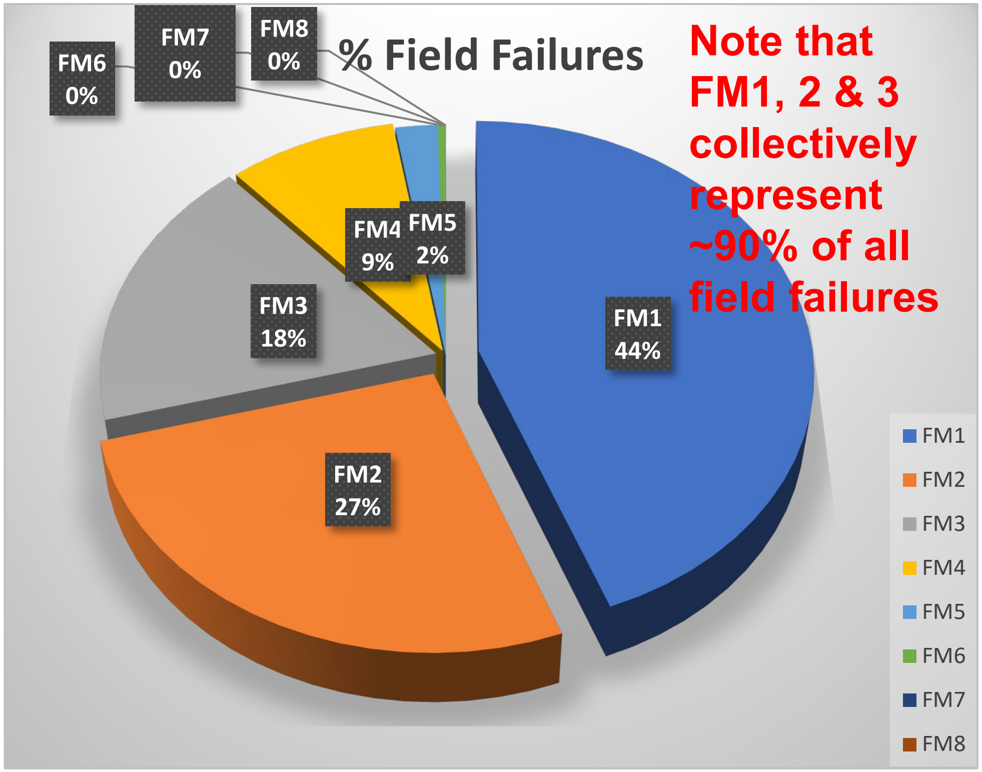
Part B Asks *Leading* Questions for Components

- **For Data Acquisition and Manipulation**
  - Machine readable info exchange?
  - Machine readable conversion of raw inputs into engineering units?
  - Severity of failures?
- **For State Detection & Health Assessment**
  - Health indicators identified?
  - Relationships/Models Identified?
  - Diagnostic Metrics?
- **For Prognostics Assessment & Advisory Generation**
  - Average advance notice (RUL—Remaining Useful Life)?
  - Typical Standard Deviation for RUL?
  - Prognostic Metrics?

Prioritize Failure Modes by Frequency of Occurrence

Failure Mode	IPTV Expected in 1st 5 * Years	% Field Failures
FM1	10.0000	44.2605
FM2	6.0000	26.5563
FM3	4.0000	17.7042
FM4	2.0000	8.8521
FM5	0.5000	2.2130
FM6	0.0900	0.3983
FM7	0.0030	0.0133
FM8	0.0005	0.0022
Total	22.5935	100.0000

* or other reference period
IPTV=Incidents Per Thousand Vehicles



Other Factors to Consider

- **Cost Per Vehicle** (CPV) – This measure tells us how costly on average it is to repair a vehicle once a given failure mode has happened
- **Severity** (Type) – This measure tells us how important this failure mode is in terms of loss of functionality or its impact on vehicle safety

5. ***Most Severe***: Non-operational Vehicle or Safety Issue
4. Urgent Vehicle Repair
3. Important Repair or Customer Inconvenience
2. Minor Vehicle Repairs
1. ***Least Severe:*** Routine Vehicle Maintenance

SAE AIR7999 - Diagnostic & Prognostic Metrics for Engine Health Management Systems (Draft)

Metric Name	Definition	Description
Accuracy Based Metrics		
True Positive Rate (TPR)	$TPR = \frac{TP}{TP + FN} = P(D1\|F1)$	The proportion of fault conditions correctly detected. Also known as "sensitivity."
True Negative Rate (TNR)	$TNR = \frac{TN}{FP + TN} = P(D0\|F0)$	The proportion of no fault conditions correctly rejected as a fault. Also known as "specificity."
False Positive Rate (FPR)	$FPR = \frac{FP}{FP + TN} = P(D1\|F0)$	The proportion of no fault conditions incorrectly detected as a fault. Also known as "false alarm rate".
False Negative Rate (FNR)	$FNR = \frac{FN}{TP + FN} = P(D0\|F1)$	The proportion of fault conditions incorrectly rejected as a fault.
Positive Predictive Value (PPV)	$PPV = \frac{TP}{TP + FP} = P(F1\|D1)$	The proportion of positive fault prediction cases actually having a fault.
Negative Predictive Value (NPV)	$NPV = \frac{TN}{TN + FN} = P(F0\|D0)$	The proportion of negative fault prediction cases that are fault free.
False Discovery Rate (FDR)	$FDR = \frac{FP}{TP + FP} = P(F0\|D1)$	The proportion of positive fault prediction cases that are fault free.
False Omission Rate (FOR)	$FOR = \frac{FN}{TN + FN} = P(F1\|D0)$	The proportion of negative fault prediction cases actually having a fault.
Fault Detection Coverage	$C_D = \frac{N_{DF}}{N_{TF}} * 100\%$	The percentage of fault modes that can be detected.

		Predicted State	
		Fault	**No Fault**
True State	**Fault**	*TP* *(true positives)*	*FN* *(false negatives)*
	No Fault	*FP* *(false positives)*	*TN* *(true negatives)*

A 2×2 matrix that reflects an algorithm's ability to discriminate between fault and no-fault cases. Its main diagonal reflects the number of correct predictions (true positives and true negatives) and its off-diagonal elements reflect the number of incorrect predictions (false negatives and false positives)

Stage 2: Failure Modes Assessment

Similar to Stage 1 but based on each individual failure mode instead of aggregate performance

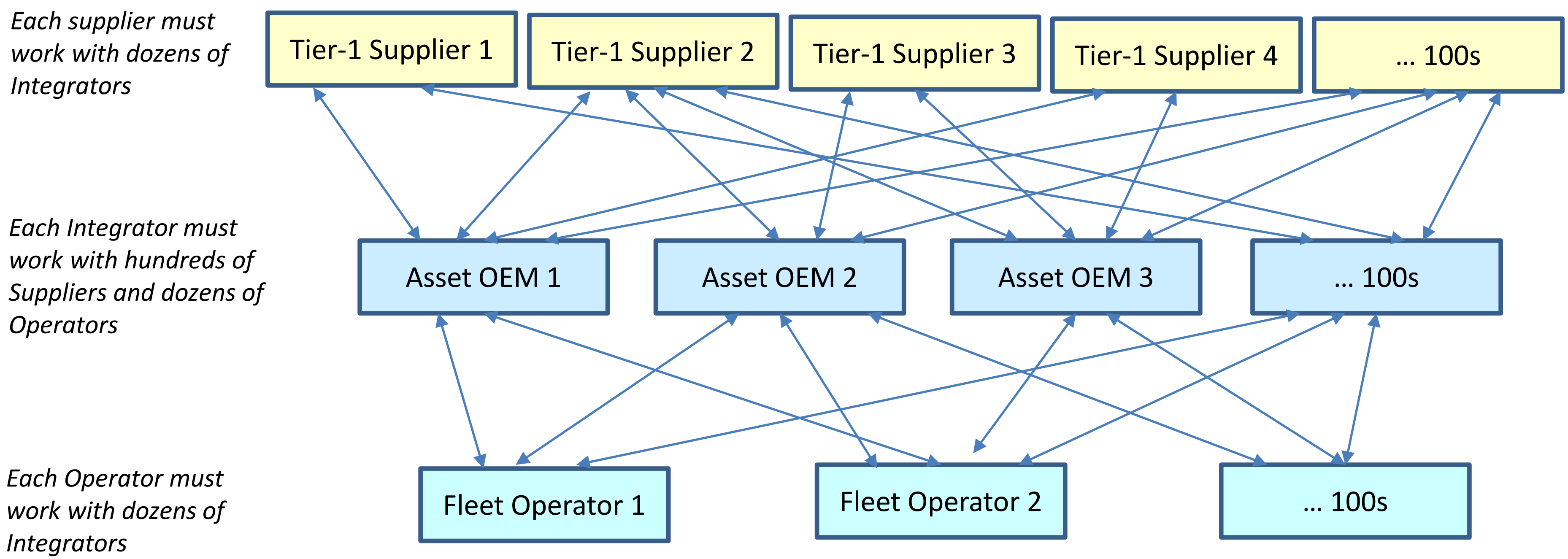
Failure Mode Descrip-tion	% Field Failures	Severity of Failure (5-1)	Avg Cost of Repairs (CPV) $	Health Indicators ID'd (describe)	Relationships / Models ID'd (describe)	Machine Readable Information Exchange? (Y/N)	Machine Readable Conv of Raw Inputs to Eng Units? (Y/N)	Data Acquisition & Manipulation (DA & DM) % Coverage for Given Failure Mode	State Detection & Health Assesment (SD & HA) % Coverage for Given Failure Mode	Prognostics Assessment & Advisory Generation (PA & AG) % Coverage for Given Failure Mode
						<select>	<select>	0.0%	0.0%	0.0%
						<select>	<select>	0.0%	0.0%	0.0%
						<select>	<select>	0.0%	0.0%	0.0%
						<select>	<select>	0.0%	0.0%	0.0%
						<select>	<select>	0.0%	0.0%	0.0%

...

Stated RUL Units:

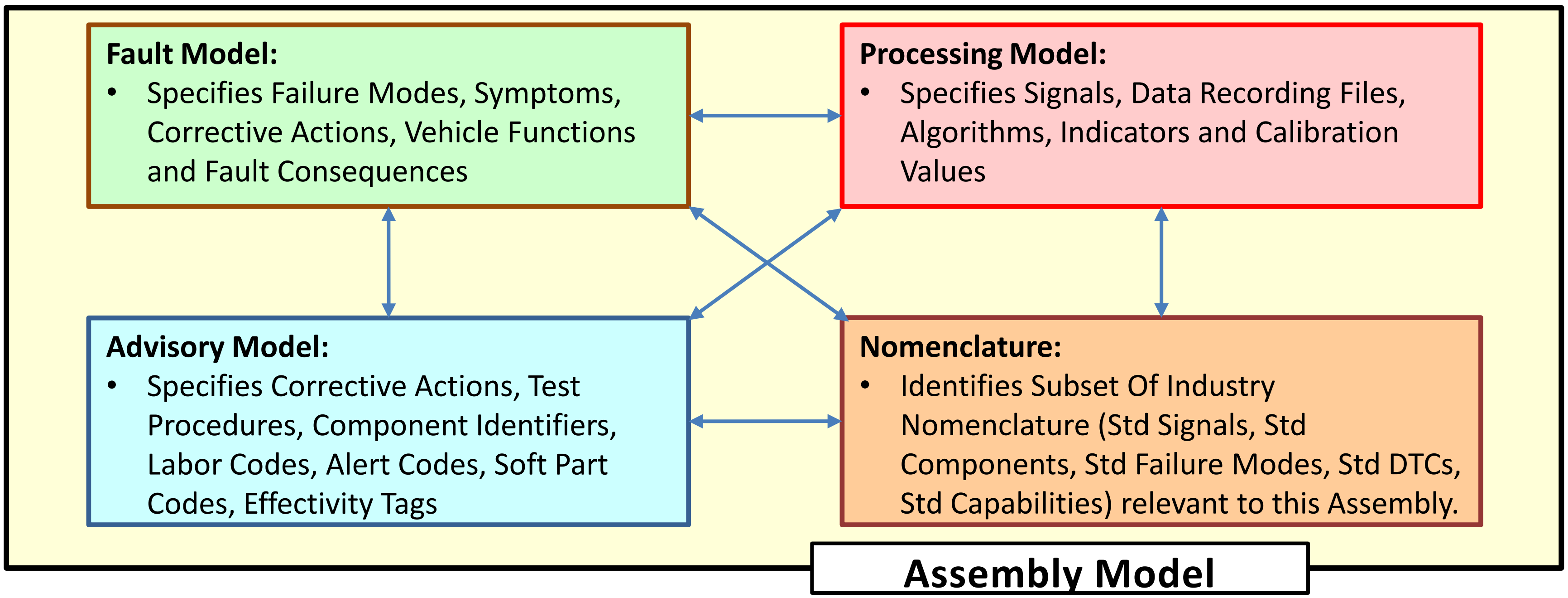
- ○ Hours
- ● Days
- ○ Weeks
- ○ Months
- ○ Cycles (flights/trips/starts)
- ○ Engine Hrs
- ○ Operation Hrs
- ○ Other: _______________

Stage 3: Detailed Design Assessment *Focuses on Detailed Info Exchange*



Interoperability of IVHM functions is hampered by differences between data definitions among other things

JA6268 Stage 3 Datasheet Content



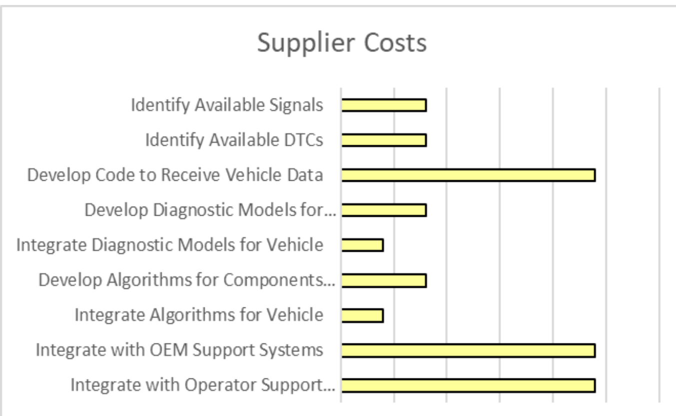
Datasheets Can be Created for Components, Assemblies, Systems, etc. and at Different Levels of Detail (i.e., Industry Standard, Operator, OEM and Supplier)

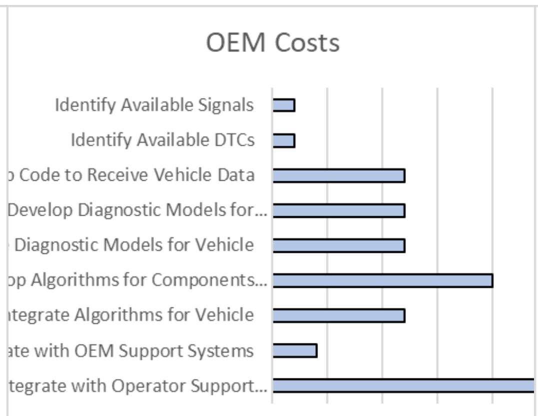
JA6268 Primary Use Case – Current Cost Factors

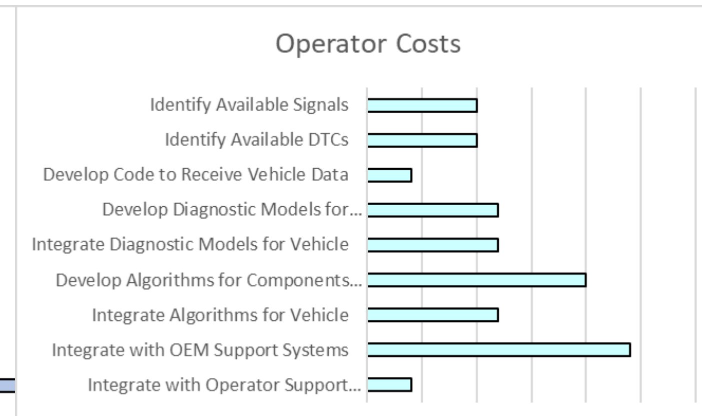
Tier-1 Supplier

Asset OEM

Fleet Operator

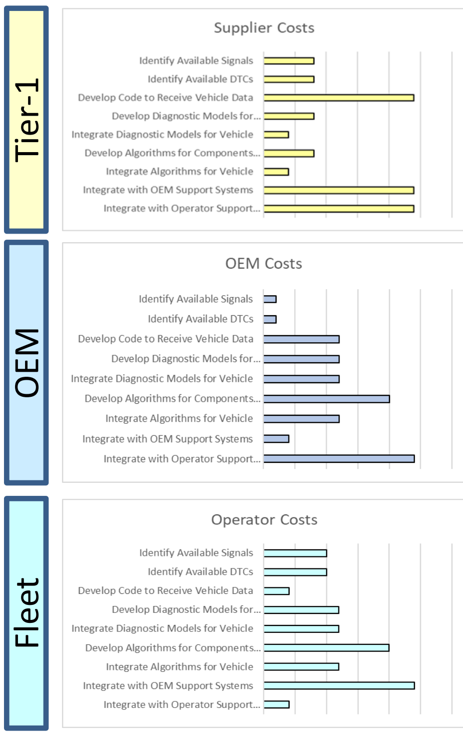


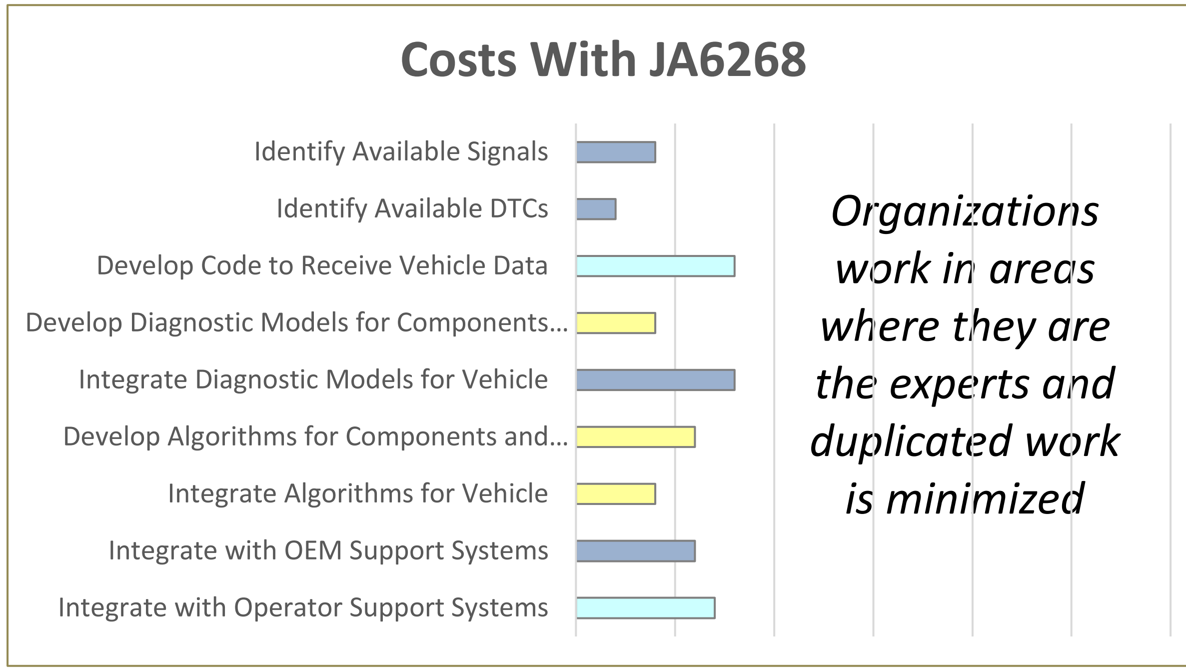




Without JA6268, organizations incur substantial costs working in areas where they are not the expert and in duplicating work of others

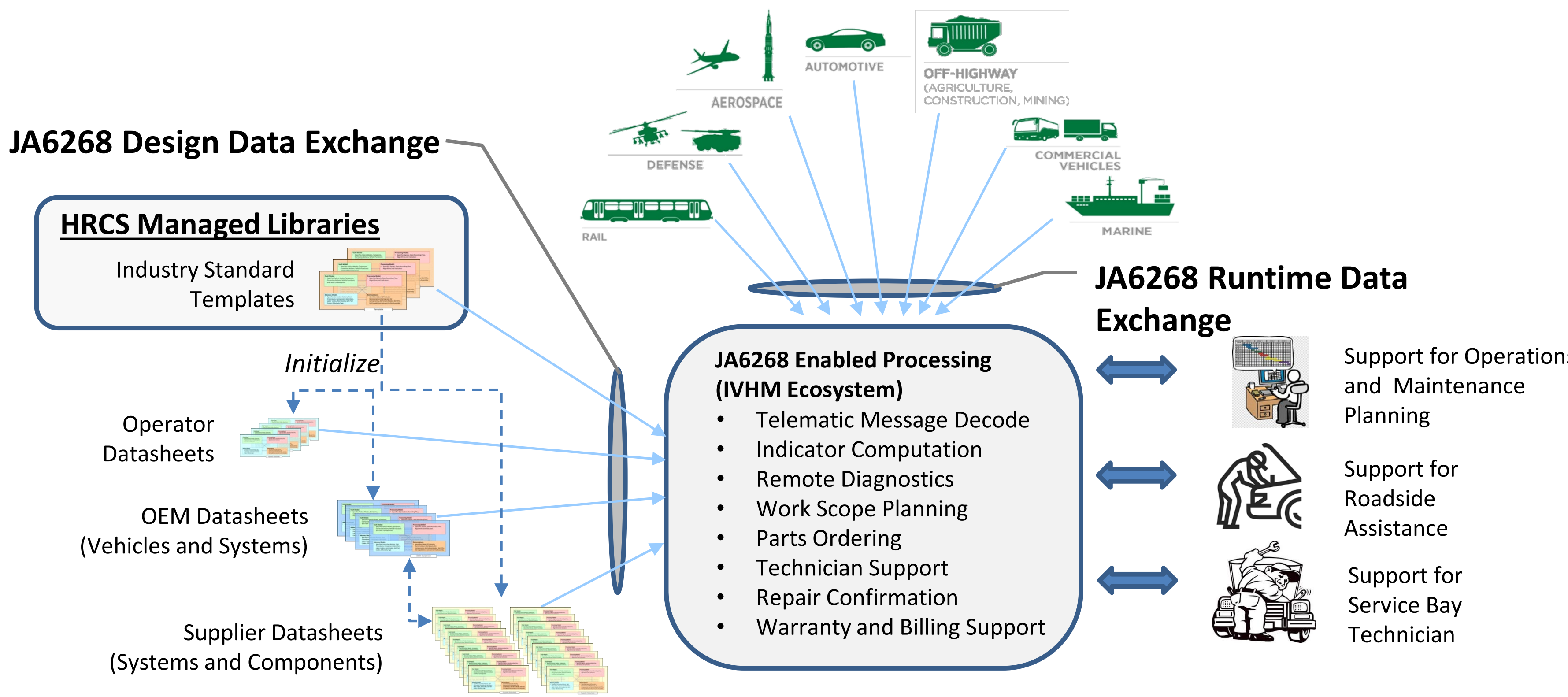
ENGINEERING COST SAVINGS WITH JA2628





JA6268 has potential to reduce effort to develop high accuracy IVHM functions

HRCS JA6268 Overview



JA6268 format and vocabulary aligned with industry standards

(e.g., J1939, J1979, ISO 15031, VMRS, etc)

Recapping Automotive PHM Insights

1. Prognostics is strongly indicated wherever you find high levels of ECS content (electronics, controls or software)
2. Prognostics is best focused on critical systems but that requires high accuracy
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)

Automotive PHM & the Role for Health-Ready Components

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