Issues & Opportunities in Automotive PHM

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Prognostics & Health Management Conference

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VEHICLE HEALTH MANAGEMENT
GENERAL MOTORS

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)

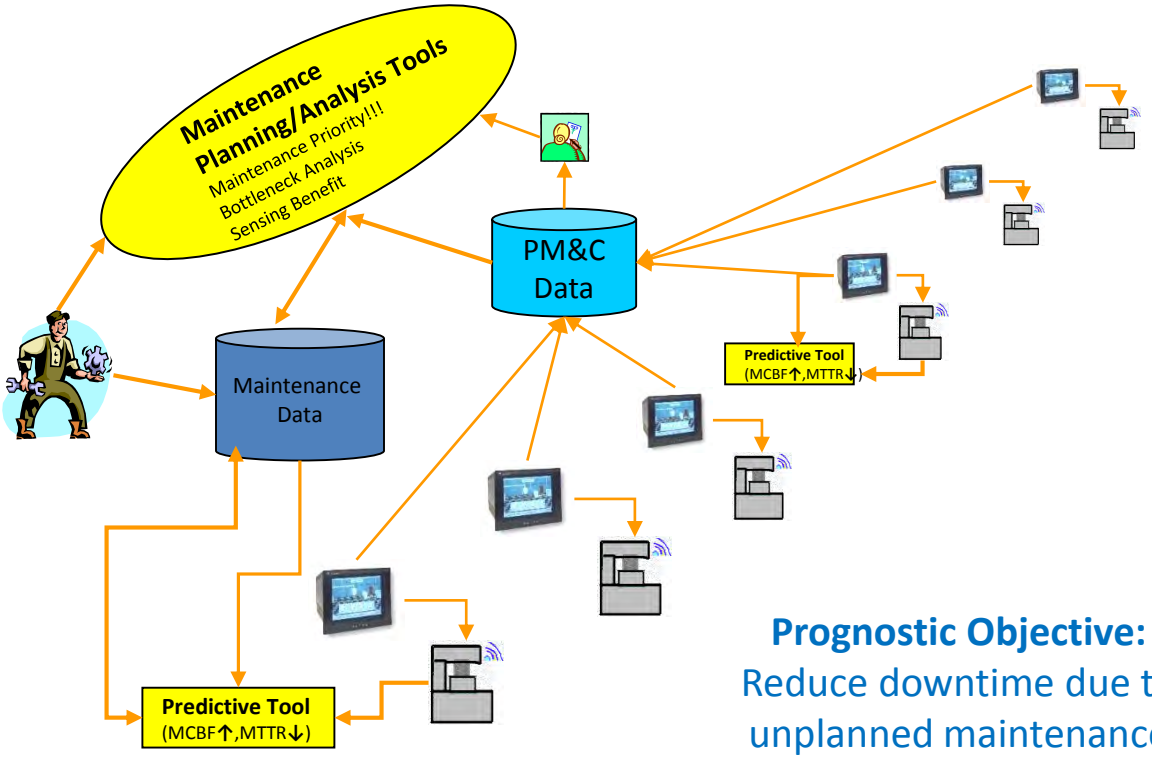
Caveat: This distinction is *very* significant to me but is mostly lost on our customers

RUL = Remaining Useful Life

Prognostics has proven *extremely* successful in aerospace, tele-communications, information technology, wind/solar 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?)

Prognostics demands clearly defined priorities for success

Lessons learned from Boeing (Keith Sellers)

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



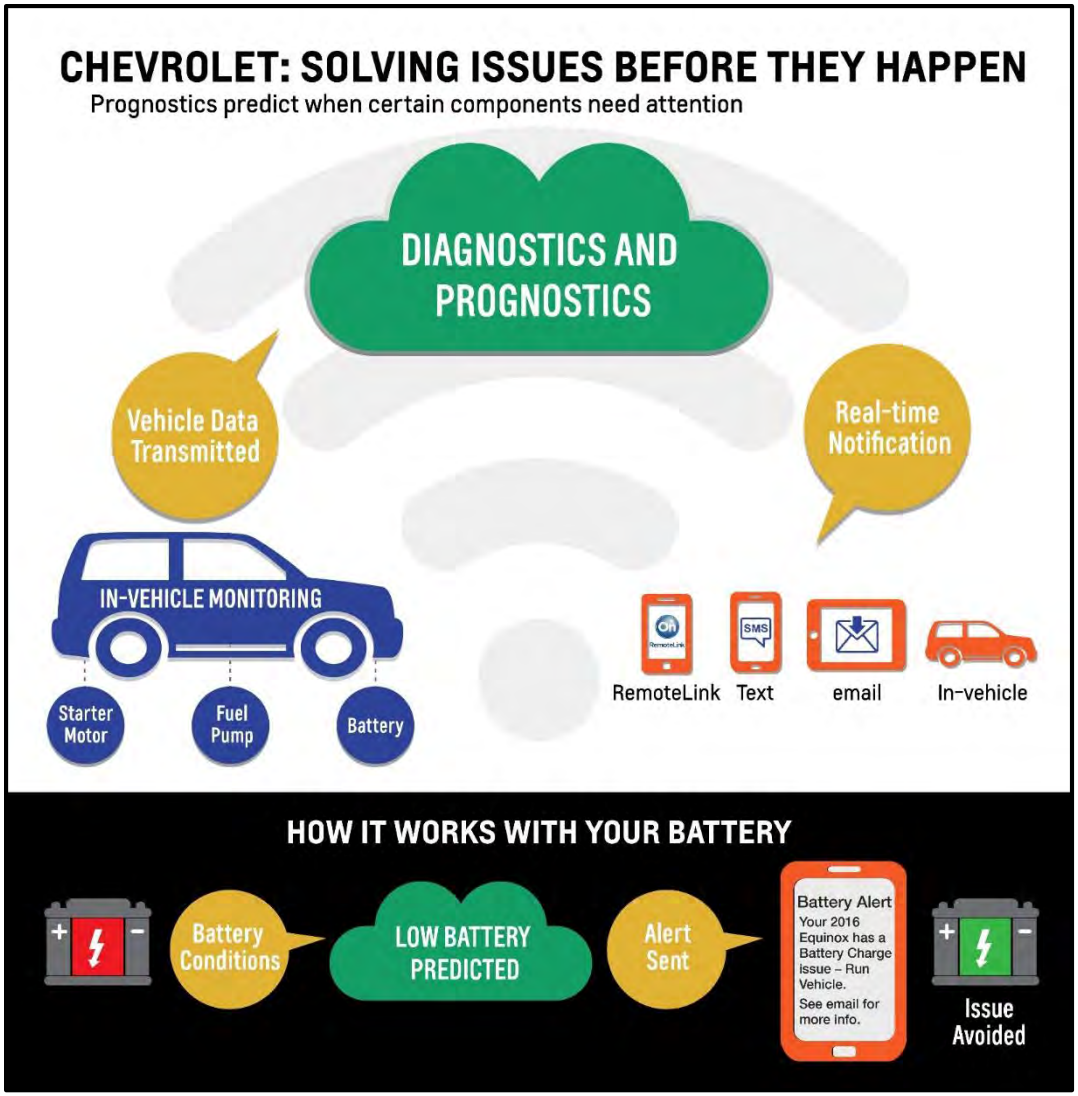
GM Mfging Applications

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

GM Vehicle Applications

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

CES 1/4/15:
OnStar Proactive Alerts



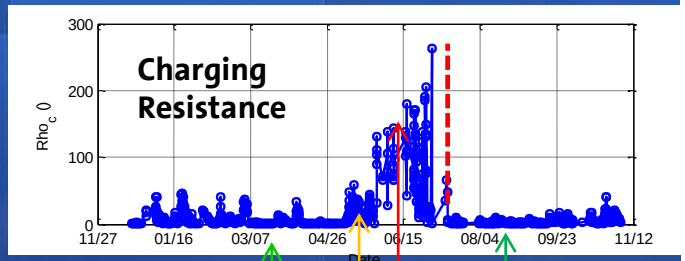
Proactive Alerts

Selected Press Coverage (2016)

Case Study – Predicted "Battery Short" in Field

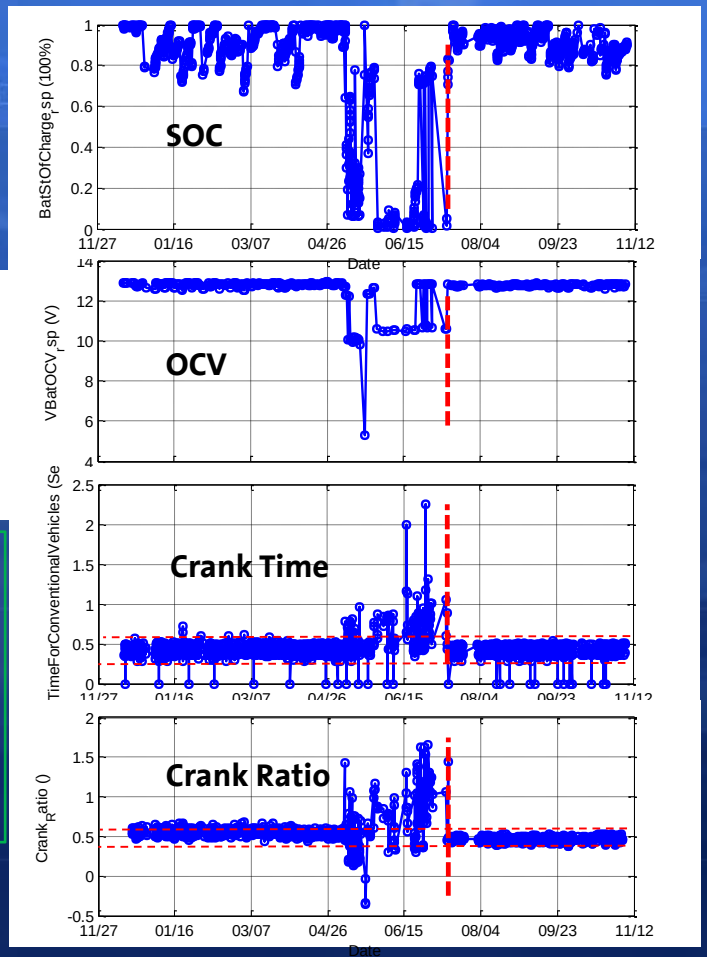
(Single Vehicle over a 1-year time window)

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

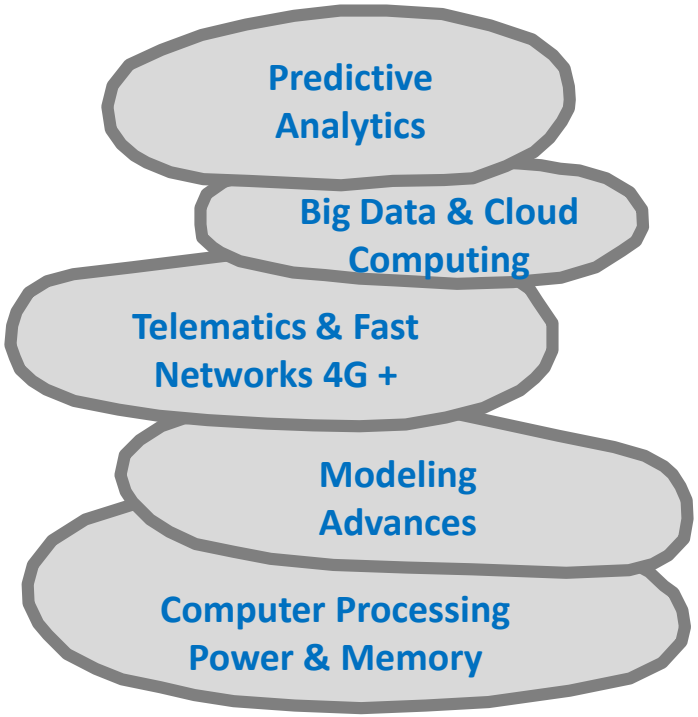


VHM Decisions

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



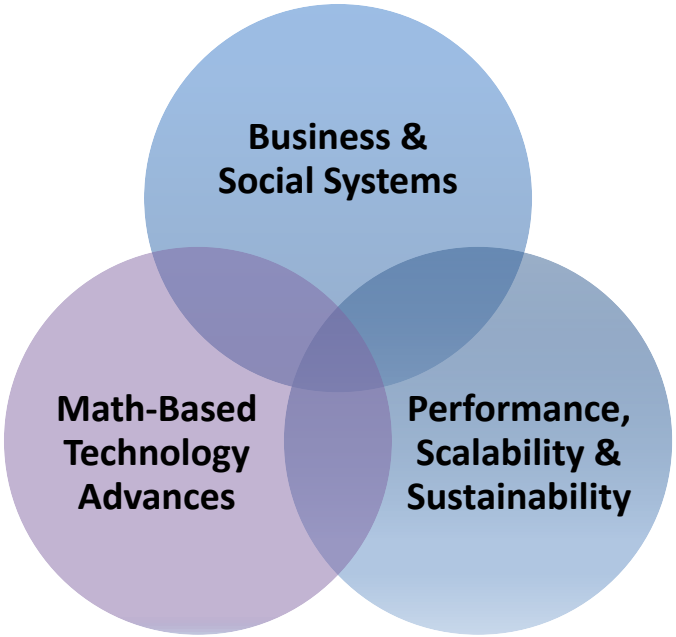
Foundations ➔ Technology advances have opened the door for a new paradigm in automotive diagnostics



- 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:

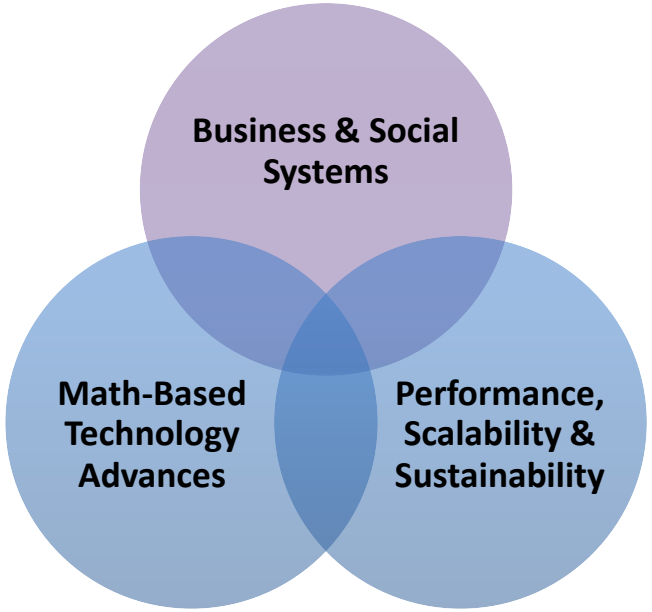
Math-Based Technology Advances



- GM's Math-Based Approach (1991)
  - GE's "Digital Twin" concept (2002)
- Analytic Methods
  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

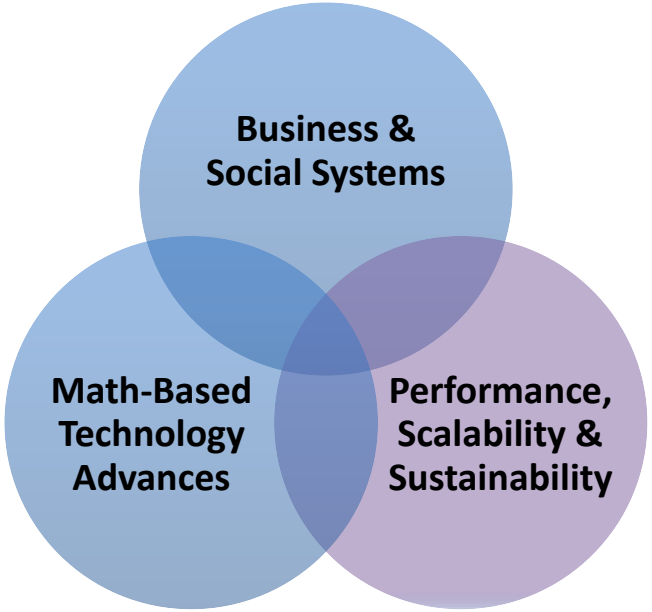


- Business & Social Relationships are critical to success
  - Prognostics cannot be implemented effectively as an afterthought
  - Traditional product design organizations control budget allocation and resources
- In the same way that OBD reached full stride when the design community realized they needed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

Similar drivers that motivated the implementation of OBD now point to the need to introduce prognostics

The advent of µ-processor based control drove Automotive OBD

- 1980: General Motors implements the ALDL proprietary interface and protocol for testing of the µ-processor based Engine Control Module (ECM)
- 1991: The California Air Resources Board (CARB) requires that all new vehicles sold in California have some basic OBD capability
- 1996: The OBD-II specification is made mandatory for all cars manufactured in the United States to be sold in the United States

The rapid growth of Electronics/Controls/Software (ECS) driving Prognostics

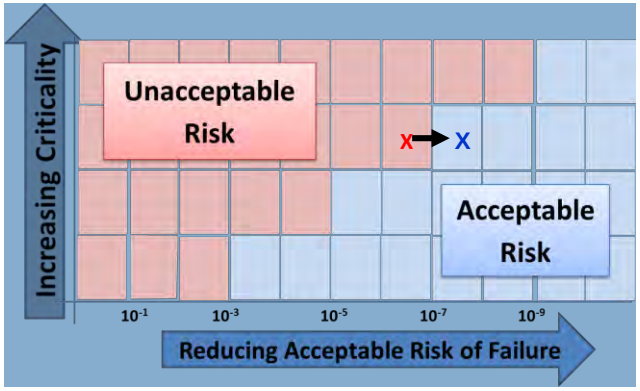
- Prognostics needed in part to mitigate risks associated with added ECS content & the electrification of our vehicles
- ECS content is likely the only means to cost effectively meet growing customer & regulatory requirements
- But ECS drives “NTF / NFF / NMF” & “Intermittents”

Value ➔ Prognostics can dramatically improve customer perception

"The customer is king"

- 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

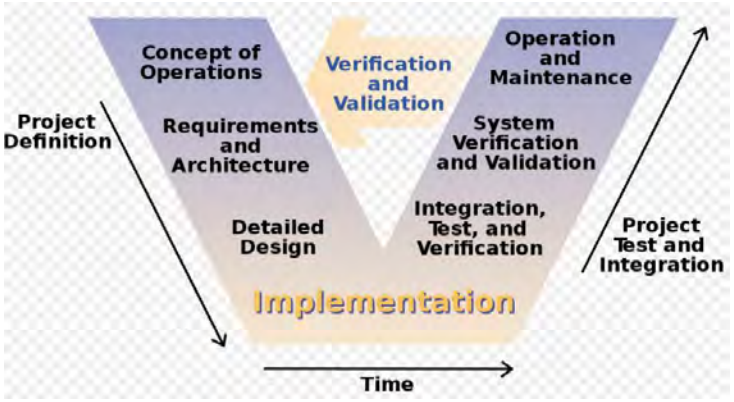
- While there is no substitute for "designed-in" reliability, consider that achieving just 90% prognostic coverage yields a 10-fold "perceived" reliability gain ➔
  - note periodic maintenance analogy to prognostics



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

Value ➔ 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
  - Also knowing what is working well in addition to problem indicators
- Warranty management
  - Narrowing recall actions
  - Prioritizing recall actions



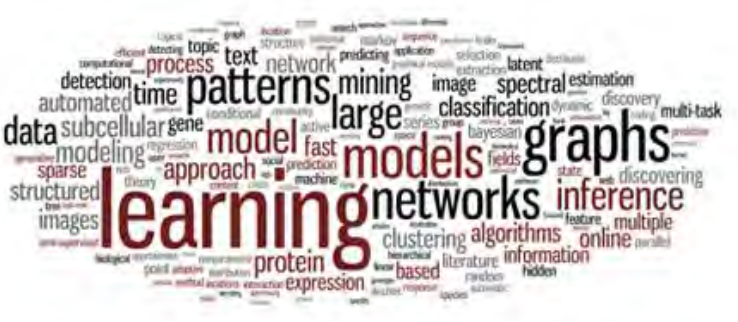
Issues ➔ The real world is "hell" - Don Hart, c.1970

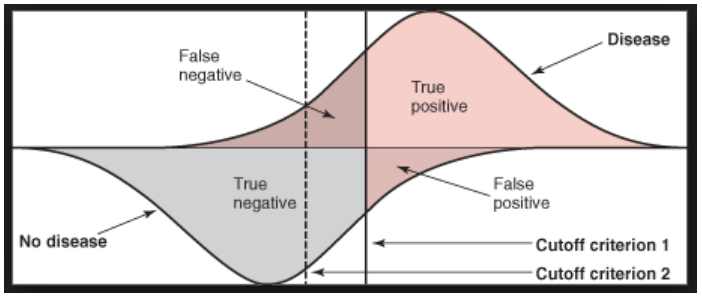
- This was a powerful lesson to me as a young researcher but it is so true
  - Nothing is as simple as you think
- GM annual global production ~10M vehicles
- OnStar Proactive Alerts monitoring >1M vehicles in NA today
- Proper validation takes 100Ks of vehicles
  - You need to identify all the *corner cases* (or pathological examples)
  - Small scale laboratory experiments simply are not adequate!

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

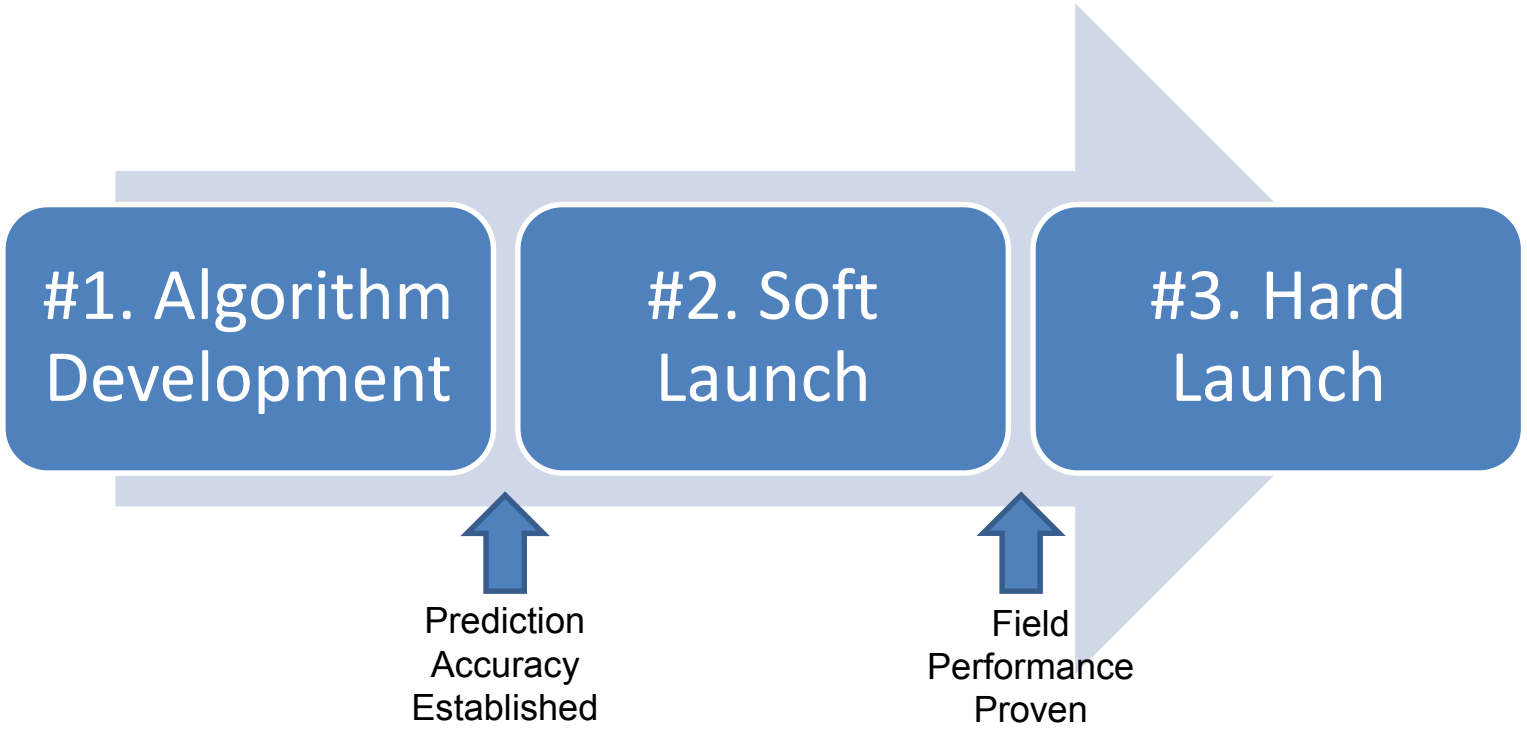
Machine Learning wants labeled training sets

- 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 not a realistic goal
- If you don't try to do prognostics, you are accepting 100% false negatives

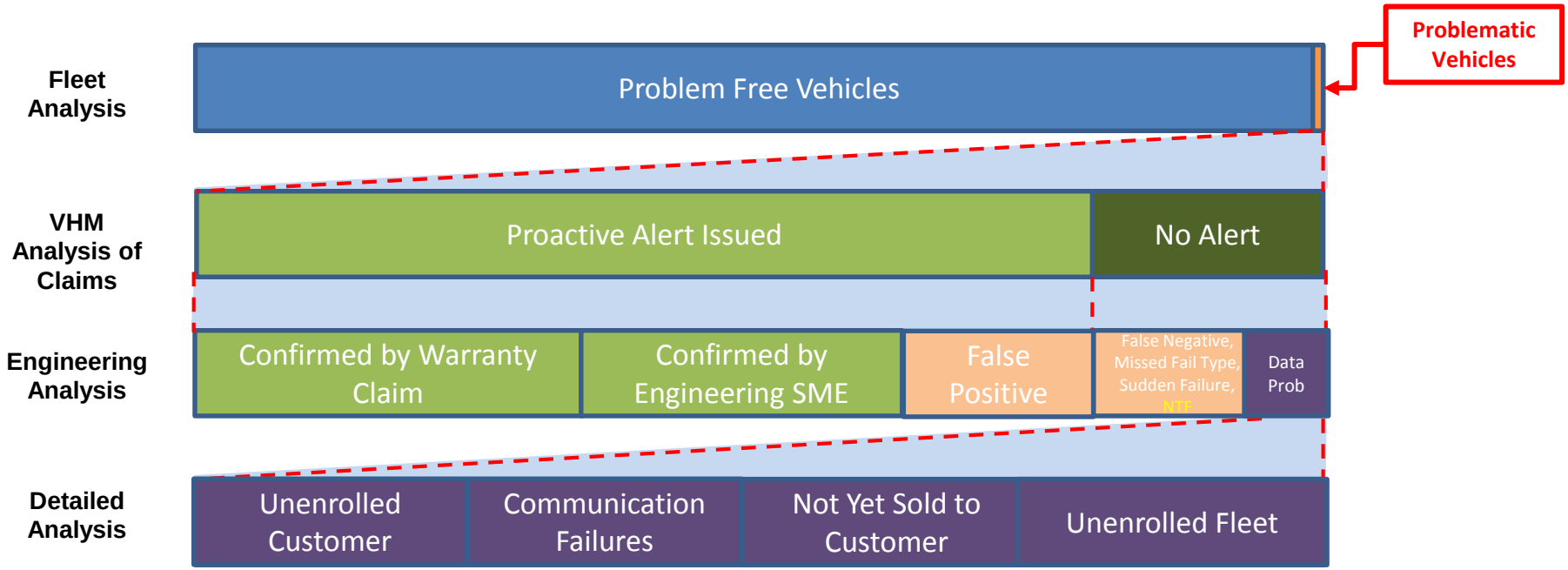




Simplified Validation & Launch Process



Understanding field results can be nuanced *



* Not Shown to Scale

Prognostics technology remains immature

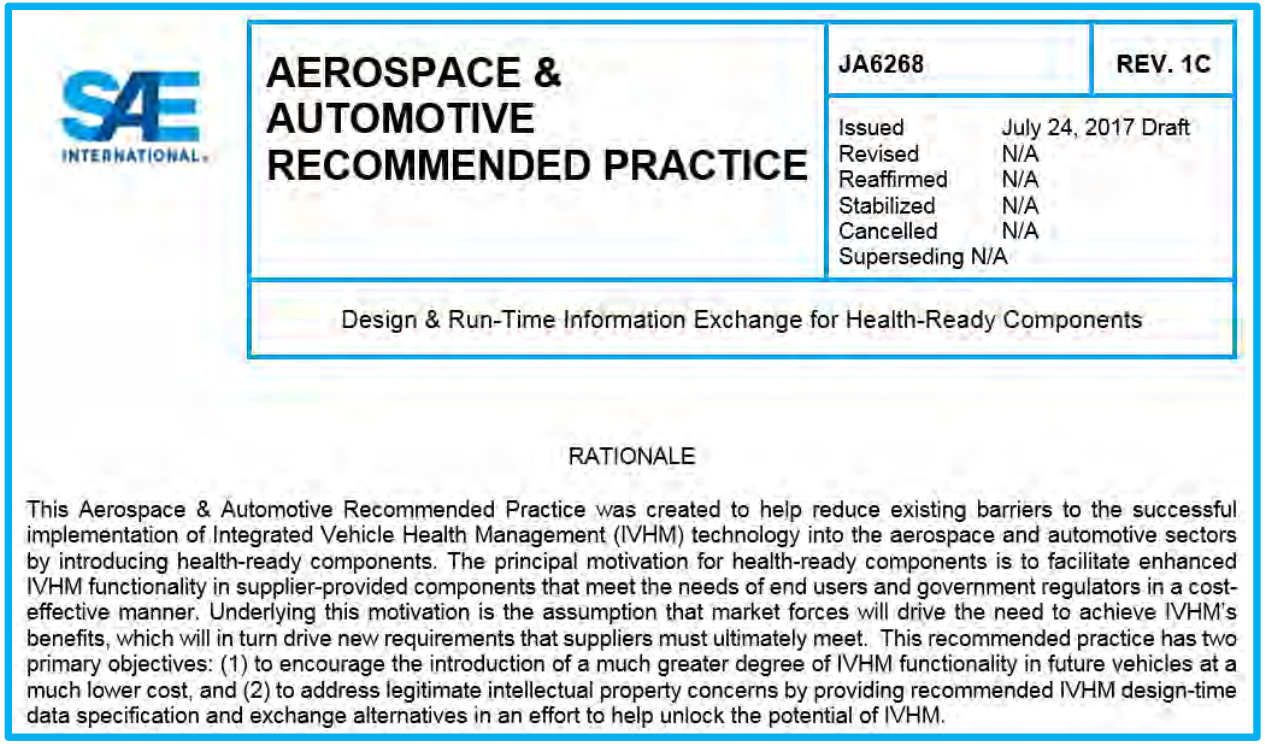
- VHM technology is impressive but the field remains *immature*
  - It has proven value in some aspects of automotive for enhancing availability & reliability
  - Indirectly, this has benefits for *vehicle safety* but care must be taken to nurture the technology
  - Excessive regulations too early might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

- VHM software is not mature enough to be used within emission or safety control systems (or flight controls to give an aerospace analogy)
  - Said differently, VHM outputs should *not* be used as emission or safety system *inputs*
  - My recommendation for this situation would be to extract only what is necessary from the VHM software and embed just that into the control system (subject to all necessary requirements)

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

SAE's new IVHM Recommended Practice for Health-Ready Components (JA6268)

- Reduce the barriers to successful implementation of IVHM
- Speed up progress
- Increase degree of IVHM functionality
- Lower cost
- Address legitimate IP concerns



SAE INTERNATIONAL

AEROSPACE & AUTOMOTIVE RECOMMENDED PRACTICE

JA6268 REV. 1C

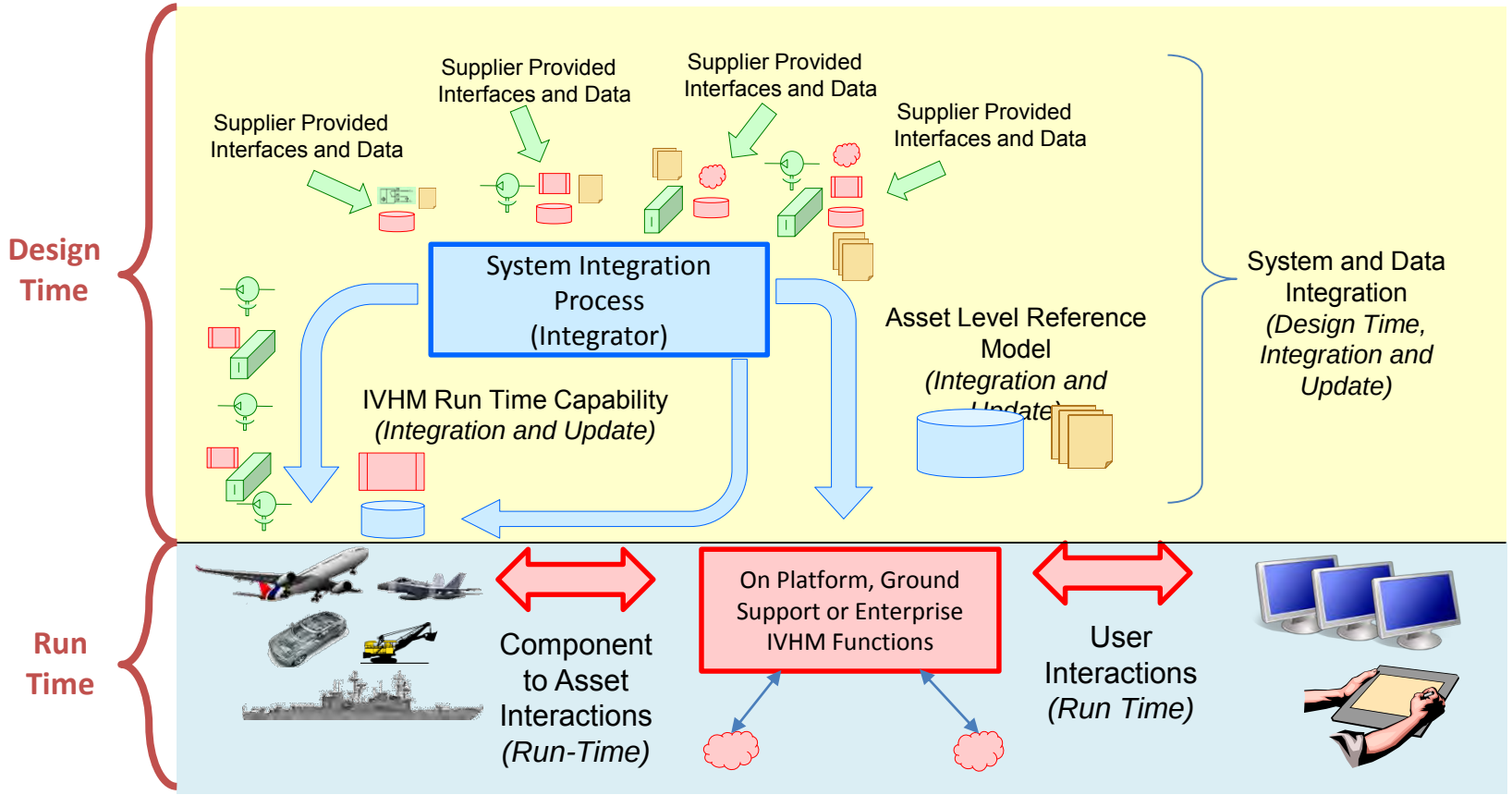
Issued	July 24, 2017 Draft
Revised	N/A
Reaffirmed	N/A
Stabilized	N/A
Cancelled	N/A
Superseding	N/A

Design & Run-Time Information Exchange for Health-Ready Components

RATIONALE

This Aerospace & Automotive 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. The principal motivation for health-ready components is to facilitate enhanced IVHM functionality in supplier-provided components that 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 data specification and exchange alternatives in an effort to help unlock the potential of IVHM.

Health Ready Components—Unlocking the Potential of IVHM



Health Ready Emphasis on VHM/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 VHM/Prognostics emphasis

* SAE JA6268 forthcoming

SAE's IVHM Capability Levels for Aero/Auto Applications

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**

http://www.sae.org/servlets/works/committeeResources.do?resourceID=570618

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