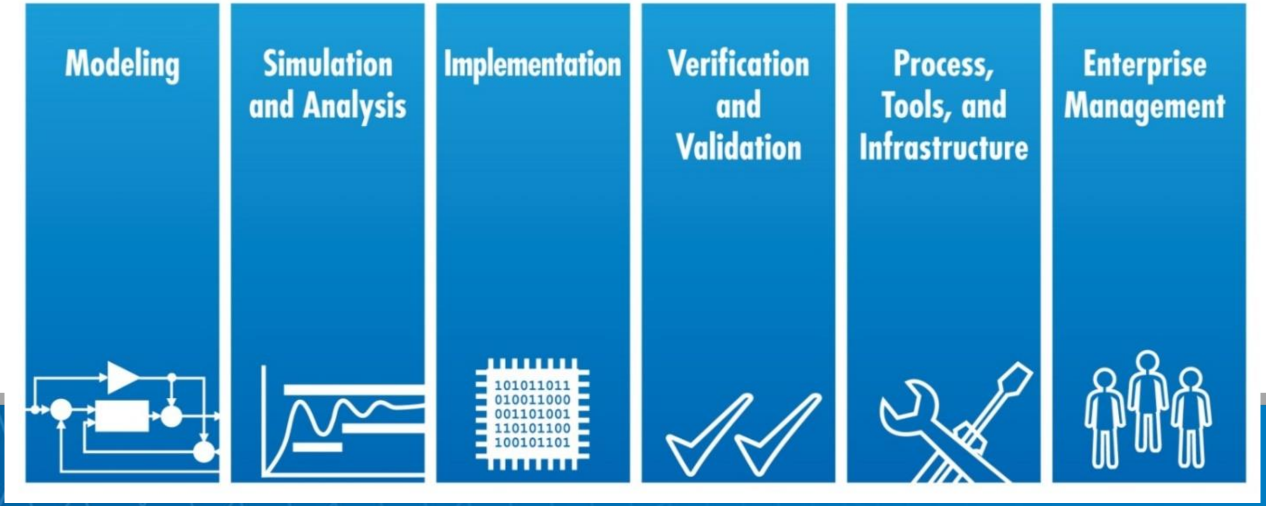
MathWorks®

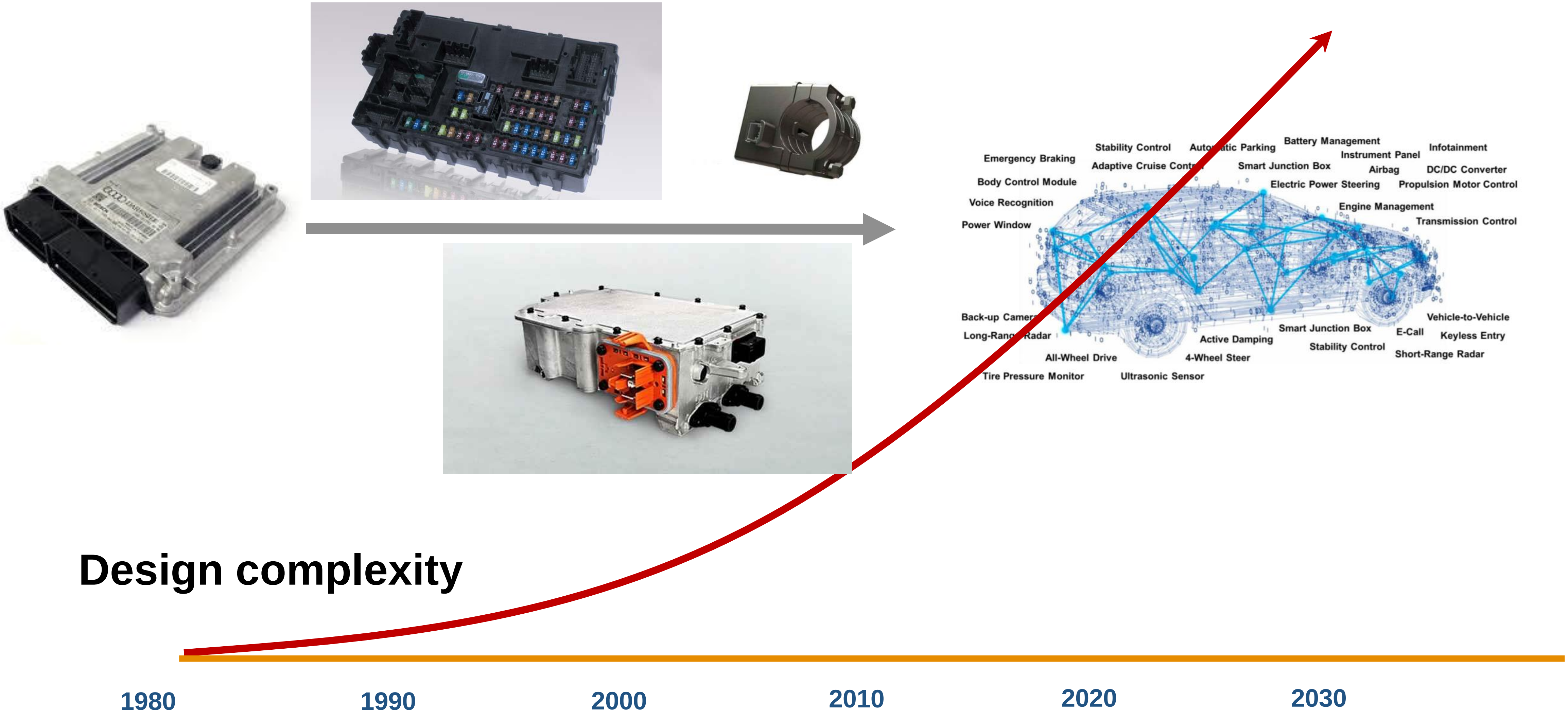
Learnings from Process Assessments

Model-Based Design Maturity Framework™



Govind Malleichervu – Industry Marketing
John Lee – Consulting Services
June 23, 2020

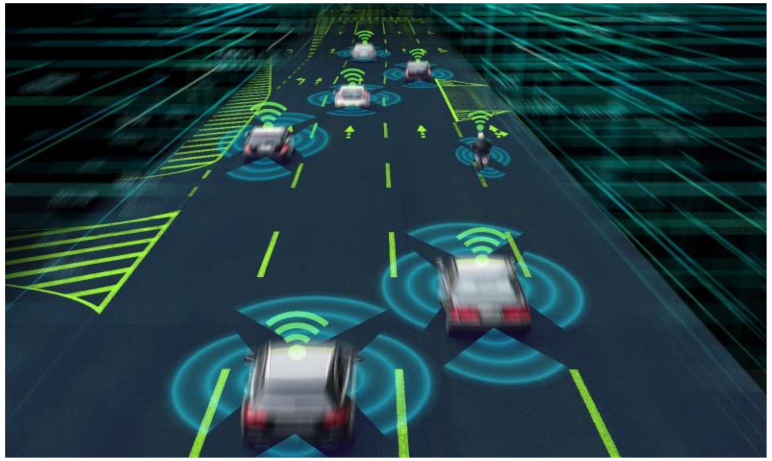
First Digital Transformation: Adding Embedded Software to Everything



Second Digital Transformation in Automotive

Vehicle Electrification

Automated Driving



Connected Vehicles

- Digital transformation is raising new questions about tools and processes

Questions to Answer

How well is your verification and validation process capable of meeting **ISO 26262**?

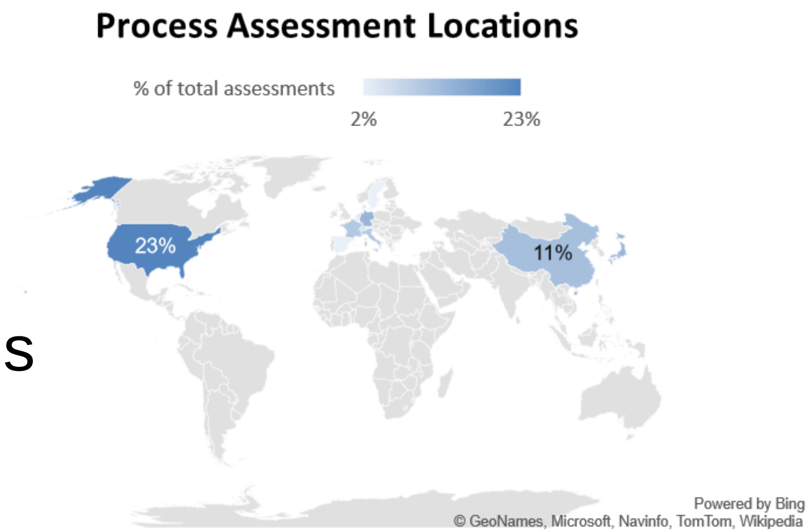
Why is **integration level testing** not being leveraged?

Are models leveraged for **validation** and **analysis** beyond code generation? How are they being maintained?

Are processes and tools being **evolved** to meet the application needs?

Objective for Today

- Over the years, MathWorks have conducted numerous Process Assessments across various industries around the world.


Process Assessment Locations
% of total assessments
2%
23%
23%
11%
Powered by Bing
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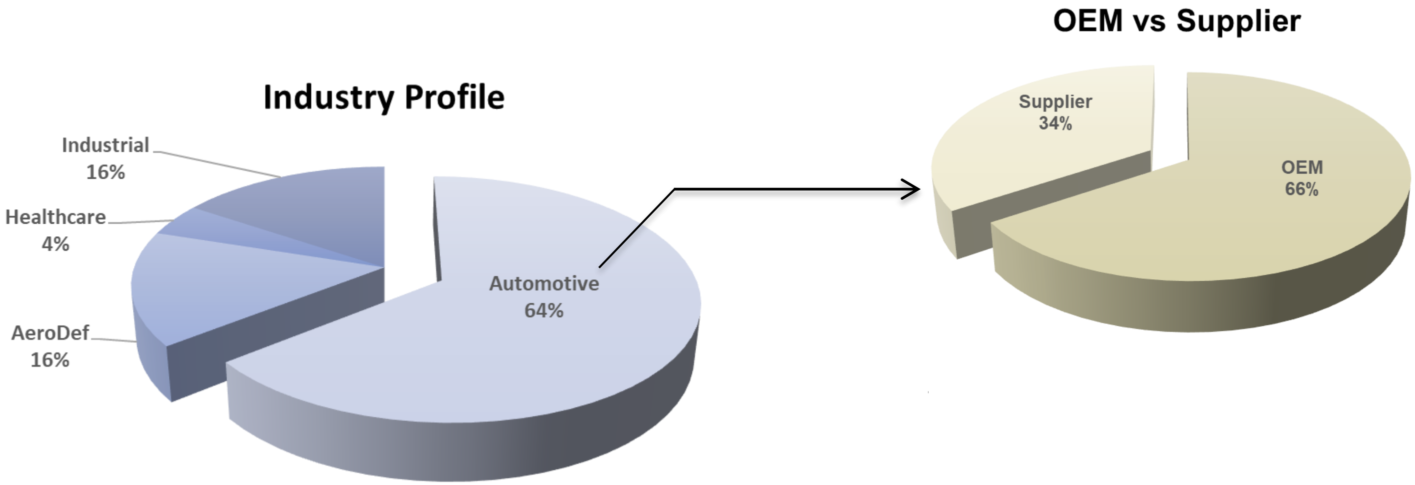
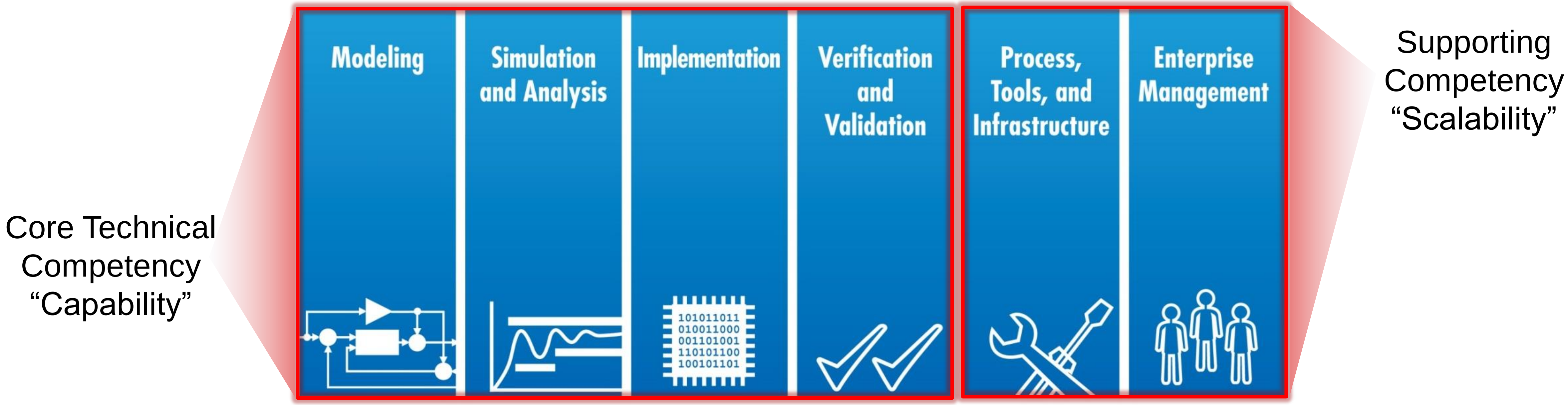
- Share findings including general trends and correlation with opportunities for tool and process improvements with a focus on Automotive Industry.

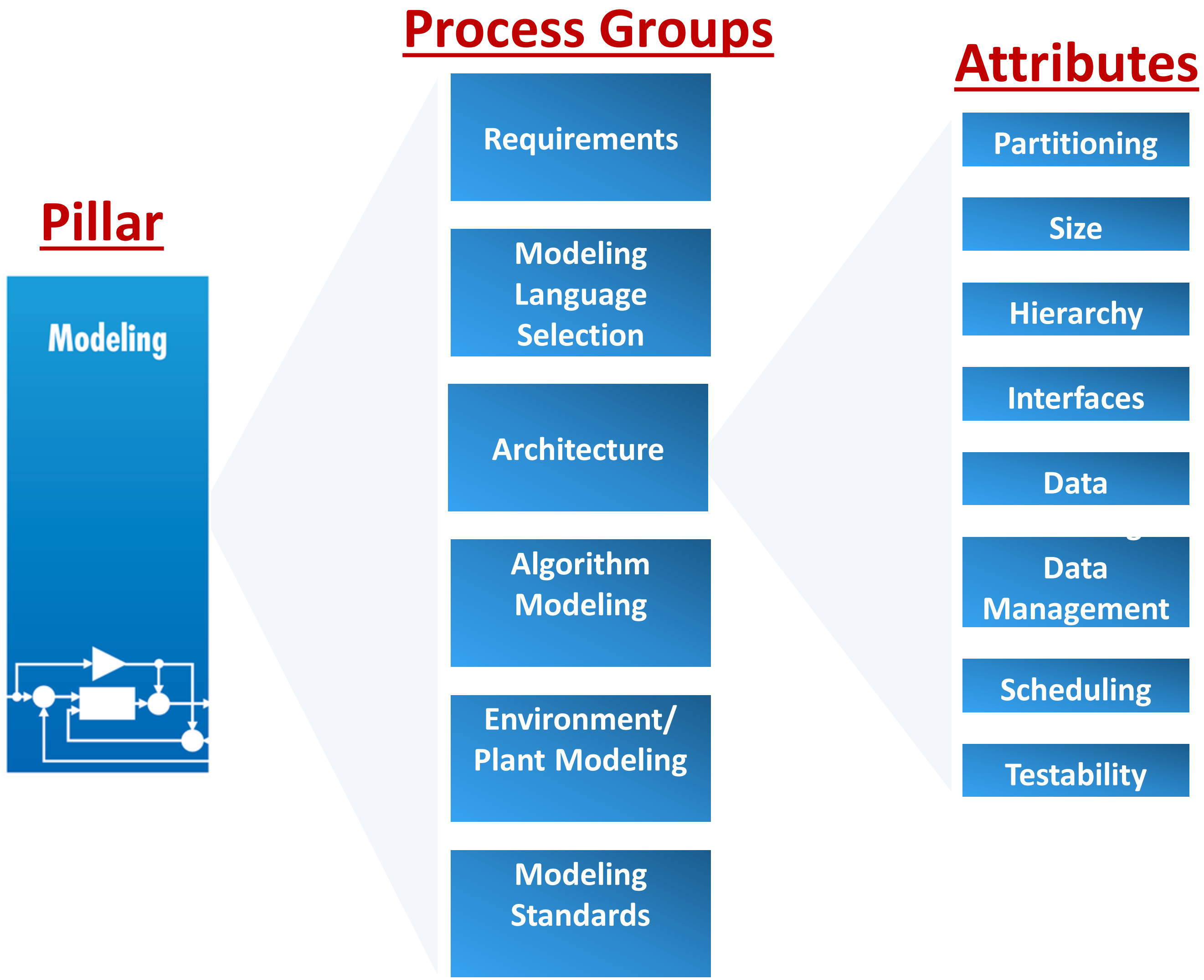


Assessment is based on Model-Based Design Maturity Framework™


Core Technical Competency “Capability”
Modeling
Simulation and Analysis
Implementation
101011011
010011000
001101001
110101100
100101101
Verification and Validation
Process, Tools, and Infrastructure
Enterprise Management
Supporting Competency “Scalability”

- Key Features
  - **Comprehensive measurement** of capabilities
  - Independently **measures each capability**
  - Applies to **any level of expertise**

Model-Based Design Maturity Framework™
Modeling Pillar Example



Pillar

Modeling

Process Groups

Requirements

Modeling Language Selection

Architecture

Algorithm Modeling

Environment/ Plant Modeling

Modeling Standards

Attributes

Partitioning

Size

Hierarchy

Interfaces

Data

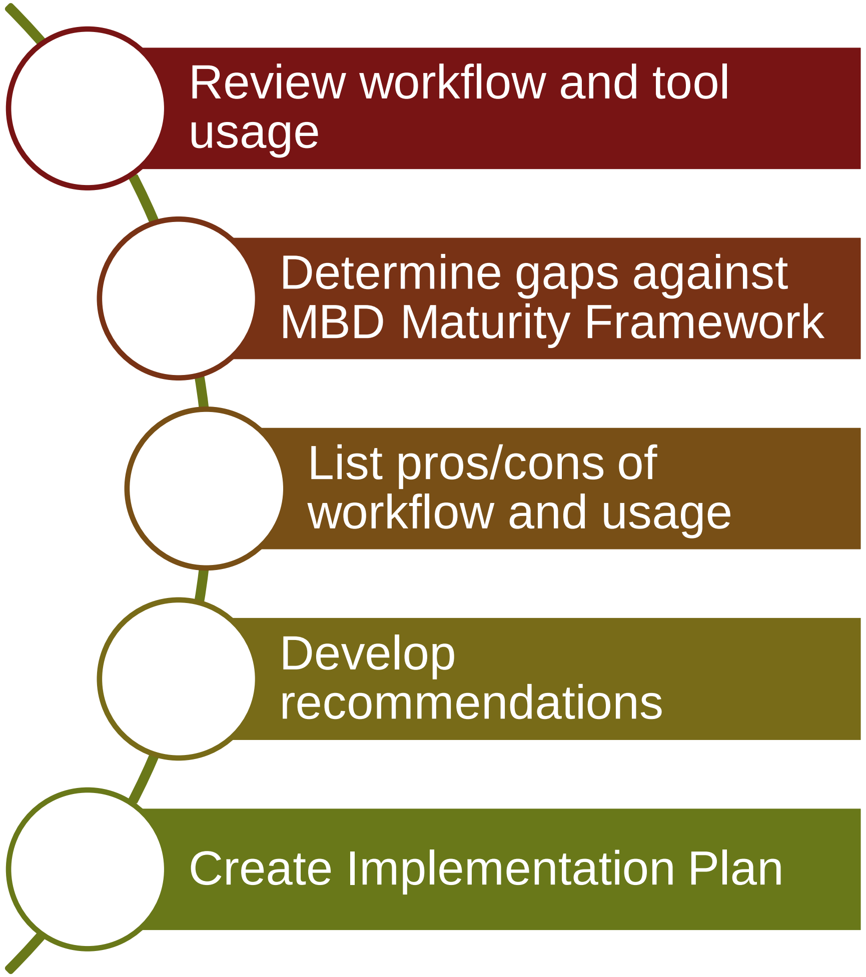
Data Management

Scheduling

Testability

- Maturity determined by rating:
  - 6 Pillars
  - 28 Key Process Groups
  - 200+ Attributes

Process Assessment Execution



Review workflow and tool usage

Determine gaps against MBD Maturity Framework

List pros/cons of workflow and usage

Develop recommendations

Create Implementation Plan

MBD Process Assessment Report

Model-Based Design Process Assessment Report

VERSION: 1.0

PREPARED BY:

MathWorks | Consulting Services

March 09, 2018

Version: 1.0

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Leaders
Average
Laggards
Modeling
100
80
60
40
20
0
Simulation and Analysis
Verification and Validation
Process, Tools and Infrastructure
Enterprise Management

Recommendations	Impact	Level of Difficulty
7.1 MBD Vision and Engineering Infrastructure		
7.1.1 Develop an enterprise-level strategic MBD vision	High	High
7.1.2 Establish a dedicated tools group for MBD	High	High
7.1.3 Establish a scalable software development process	High	Medium
7.1.4 Institute knowledge sharing and management	Medium	Medium
7.1.5 Use of metrics for forecasting (project status, process improvement, and workload)	High	Medium
7.1.6 Determine a tool upgrade strategy	Medium	Medium
7.2 Verification Strategy and Improvements		
7.2.1 Establish verification strategy	High	Medium
7.2.2 Move HIL testing to be ECU level based requirement testing	Medium	Medium
7.3 Plant model strategy and Improvements		
7.3.1 Establish strategy for plant modeling	High	High
7.3.2 Reuse of current HIL plant model for integration level testing	Medium	Medium
7.4 Redefine modeling organization with separate functional specialist and integration engineer (VSE)	Medium	Medium
7.5 Establish the use of simulation for system optimization and performance analysis for the requirement's group	High	Medium
7.6 Tool Capability Enhancements		
	Low	Low
	Medium	Low
	Medium	Medium
	Medium	Medium
	Medium	Medium
MBC) methods	Medium	Medium
	Low	Low
	Medium	Low
	Medium	Medium

6.4. Implementation (IMP)

6.4.1. Implementation Maturity

6.4.2. Strengths

6.4.3. Issues

Version: 1.0

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MBD Process Assessment Implementation Plan

…cess Assessment Report

…plementation Plan

VERSION: 1.0

PREPARED BY:

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March 09, 2018

Version: 1.0

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7.1 MBD Vision and Engineering Infrastructure

7.1.1 Develop an enterprise-level strategic MBD vision

- Short term actions
- Long term actions
- Measure of completion

7.1.2 Establish a dedicated tools person/group for MBD

- Short term actions

Version: 1.0

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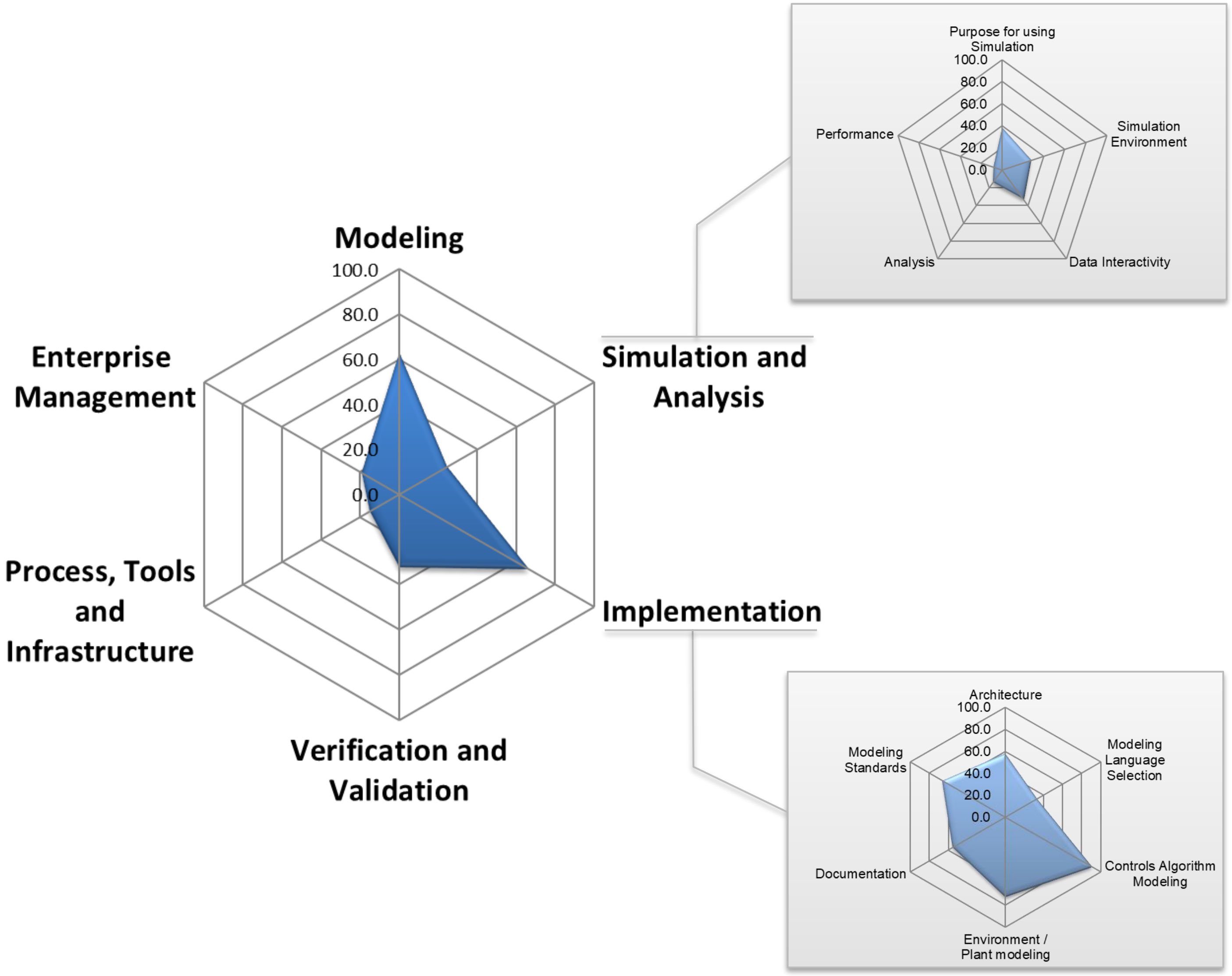
How Did We Review the Data?...Simple Example

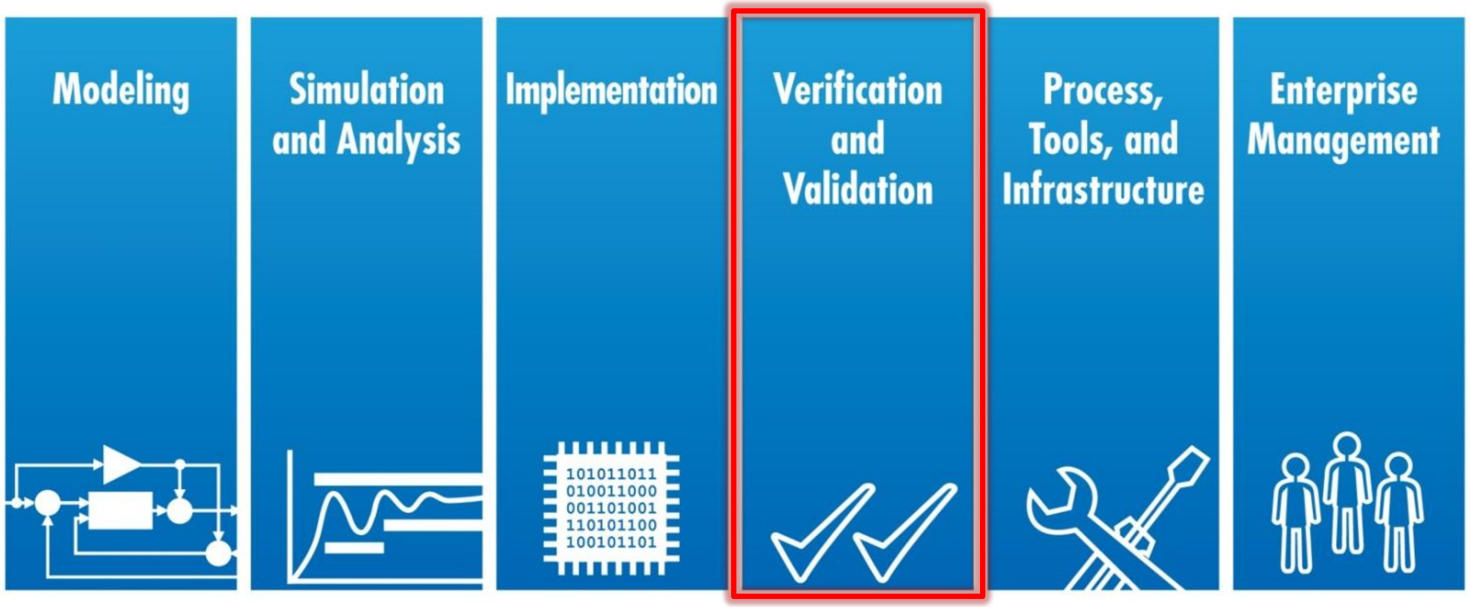


- Observation
  - Strong in Implementation (code generation)
  - Verification and Validation, and Simulation and Analysis not fully leverage
  - Model-Based Design focuses on software creation

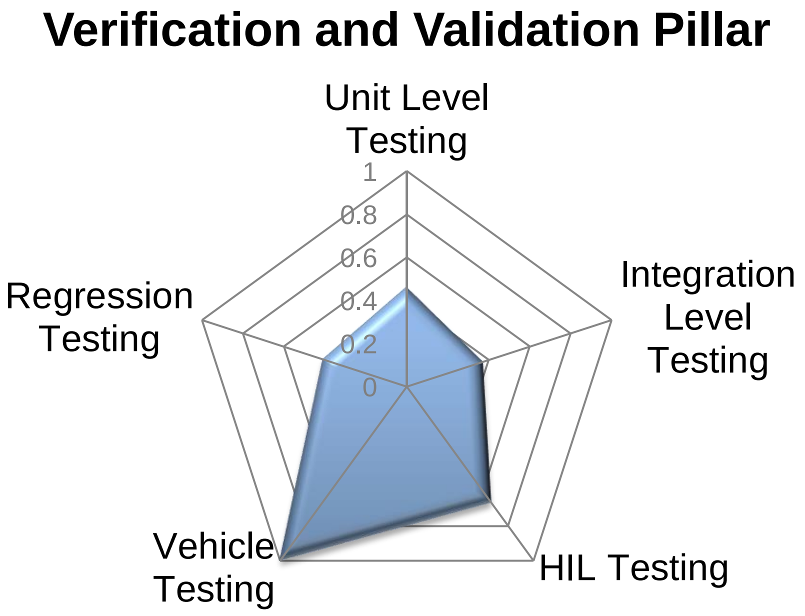
Process Assessment – Data Analysis

- Quantitative analysis
  - Plots of Process Assessment data
- Qualitative analysis
  - Analysis of detail report

How well is your verification and validation process capable of meeting **ISO 26262**?



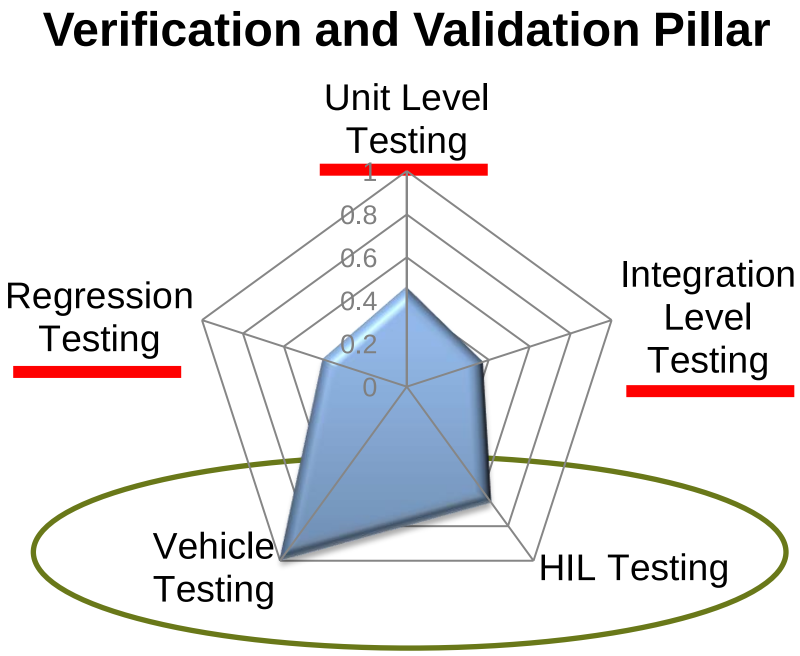
Verification and Validation Pillar Mapping with ISO 26262-6



VV Pillar	ISO 26262
Unit Level Testing	ISO 26262-6 Clause 9 Software Unit Verification
Integration Level Testing	ISO 26262-6 Clause 10 Software Integration and Verification
Vehicle and HIL Testing	ISO 26262-6 Clause 11 Testing of Embedded Software
Regression Testing	ISO 26262-8 Clause 9 Verification

*Average maturity rating V&V pillar normalized against Vehicle Testing

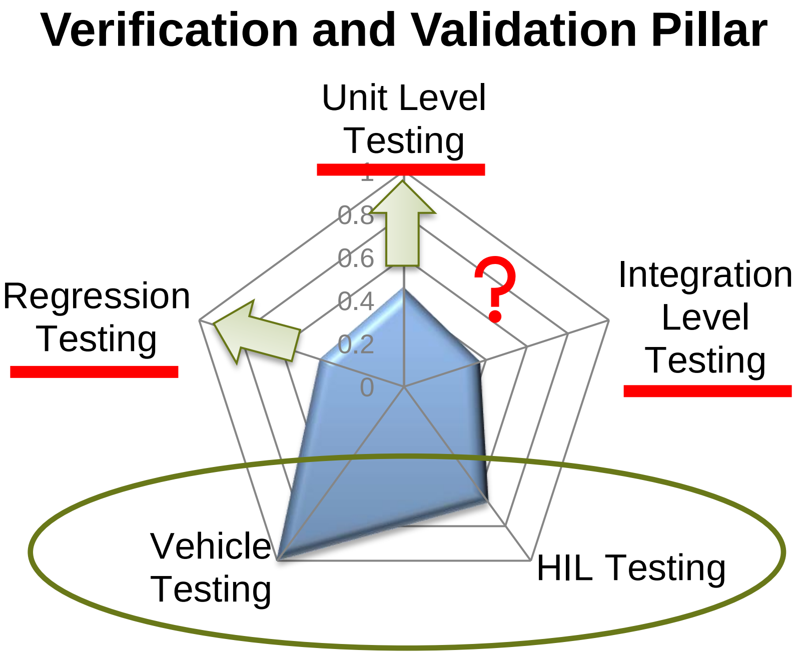
Verification and Validation Pillar Status and Trends



- Vehicle and HIL Testing are strong due to legacy reasons
- Low maturity in the other 3 process groups shows difficulty for meeting safety standards such ISO 26262

*Average maturity rating V&V pillar normalized against Vehicle Testing

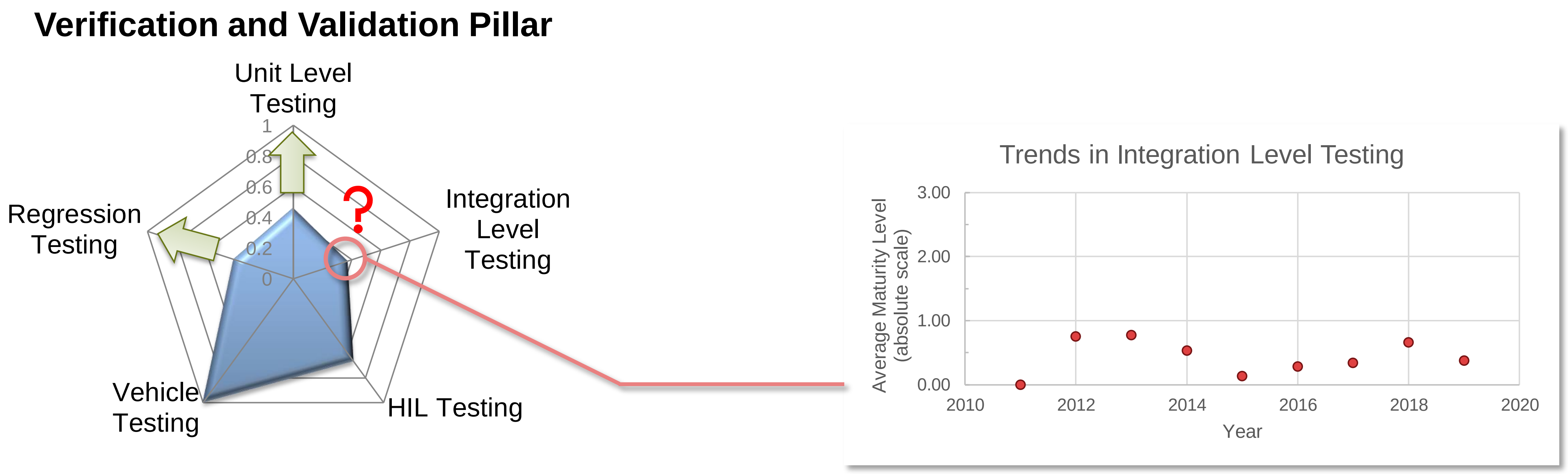
Verification and Validation Pillar
Status and Trends



- Positive trend:
  - Increasing rigor for Unit Testing and Regression Testing
  - Cause:
    - Increase system complexity
    - Standards such as ISO 26262 and ASPICE
  - Expectation is a maturity increase due to complex application – AV/ADAS/AD
- Puzzle: What about Integration Level Testing?

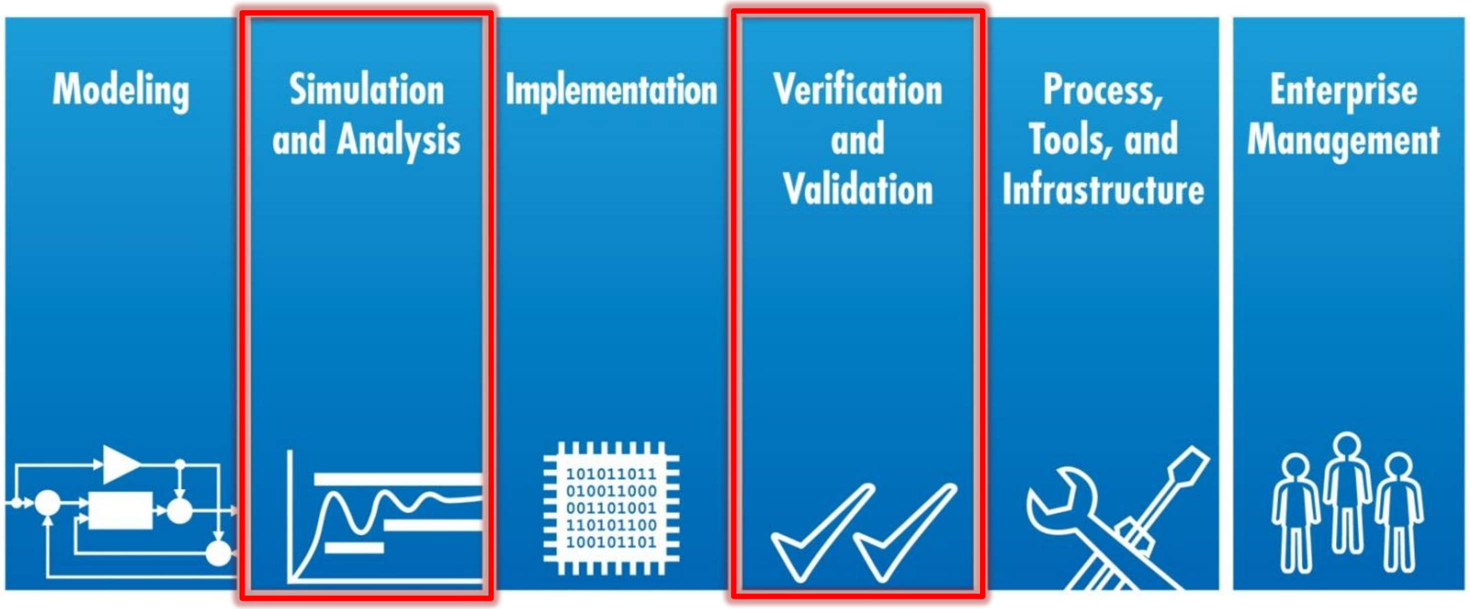
*Average maturity rating V&V pillar normalized against Vehicle Testing

Verification and Validation Pillar Status and Trends



*Average maturity rating V&V pillar normalized against Vehicle Testing

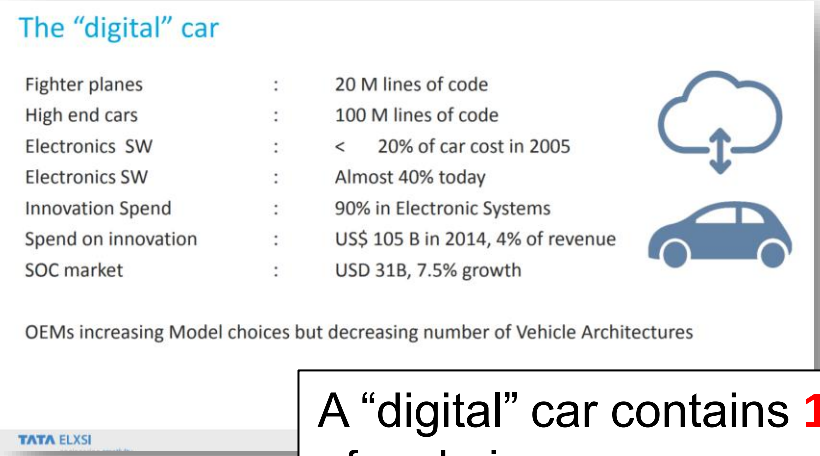
Why is **integration level testing** not being leveraged?



Why Is Integration Level Testing Important?

- Safety standard
  - Detail unit level verification
  - Ensure unit working together through integration testing

- Requirement validation
  - Top-down design approach
  - Ensuring requirement is correct



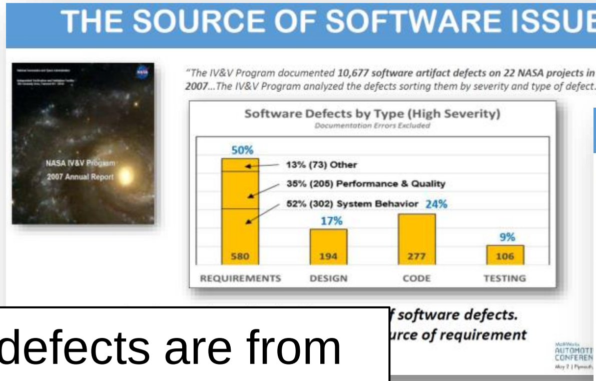
The “digital” car

Fighter planes	:	20 M lines of code
High end cars	:	100 M lines of code
Electronics SW	:	< 20% of car cost in 2005
Electronics SW	:	Almost 40% today
Innovation Spend	:	90% in Electronic Systems
Spend on innovation	:	US$ 105 B in 2014, 4% of revenue
SOC market	:	USD 31B, 7.5% growth

OEMs increasing Model choices but decreasing number of Vehicle Architectures

TATA ELXSI

A “digital” car contains **100 M** lines of code in car



THE SOURCE OF SOFTWARE ISSUES

NASA IV&V Program 2007 Annual Report

*“The IV&V Program documented **10,677 software artifact defects on 22 NASA projects** in 2007…The IV&V Program analyzed the defects sorting them by severity and type of defect.”*

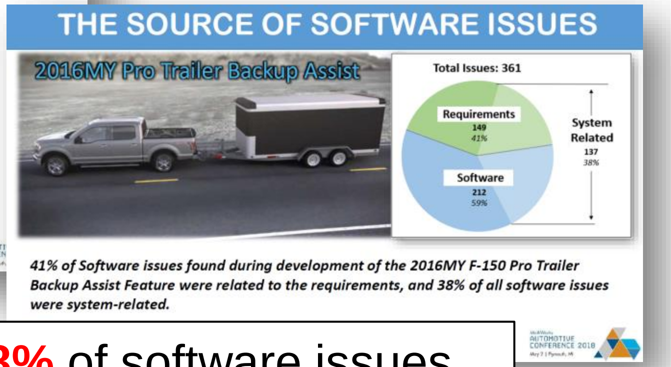
Software Defects by Type (High Severity)

Documentation Errors Excluded

f software defects.

urce of requirement

50% of defects are from requirement



THE SOURCE OF SOFTWARE ISSUES

41% of Software issues found during development of the 2016MY F-150 Pro Trailer Backup Assist Feature were related to the requirements, and 38% of all software issues were system-related.

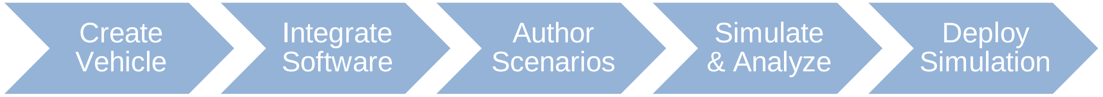
MathWorks AUTOMOTIVE CONFERENCE 2018

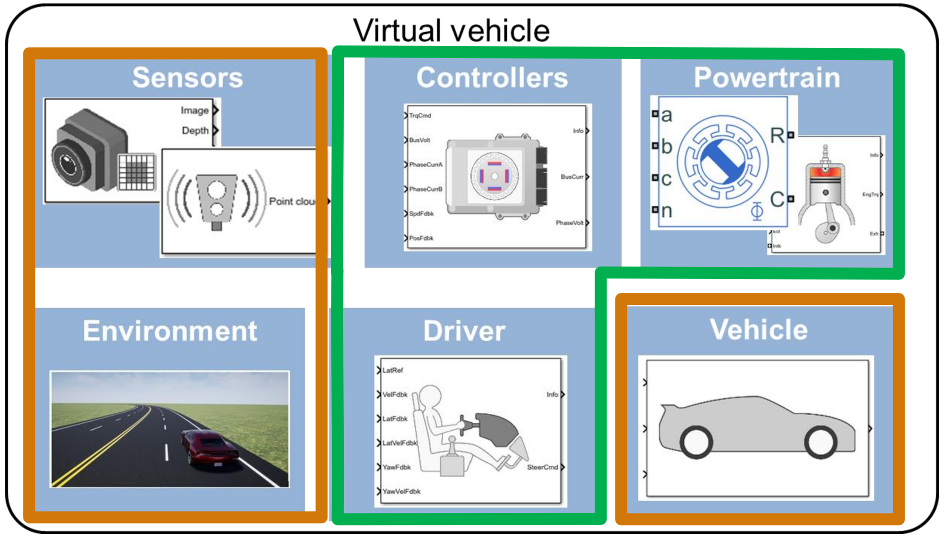
38% of software issues were system-related

Key Components for Building Integration Level Model

- Automatic integration of unit level models
- Stronger integration with Software/Model repository
- Out of box solution for Plant Model
- Simulation in scalability
- Matching software construct such as scheduler
- ….etc.

Development for Integration Level Testing



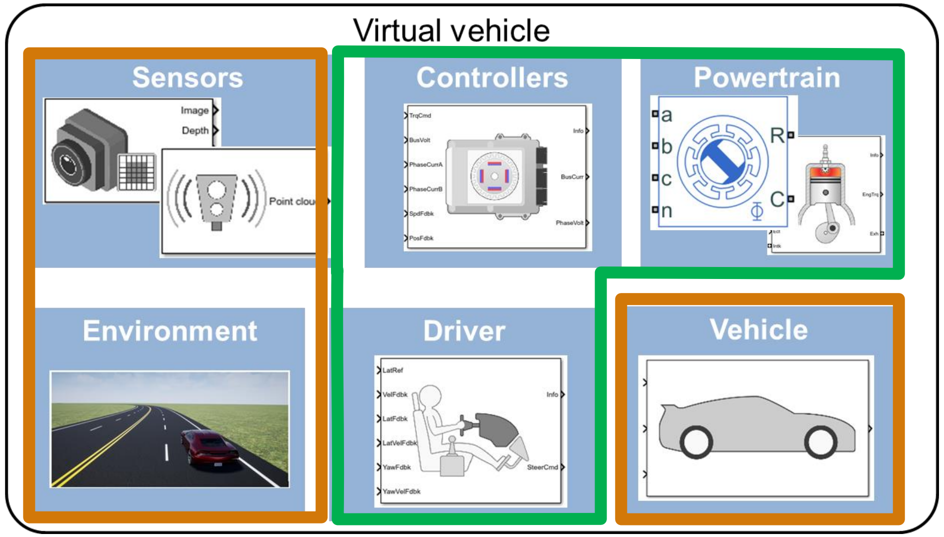


R2016b release – Powertrain Blockset

R2018a release – Vehicle Dynamic Blockset

Enable Integration Level Testing

Create Vehicle → Integrate Software → Author Scenarios → Simulate & Analyze → Deploy Simulation



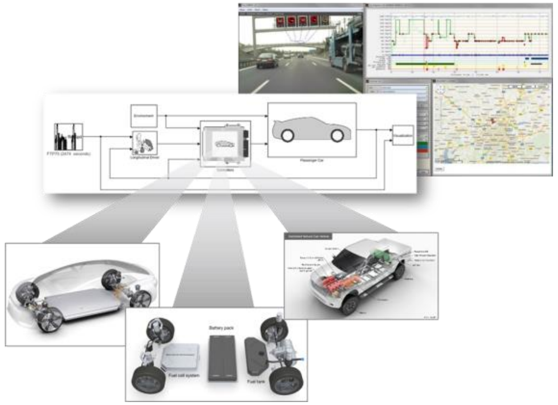
MathWorks Consulting Services

- Provide expert-level guidance
- Automate workflows
- Develop custom UI’s

Model Architecture
Model assessment
Simulation performance
Interface standardization
…

Construction
Build process automation
Database/Repo interface
Model-Building know-how
…

User Experience
GUI driven workflow
Tool compatibility support
Artifact creation
…



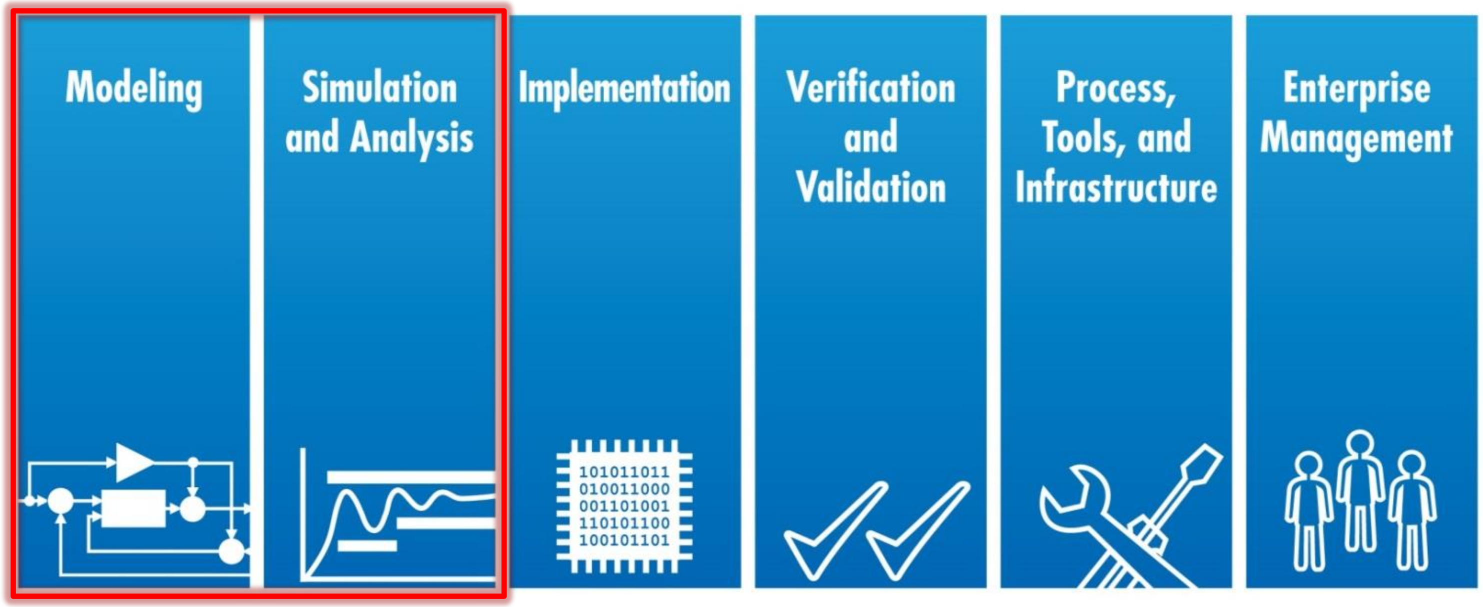
Out-of-the-box capability

Custom virtual vehicle solution

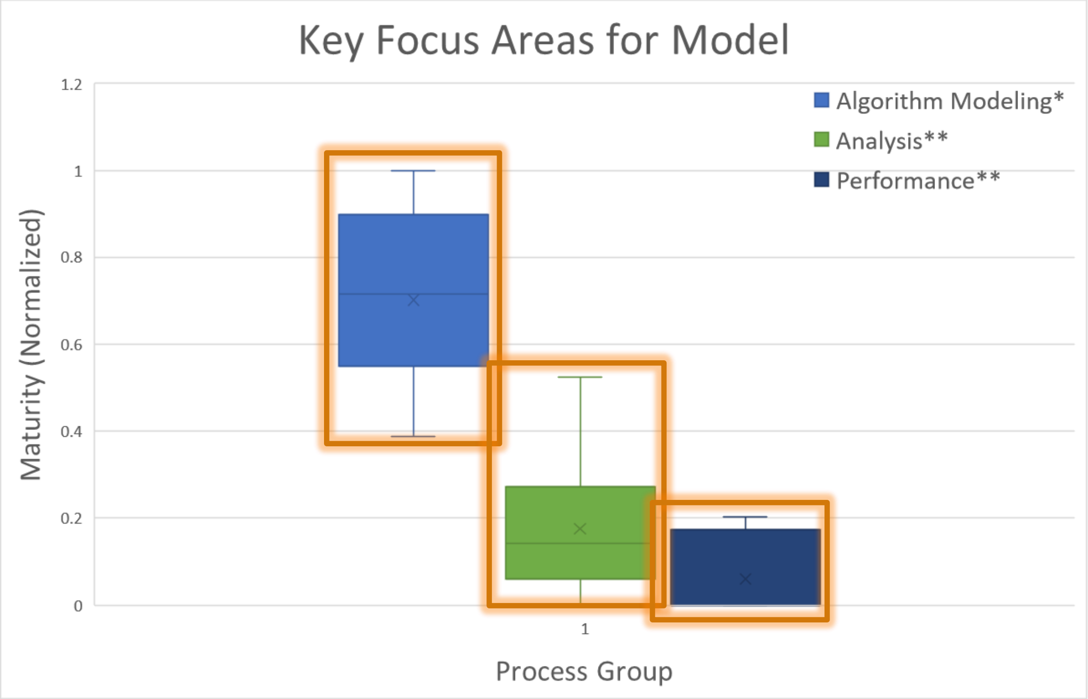
R2016b release – Powertrain Blockset

R2018a release – Vehicle Dynamic Blockset

Are models leveraged for **validation** and **analysis** beyond code generation? How are they being maintained?



Model Usage

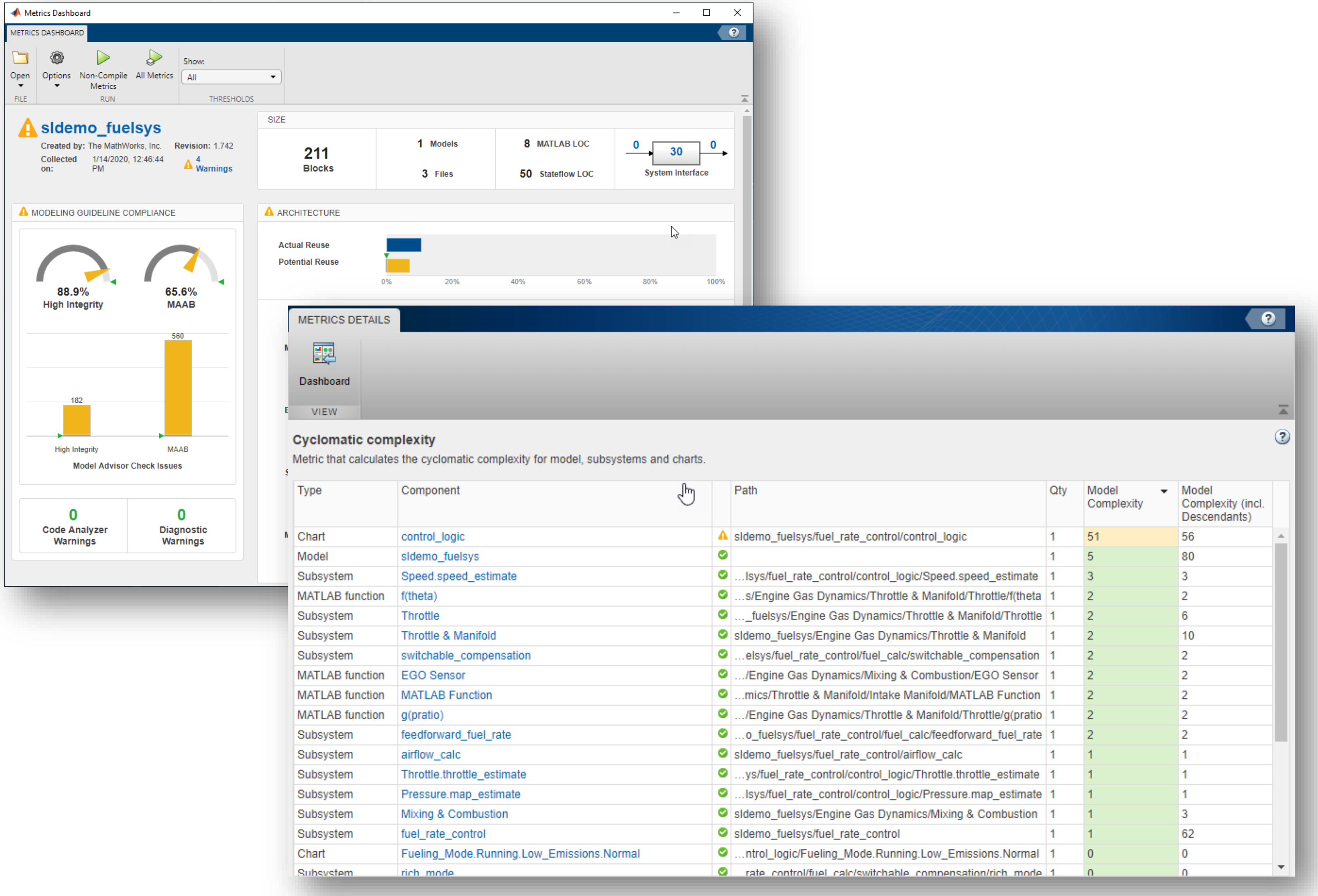


* Part of the Model Pillar
** Part of the Simulation Pillar

- Most companies develop model for algorithm development.
- Leading companies also develop models for
  - Requirement validation
  - Performance optimization
- Leading companies maintain models and
  - Gather metrics and reports
  - Optimize simulation speed
- Usage of models is an area that exhibits wide differences between leaders and laggards

Model Lifecycle Management Through Metrics

- Out-of-the-Box
  - Model Metric Dashboard



Show: All

sldemo_fuelsys

Created by: The MathWorks, Inc. Revision: 1.742

Collected on: 1/14/2020, 12:46:44 PM

4 Warnings

SIZE

211 Blocks

1 Models

3 Files

8 MATLAB LOC

50 Stateflow LOC

0 30 0 System Interface

MODELING GUIDELINE COMPLIANCE

88.9% High Integrity

65.6% MAAB

Model Advisor Check Issues

0 Code Analyzer Warnings

0 Diagnostic Warnings

ARCHITECTURE

Actual Reuse

Potential Reuse

Cyclomatic complexity

Metric that calculates the cyclomatic complexity for model, subsystems and charts.

Type	Component		Path	Qty	Model Complexity	Model Complexity (incl. Descendants)
Chart	control_logic	⚠	sldemo_fuelsys/fuel_rate_control/control_logic	1	51	56
Model	sldemo_fuelsys	✓		1	5	80
Subsystem	Speed.speed_estimate	✓	…lsys/fuel_rate_control/control_logic/Speed.speed_estimate	1	3	3
MATLAB function	f(theta)	✓	…s/Engine Gas Dynamics/Throttle & Manifold/Throttle/f(theta	1	2	2
Subsystem	Throttle	✓	…_fuelsys/Engine Gas Dynamics/Throttle & Manifold/Throttle	1	2	6
Subsystem	Throttle & Manifold	✓	sldemo_fuelsys/Engine Gas Dynamics/Throttle & Manifold	1	2	10
Subsystem	switchable_compensation	✓	…elsys/fuel_rate_control/fuel_calc/switchable_compensation	1	2	2
MATLAB function	EGO Sensor	✓	…/Engine Gas Dynamics/Mixing & Combustion/EGO Sensor	1	2	2
MATLAB function	MATLAB Function	✓	…mics/Throttle & Manifold/Intake Manifold/MATLAB Function	1	2	2
MATLAB function	g(pratio)	✓	…/Engine Gas Dynamics/Throttle & Manifold/Throttle/g(pratio	1	2	2
Subsystem	feedforward_fuel_rate	✓	…o_fuelsys/fuel_rate_control/fuel_calc/feedforward_fuel_rate	1	2	2
Subsystem	airflow_calc	✓	sldemo_fuelsys/fuel_rate_control/airflow_calc	1	1	1
Subsystem	Throttle.throttle_estimate	✓	…ys/fuel_rate_control/control_logic/Throttle.throttle_estimate	1	1	1
Subsystem	Pressure.map_estimate	✓	…lsys/fuel_rate_control/control_logic/Pressure.map_estimate	1	1	1
Subsystem	Mixing & Combustion	✓	sldemo_fuelsys/Engine Gas Dynamics/Mixing & Combustion	1	1	3
Subsystem	fuel_rate_control	✓	sldemo_fuelsys/fuel_rate_control	1	1	62
Chart	Fueling_Mode.Running.Low_Emissions.Normal	✓	…ntrol_logic/Fueling_Mode.Running.Low_Emissions.Normal	1	0	0
Subsystem	rich_mode	✓	…rate_control/fuel_calc/switchable_compensation/rich_mode	1	0	0

Model Lifecycle Management Through Metrics

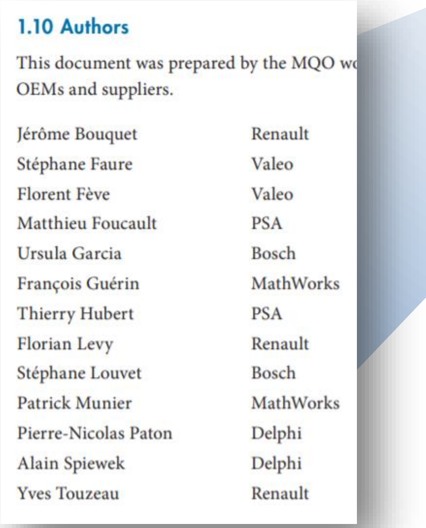
- Out-of-the-Box
  - Model Metric Dashboard

- Industry partnership
  - Model Quality Objectives

Model Quality Objectives

Embedded software development with MATLAB/Simulink

Author: MQO Working Group | Version: 1.0 | Release date: 09-2018



1.10 Authors

This document was prepared by the MQO w
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Patrick Munier	MathWorks
Pierre-Nicolas Paton	Delphi
Alain Spiewek	Delphi
Yves Touzeau	Renault

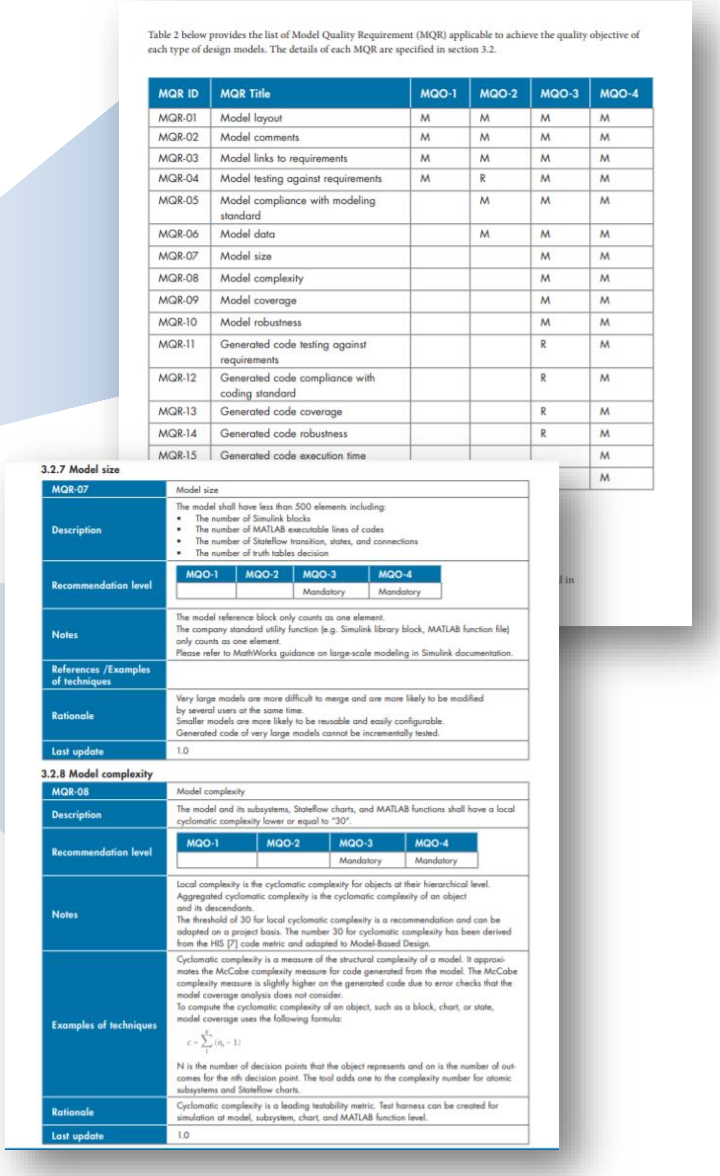


Table 2 below provides the list of Model Quality Requirement (MQR) applicable to achieve the quality objective of each type of design models. The details of each MQR are specified in section 3.2.

MQR ID	MQR Title	MQO-1	MQO-2	MQO-3	MQO-4
MQR-01	Model layout	M	M	M	M
MQR-02	Model comments	M	M	M	M
MQR-03	Model links to requirements	M	M	M	M
MQR-04	Model testing against requirements	M	R	M	M
MQR-05	Model compliance with modeling standard		M	M	M
MQR-06	Model data		M	M	M
MQR-07	Model size			M	M
MQR-08	Model complexity			M	M
MQR-09	Model coverage			M	M
MQR-10	Model robustness			M	M
MQR-11	Generated code testing against requirements			R	M
MQR-12	Generated code compliance with coding standard			R	M
MQR-13	Generated code coverage			R	M
MQR-14	Generated code robustness			R	M
MQR-15	Generated code execution time				M
					M

3.2.7 Model size

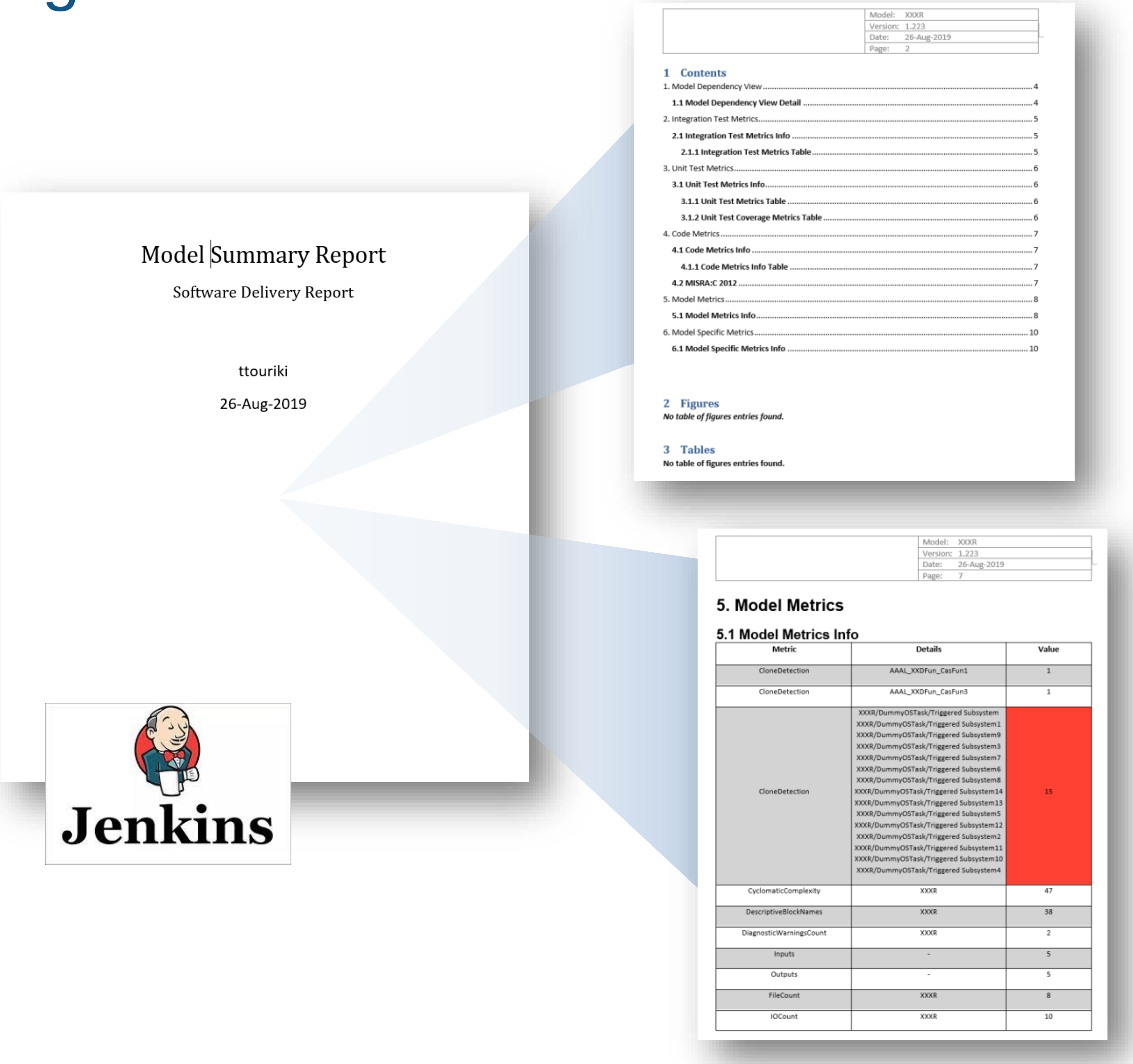
<table>
<tr><td>MQR-07</td><td>Model size</td></tr>
<tr><td>Description</td><td>The model shall have less than 500 elements including:
• The number of Simulink blocks
• The number of MATLAB executable lines of codes
• The number of Stateflow transition, states, and connections
• The number of truth tables decision</td></tr>
<tr><td>Recommendation level</td><td><table><tr><td>MQO-1</td><td>MQO-2</td><td>MQO-3</td><td>MQO-4</td></tr><tr><td></td><td></td><td>Mandatory</td><td>Mandatory</td></tr></table></td></tr>
<tr><td>Notes</td><td>The model reference block only counts as one element.
The company standard utility function (e.g. Simulink library block, MATLAB function file) only counts as one element.
Please refer to MathWorks guidance on large-scale modeling in Simulink documentation.</td></tr>
<tr><td>References /Examples of techniques</td><td></td></tr>
<tr><td>Rationale</td><td>Very large models are more difficult to merge and are more likely to be modified by several users at the same time.
Smaller models are more likely to be reusable and easily configurable.
Generated code of very large models cannot be incrementally tested.</td></tr>
<tr><td>Last update</td><td>1.0</td></tr>
</table>

3.2.8 Model complexity

<table>
<tr><td>MQR-08</td><td>Model complexity</td></tr>
<tr><td>Description</td><td>The model and its subsystems, Stateflow charts, and MATLAB functions shall have a local cyclomatic complexity lower or equal to "30".</td></tr>
<tr><td>Recommendation level</td><td><table><tr><td>MQO-1</td><td>MQO-2</td><td>MQO-3</td><td>MQO-4</td></tr><tr><td></td><td></td><td>Mandatory</td><td>Mandatory</td></tr></table></td></tr>
<tr><td>Notes</td><td>Local complexity is the cyclomatic complexity for objects at their hierarchical level.
Aggregated cyclomatic complexity is the cyclomatic complexity of an object and its descendants.
The threshold of 30 for local cyclomatic complexity is a recommendation and can be adapted on a project basis. The number 30 for cyclomatic complexity has been derived from the HIS [7] code metric and adapted to Model-Based Design.</td></tr>
<tr><td>Examples of techniques</td><td>Cyclomatic complexity is a measure of the structural complexity of a model. It approximates the McCabe complexity measure for code generated from the model. The McCabe complexity measure is slightly higher on the generated code due to error checks that the model coverage analysis does not consider.
To compute the cyclomatic complexity of an object, such as a block, chart, or state, model coverage uses the following formula:
$c = \sum_{1}^{N} (o_n - 1)$
N is the number of decision points that the object represents and on is the number of outcomes for the nth decision point. The tool adds one to the complexity number for atomic subsystems and Stateflow charts.</td></tr>
<tr><td>Rationale</td><td>Cyclomatic complexity is a leading testability metric. Test harness can be created for simulation at model, subsystem, chart, and MATLAB function level.</td></tr>
<tr><td>Last update</td><td>1.0</td></tr>
</table>

Model Lifecycle Management Through Metrics

- Out-of-the-Box
  - Model Metric Dashboard
- Partnering with industry
  - Model Quality Objectives
- Customized solution - Consulting
  - Custom report with integration to Jenkins
  - Embedded pass/fail thresholds



Model Summary Report

Software Delivery Report

ttouriki

26-Aug-2019

Model:	XXXR
Version:	1.223
Date:	26-Aug-2019
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1 Contents

2 Figures

No table of figures entries found.

3 Tables

No table of figures entries found.

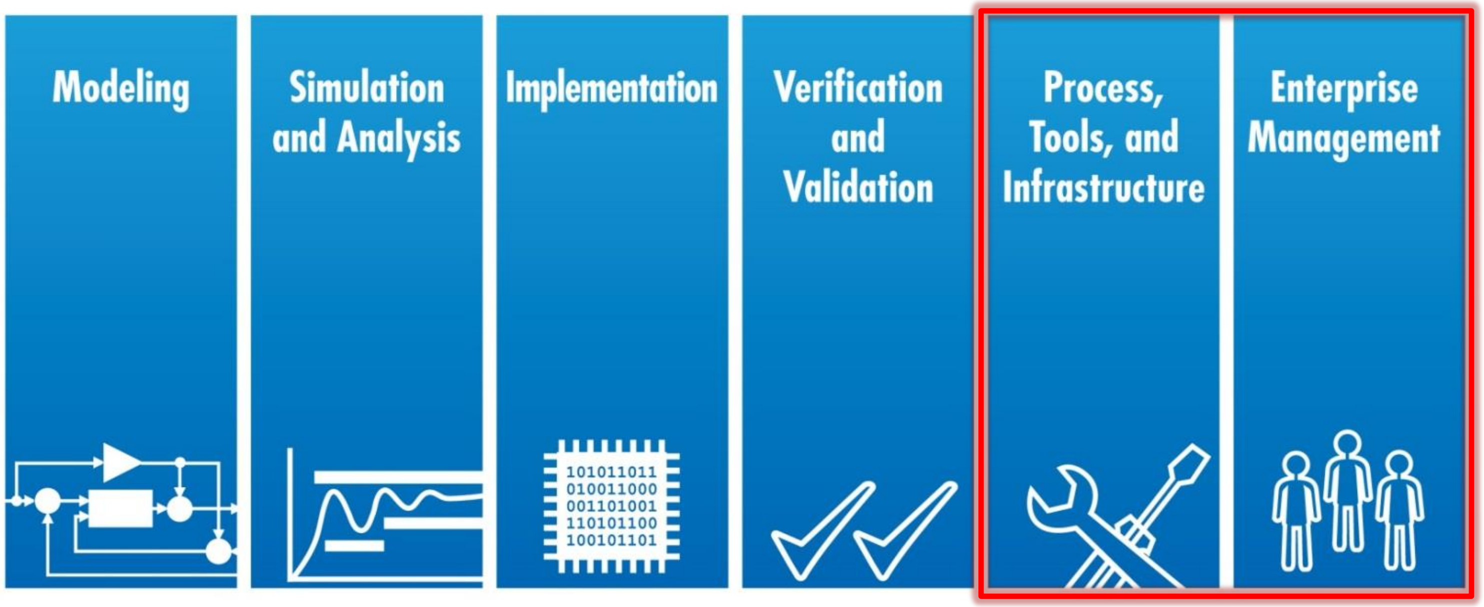
Model:	XXXR
Version:	1.223
Date:	26-Aug-2019
Page:	7

5. Model Metrics

5.1 Model Metrics Info

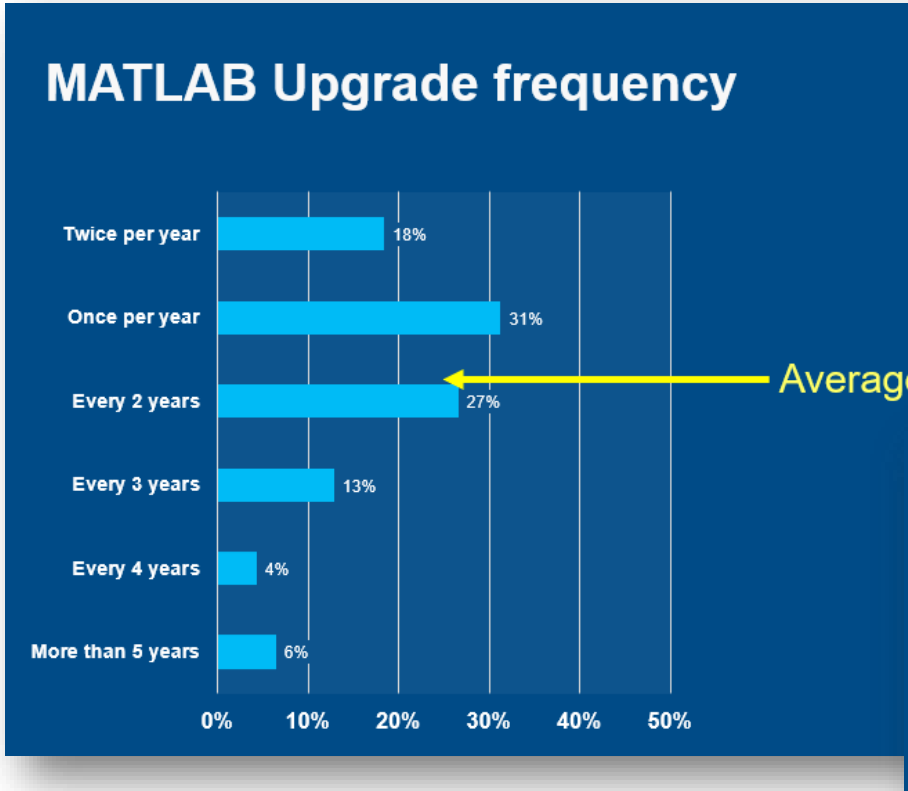
Metric	Details	Value
CloneDetection	AAAL_XXDFun_CasFun1	1
CloneDetection	AAAL_XXDFun_CasFun3	1
CloneDetection	XXXR/DummyOSTask/Triggered Subsystem XXXR/DummyOSTask/Triggered Subsystem1 XXXR/DummyOSTask/Triggered Subsystem9 XXXR/DummyOSTask/Triggered Subsystem3 XXXR/DummyOSTask/Triggered Subsystem7 XXXR/DummyOSTask/Triggered Subsystem6 XXXR/DummyOSTask/Triggered Subsystem8 XXXR/DummyOSTask/Triggered Subsystem14 XXXR/DummyOSTask/Triggered Subsystem13 XXXR/DummyOSTask/Triggered Subsystem5 XXXR/DummyOSTask/Triggered Subsystem12 XXXR/DummyOSTask/Triggered Subsystem2 XXXR/DummyOSTask/Triggered Subsystem11 XXXR/DummyOSTask/Triggered Subsystem10 XXXR/DummyOSTask/Triggered Subsystem4	15
CyclomaticComplexity	XXXR	47
DescriptiveBlockNames	XXXR	38
DiagnosticWarningsCount	XXXR	2
Inputs	-	5
Outputs	-	5
FileCount	XXXR	8
IOCount	XXXR	10

Are processes and tools being **evolved** to meet the application needs?



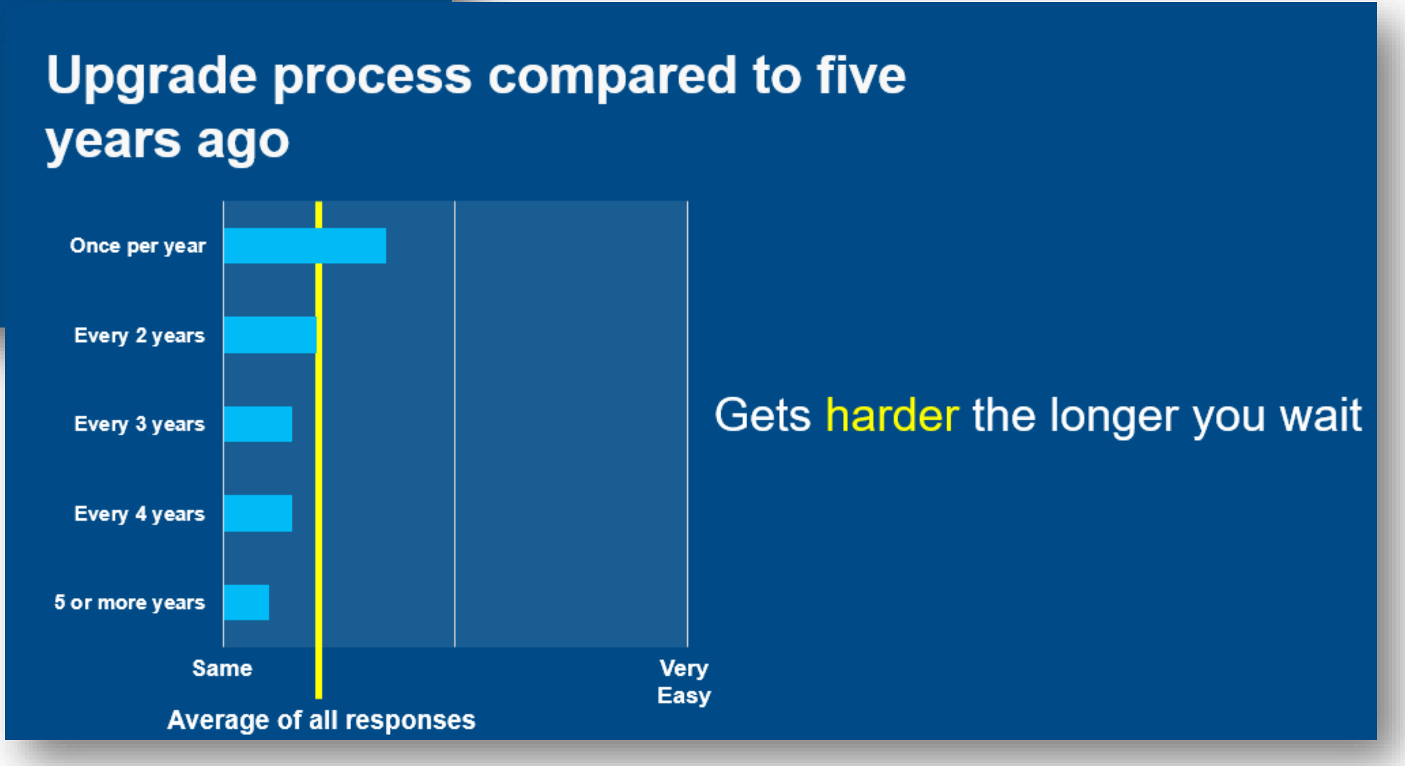
Version Upgrade – MathWorks Advisory Board (MAB) Survey

MATLAB Upgrade frequency



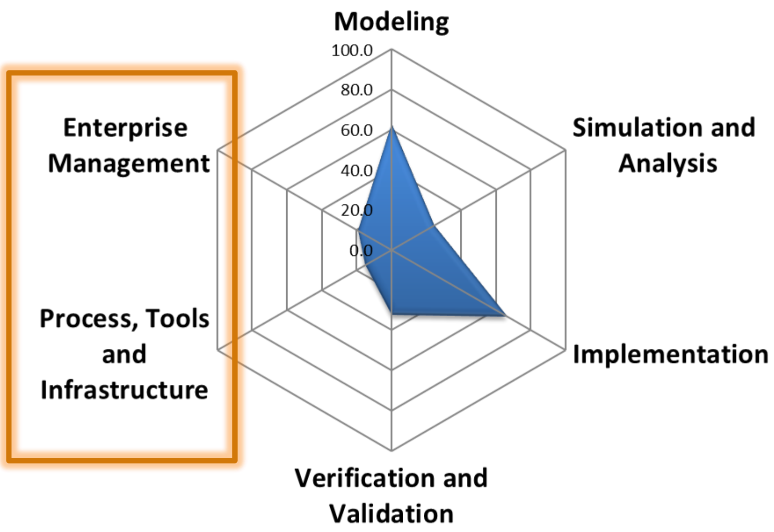
Average: 1.9 years

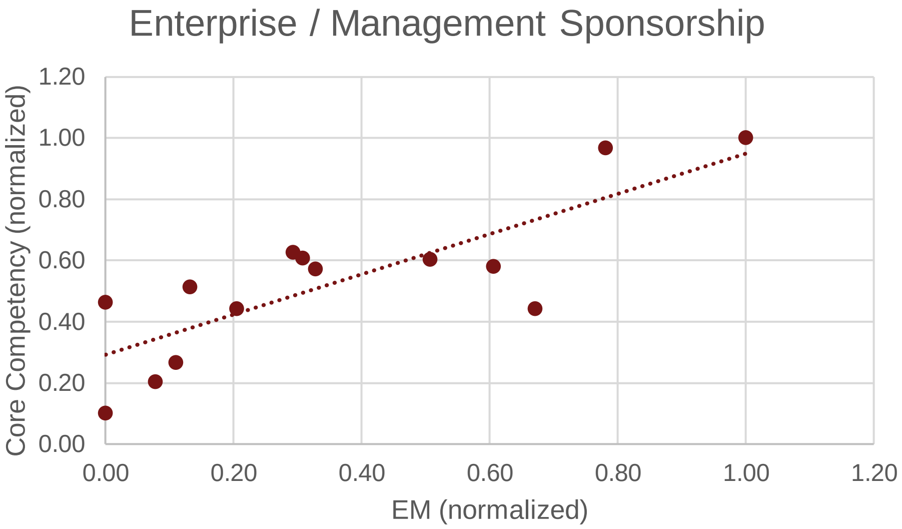
Upgrade process compared to five years ago



Gets harder the longer you wait

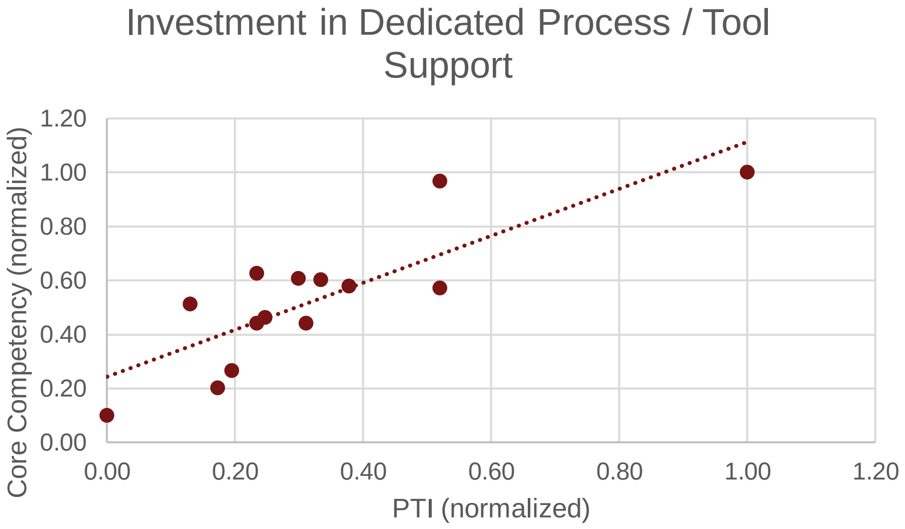
Effect of Supporting Competency




Enterprise / Management Sponsorship

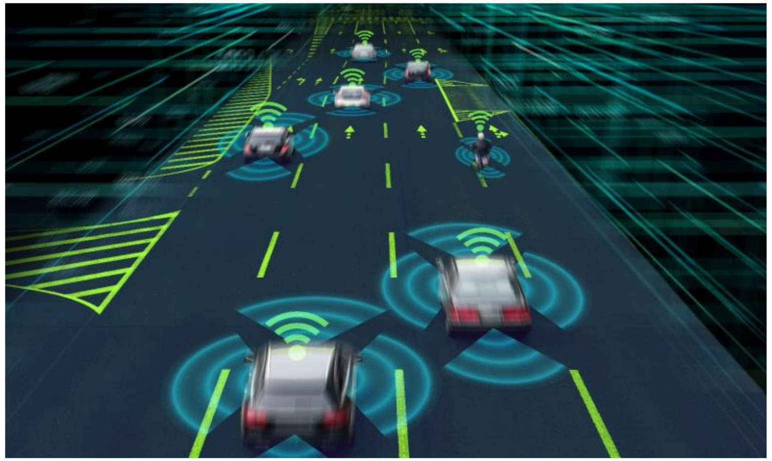
EM ➔ Management Sponsorship

PTI ➔ Process/Tool Investment


Investment in Dedicated Process / Tool Support

Summary

- Improve Verification and Validation process to meet safety standards
- Leverage Integration Level Model for requirement validation
- Ensure models are used for analysis and are maintained using leading indicator metrics
- Invest in processes and tools



Thank You for Your Attention!

- Poll Questions
  - Are you interested in learning more about Process Assessment?
    - Yes
    - No
  - I am interested in Process Assessment for this reason
    - Gap analysis against standard such ISO 26262, ASPICE, …etc.
    - Optimize existing process
    - Establish a new process
    - None

Please contact Govind Malleichervu / John Lee for questions:

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