

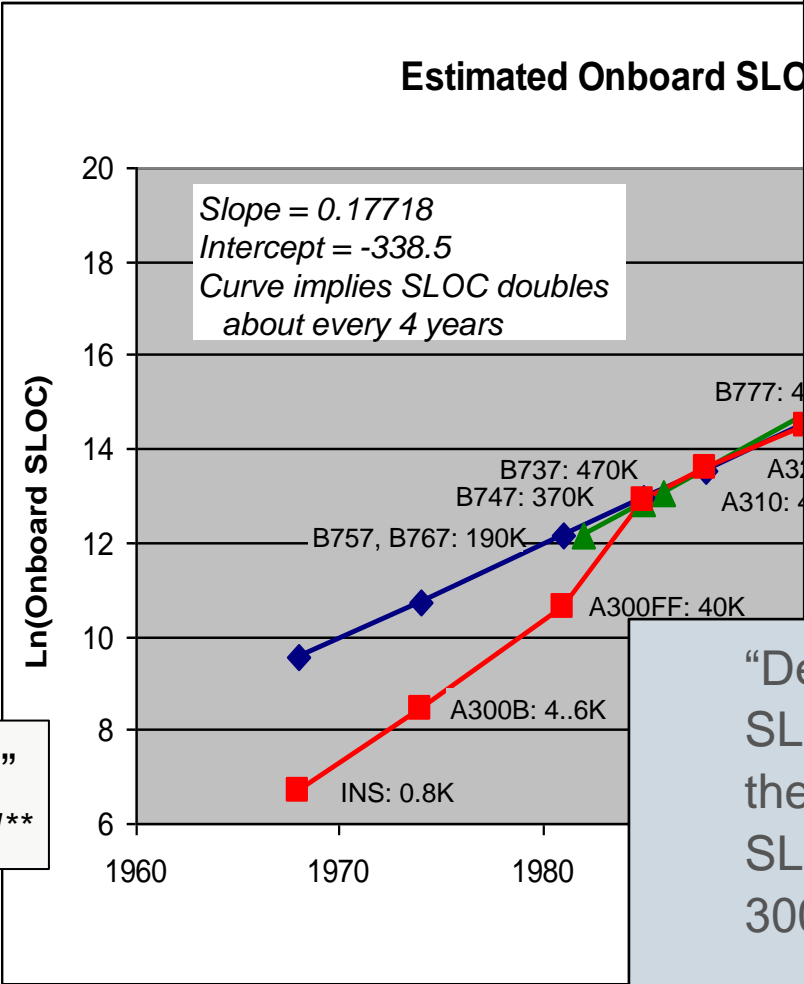
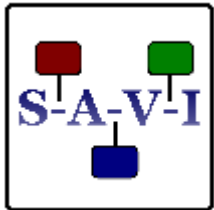


# **Start Integrated Stay Integrated**

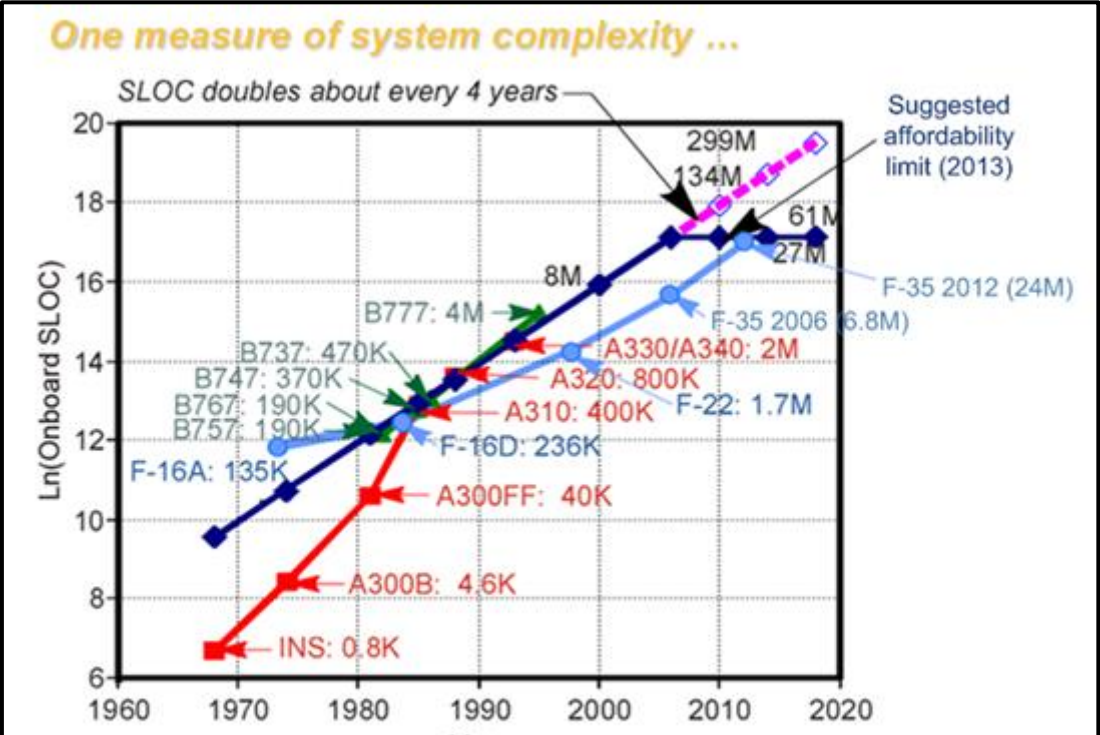
Continuous Integration: Moving from Spec→Design→Integrate to Integrate→Build

# Unprecedented Product Complexity: becoming unaffordable...

Norm was right (Augustine's Law #16)\*



“Integrate, then build”  
AVSI\*\*



“Development effort, which increases exponentially with SLOC, is increasing at an alarming rate. For example, the F35 has approximately 175 times the number of SLOC as the F16. But, it is estimated to have required 300 times the development effort”

<https://savi.avsi.aero/about-savi/>



## Requirement disconnects are costly...

- ~21 million automotive recalls in the US last year
- Per AlixPartners\*, each recall costs ~\$500/vehicle, that's \$105 billion in direct costs fixing the problems in 2021
- Auto Manufacturers carrying ~\$113B in warranty reserves\*\* (2.5% of revenue) on their books

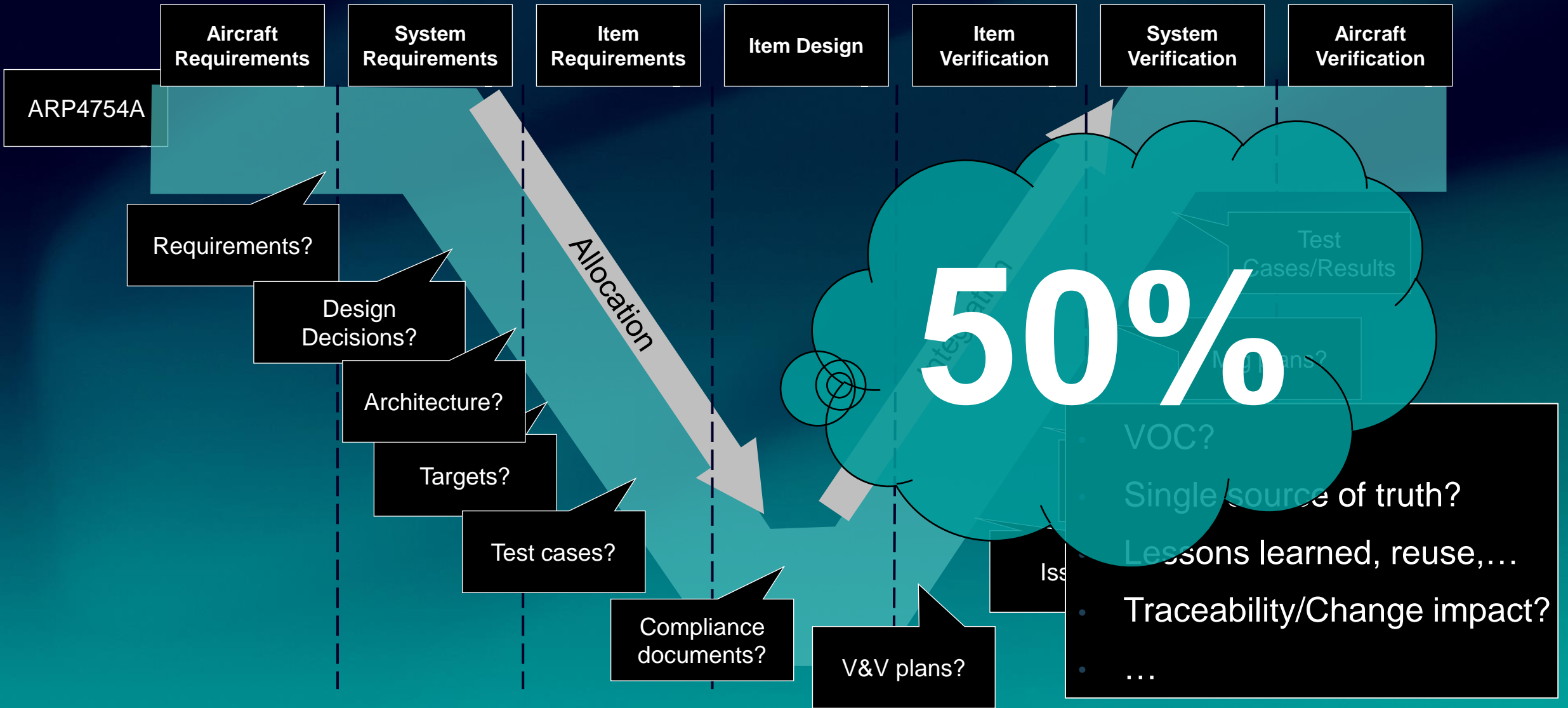
...mostly due to cross organization/interdisciplinary communication issues



\* [http://lite.cnn.com/en/article/h\\_a9a78e0bc97dc033569b8b2fefe63d47](http://lite.cnn.com/en/article/h_a9a78e0bc97dc033569b8b2fefe63d47)

\*\* <https://www.warrantyweek.com/archive/ww20200910.html>

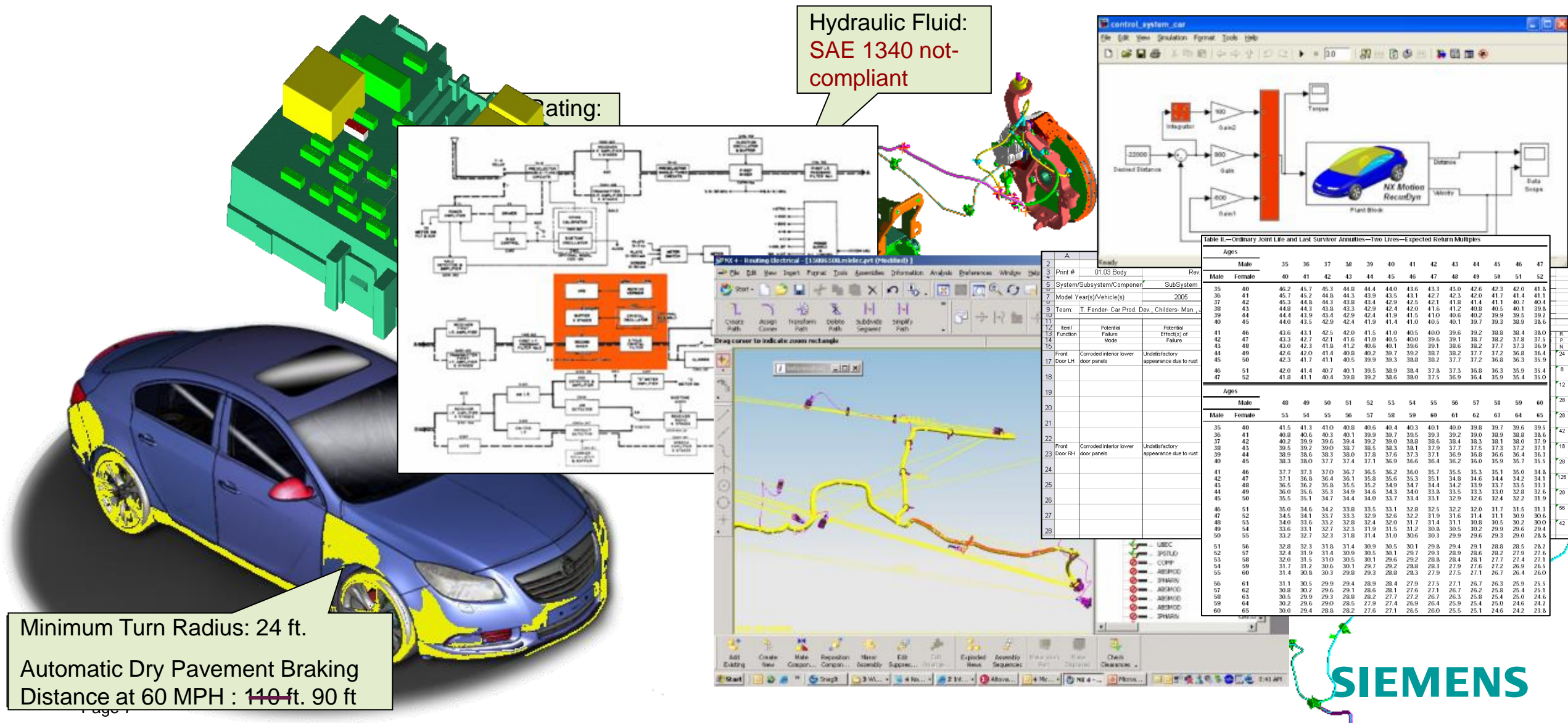
The result of a siloed product development process...  
Mel Conway was right \*





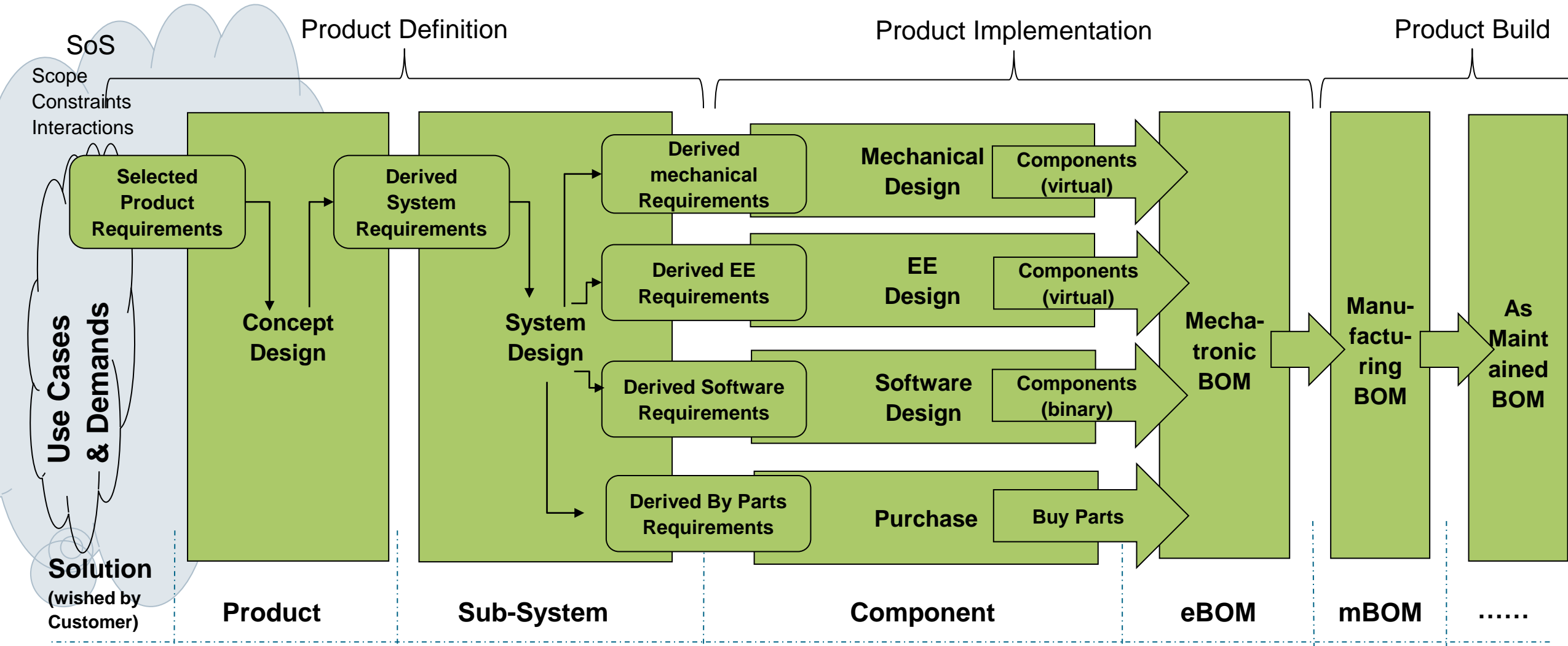
# INCOSE Integrated MBSE Vision

## What does information integration (Digital Thread) vs data integration look like...



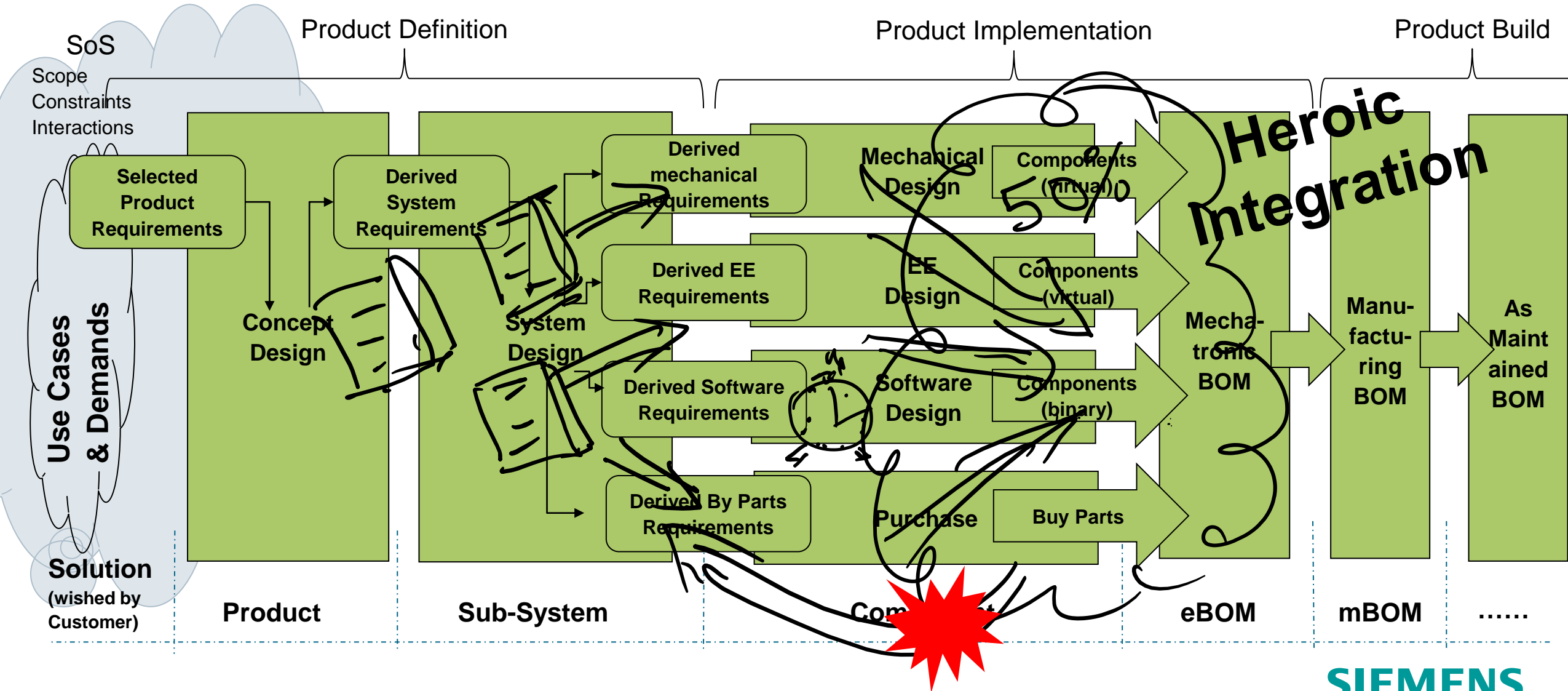
# SE Process...

## Shift left...



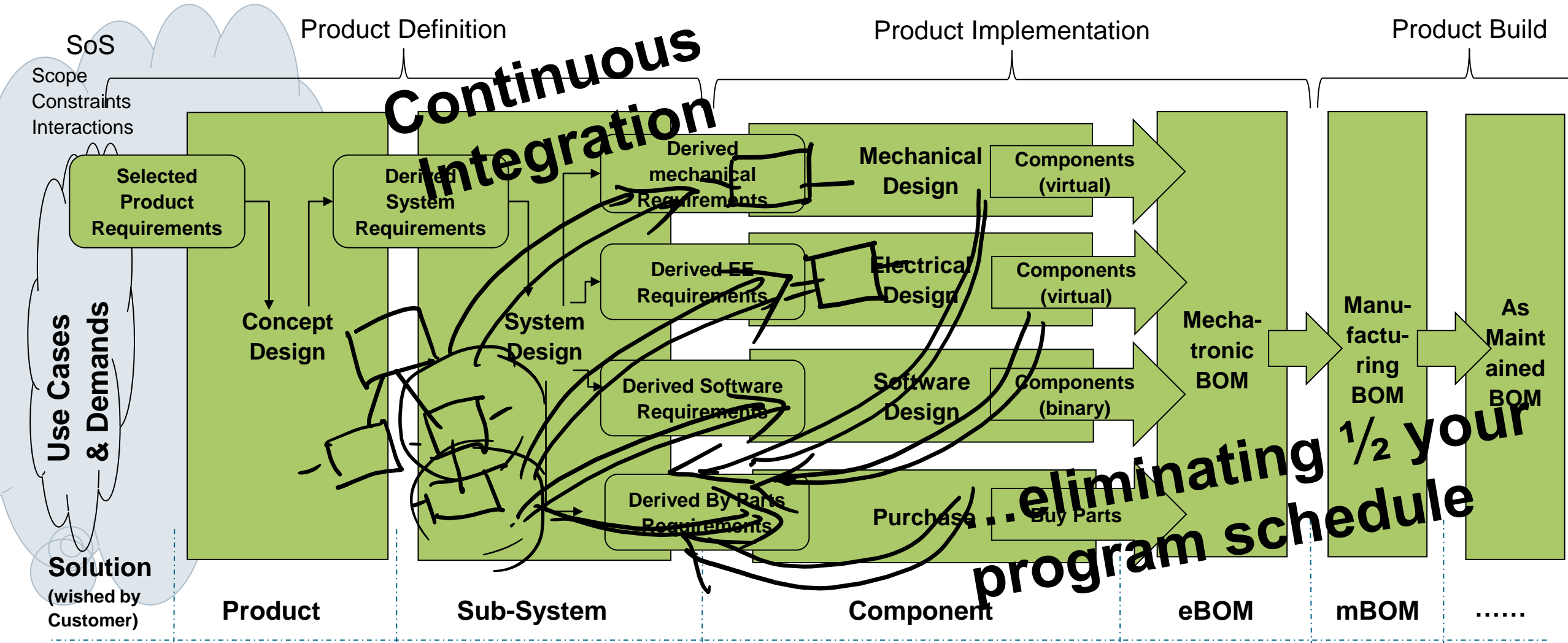
# MBSE Process...

## How it works today...



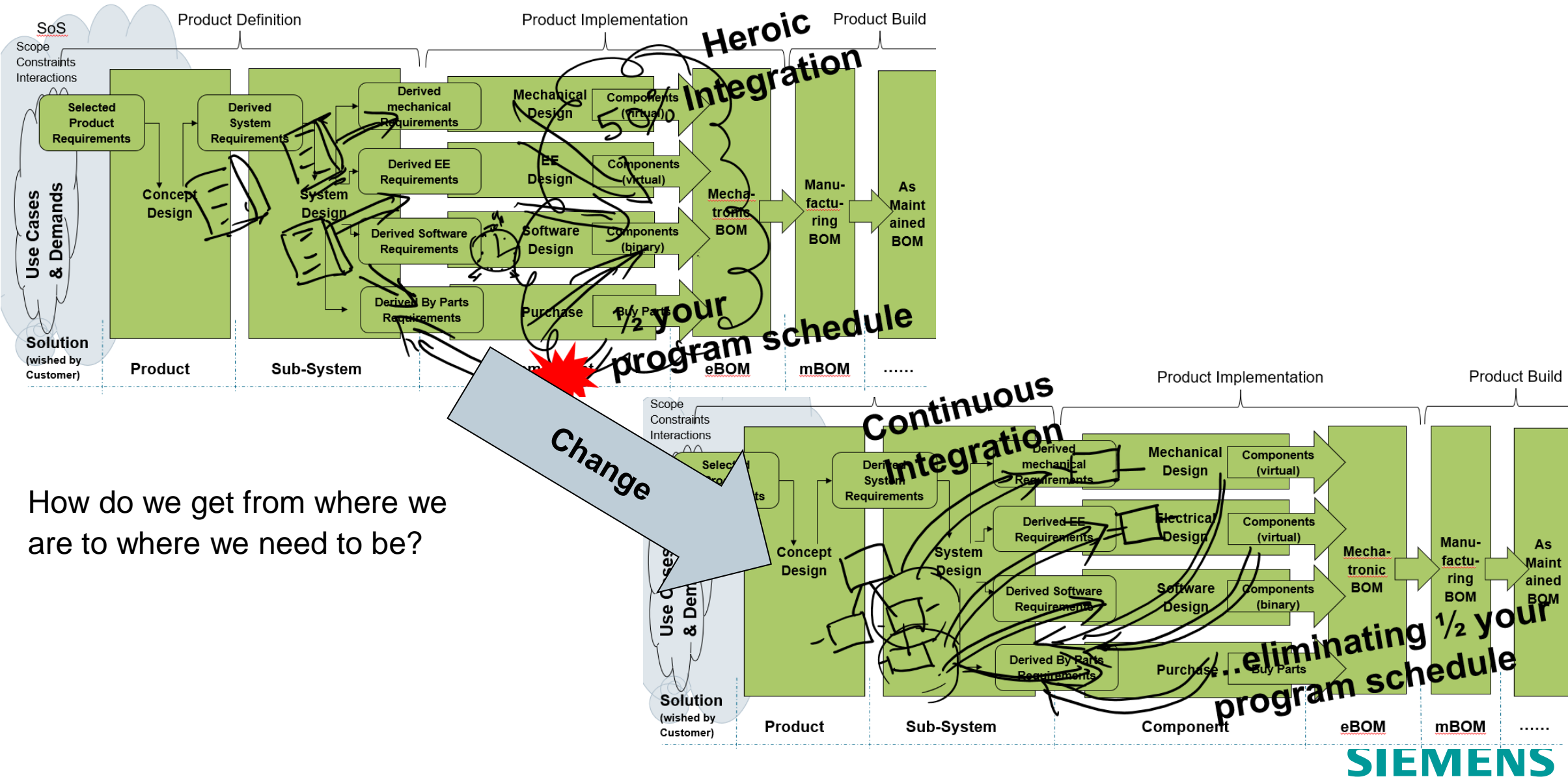
# MBSE→MBDC Process...

How it can work with an integrated product architecture





# This will require change...



# Where are we?

## MBSE Maturity

Solution	(1) Initial	(2) Managed	(3) Defined	(4) Qualitative	(5) Optimizing
<b>Product engineering</b>	Uncontrolled	Controlled Documents	Isolated models	Enterprise Integration	Continuous Engineering
<b>System Architecture Modeling</b> <i>Product architecture definition</i>	PPT in docs	Disconnected Visio diagrams	Standalone SysML with simulations	Fine-grained integrated system architecture	Continuous integration via PLM-based architecture drives closed-loop MBDC
<b>Planned Product Variability</b> <i>PLE/Configuration/Variation</i>	None	Variation documents & spreadsheets	Disconnected variation rules	PLM Integrated variation rules	PLM variation definition drive architecture decisions
<b>Reliability &amp; System Safety Analysis</b> <i>Technical Risk (RAMS)</i>	Risk documents & spreadsheets	Combined Risk Mgmt plans with manual RAMS artifacts (FMEA)	Disconnected RAMS tools output artifacts (FMECA ...)	RAMS analysis tools integrated with product architecture via PLM	Integrated RAMS, continuous risk assessment, alarms, dashboards..
<b>Cross domain services</b>					
<b>System Definition &amp; Design Integration</b> <i>Logical modeling &amp; Interface mgmt</i>	ICD & logical description documents	Managed interfaces & logical hierarchy	SE artifacts linked to Logical models & Std interface libraries	Integrated fine-grained logical arch with interfaces	Logical architecture carries across domains. Interfaces everywhere
<b>Integrated services</b>					
<b>Feature Engineering</b> <i>Feature/Functional Modeling</i>	Feature/Functional description docs	Functional hierarchy	Isolated functional behavior models	Integrated fine-grained functional modeling	Functional arch with allocations & traceability
<b>Parameter/Target Mgmt</b> <i>Characteristic/Targets/TPM</i>	Uncontrolled Excel/Docs	Controlled spreadsheets/Docs	Project-based Parameter/Target libraries	Enterprise PLM parameter/target mgmt & reuse	Integrated parameters, targets,... drive continuous compliance monitoring
<b>Change management</b>	Document-based change process	Isolated models included in change	Change impact analysis & suspicion mgmt	Complete PLM configuration with models, parameters, history,...	Cross-project level reuse, starting point for next project
<b>Content Management</b>					
<b>Requirements Analysis</b> <i>Requirements engineering &amp; mgmt</i>	Uncontrolled spreadsheets & docs	Managed requirements docs	Disconnected RM tools with exchange	Integrated requirements & traceability inside PLM	Continuous compliance thru connected, configured, cross-domain traceability & reuse
<b>Behavior Model Management</b> <i>System, performance, et al simulation</i>	Uncontrolled models on desktops	Version controlled models	SE artifacts linked into models	Integrated model & product configuration with simulation	Continuous, focused simulation & multi-domain optimization, dash boards
<b>Verification Management &amp; Governance</b> <i>Product Test/V&amp;V</i>	Document-based test procedures	Managed test cases	SE artifacts linked to test	Devops-like V&V HIL/SIL simulation	Continuous, focused testing, reuse results, model swap out
<b>Physical Design Management</b> <i>CAD, CAE,... control/mgmt</i>	Unmanaged CAx models	PDM controlled CAx	SE artifacts linked into CAD	Cross-domain fine-grained PLM integration	Continuous physical design verification (Digital Twin)

# Where are we?

## Avg MBSE Maturity

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Avg Organization (best case)



Where are we?

Everyone in the same boat

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Reliability & System Safety Analysis <i>Technical Risk (RAMS)</i>	Risk documents & spreadsheets	Combined Risk Mgmt plans with manual RAMS artifacts (FMEA)	Disconnected RAMS tools output artifacts (FMEA)	RAMS analysis tools integrated with product architecture via PLM	Integrated RAMS, continuous risk assessment, alarms, dashboards..
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<b>Content Management</b>					
Requirements Analysis <i>Requirements engineering &amp; mgmt</i>	Uncontrolled spreadsheets & docs	Managed requirements docs	Disconnected RM tools with exchange	Integrated requirements & traceability inside PLM	Continuous compliance thru connected, configured, cross-domain traceability & reuse
Behavior Model Management <i>System, performance, et al simulation</i>	Uncontrolled models on desktops	Version controlled models	SE artifacts linked into models	Integrated model & product configuration with simulation	Continuous, focused simulation & multi-domain dashboards
Verification Management & Governance <i>Product Test/V&amp;V</i>	Document-based test procedures	Managed test cases	SE artifacts linked to test	Devops-like V&V simulation	focused testing, model swap out
Physical Design Management <i>CAD, CAE,.. control/mgmt</i>	Unmanaged CAx models	PDM controlled CAx	SE artifacts linked into CAD	Cross-domain fine-grained PLM integration	Continuous physical design verification (Digital Twin)

You are here

Best Auto  
(best case)

Best Aero  
(best case)

## Is SE education helping our design sanity problem?

Solution	(1) Initial	(2) Managed	(3) Defined	(4) Qualitative	(5) Optimizing
<b>Product engineering</b>	Uncontrolled	Controlled Documents	Isolated models	Enterprise Integration	Continuous Engineering
<b>System Architecture Modeling</b> <i>Product architecture definition</i>	PPT in docs	Disconnected Visio diagrams	Standalone SysML with simulations	Fine-grained integrated system architecture	Continuous integration via PLM-based architecture drives closed-loop MBDC
<b>Planned Product Variability</b> <i>PLE/Configuration/Variation</i>	None	Variation documents & spreadsheets	Disconnected variation rules	PLM Integrated variation rules	PLM variation definition drive architecture decisions
<b>Reliability &amp; System Safety Analysis</b> <i>Technical Risk (RAMS)</i>	Risk documents & spreadsheets	Integrated Risk Mgmt plans with aspects of RAMS (FMEA)	Disconnected RAMS tools output artifacts (FMECA ...)	RAMS analysis tools integrated with product architecture via PLM	Integrated RAMS, continuous risk assessment, alarms, dashboards..
<b>Cross domain services</b>					
<b>System Definition &amp; Design Integration</b> <i>Logical modeling &amp; Interface mgmt</i>	ICD & logical description documents	Managed interfaces & logical hierarchy	SE artifacts linked to Logical models & Std interface libraries	Integrated fine-grained logical arch with interfaces	Logical architecture carries across domains. Interfaces everywhere
<b>Integrated services</b>					
<b>Feature Engineering</b> <i>Feature/Functional Modeling</i>	Feature/Functional description docs	Functional hierarchy	Isolated functional behavior models	Integrated fine-grained functional modeling	Functional arch with allocations & traceability
<b>Parameter/Target Mgmt</b> <i>Characteristic/Targets/TPM</i>	Uncontrolled Excel/Docs	Controlled spreadsheets/Docs	Project-based Parameter/Target libraries	Enterprise PLM parameter/target mgmt & reuse	Integrated parameters, targets,... drive continuous compliance monitoring
<b>Change management</b>	Document-based change process	Isolated models included in change	Impact analysis & suspicion mgmt	Complete PLM configuration with models, parameters, history,...	Cross-project level reuse, starting point for next project
<b>Content Management</b>					
<b>Requirements Analysis</b> <i>Requirements engineering</i>	Uncontrolled spreadsheets	Managed requirements docs	Disconnected RM tools with exchange	Integrated requirements & traceability inside PLM	Continuous compliance thru connected, configured, cross-domain traceability
<b>Behavior Model Management</b> <i>System, performance, et al simulation</i>	Uncontrolled models on desktops	Version controlled models	SE artifacts linked into models	Integrated model & product configuration with simulation	Continuous, focused simulation & multi-domain optimization, dashboards
<b>Verification Management &amp; Governance</b> <i>Product Test/V&amp;V</i>	Document-based test procedures	Managed test cases	SE artifacts linked to test	Devops-like V&V HIL/SIL simulation	Continuous, focused testing, reuse results, model swap out
<b>Physical Design Management</b> <i>CAD, CAE,... control/mgmt</i>	Unmanaged CAx models	PDM controlled CAx	SE artifacts linked into CAD	Cross-domain fine-grained PLM integration	Continuous physical design verification (Digital Twin)

Avg Organization  
(best case)

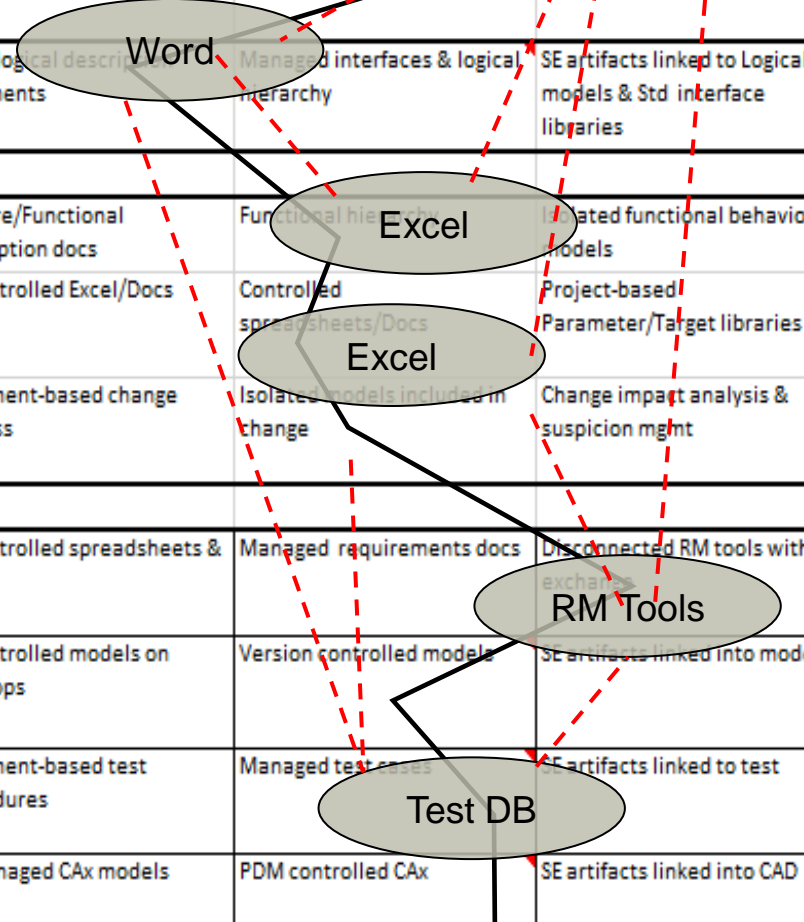
Avg University  
(best case)

# Barriers to implementation...

Silos locked-in by tools creating automated chaos

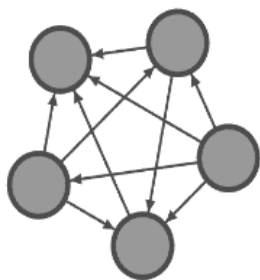
2<sup>n</sup> problem...

Solution	(1) Initial	(2) Managed	(3) Defined	(4) Qualitative	(5) Optimizing
<b>Product engineering</b>	Uncontrolled	Controlled Documents	Related models	Enterprise Integration	Continuous Engineering
System Architecture Modeling <i>Product architecture definition</i>	PPT in docs	Disconnected Visio diagrams	Standards SysML with simulations	Fine-grained integrated system architecture	Continuous integration via PLM-based architecture drives closed-loop MBDC
Planned Product Variability <i>PLE/Configuration/Variation</i>	None	Variation documents & spreadsheets	Direct variation rules	PLM Integrated variation rules	PLM variation definition drive architecture decisions
Reliability & System Safety Analysis <i>Technical Risk (RAMS)</i>	Risk documents & spreadsheets	Combined Risk Mgmt plans with manual RAMS artifacts (FMEA)	Output artifacts (FMECA ...)	RAMS analysis tools integrated with product architecture via PLM	Integrated RAMS, continuous risk assessment, alarms, dashboards..
<b>Cross domain services</b>					
System Definition & Design Integration <i>Logical modeling &amp; Interface mgmt</i>	ICD & logical description documents	Managed interfaces & logical hierarchy	SE artifacts linked to Logical models & Std interface libraries	Integrated fine-grained logical arch with interfaces	Logical architecture carries across domains. Interfaces everywhere
<b>Integrated services</b>					
Feature Engineering <i>Feature/Functional Modeling</i>	Feature/Functional description docs	Functional hierarchy	Integrated functional behavior models	Integrated fine-grained functional modeling	Functional arch with allocations & traceability
Parameter/Target Mgmt <i>Characteristic/Targets/TPM</i>	Uncontrolled Excel/Docs	Controlled spreadsheets/Docs	Project-based Parameter/Target libraries	Enterprise PLM parameter/target mgmt & reuse	Integrated parameters, targets,... drive continuous compliance monitoring
Change management	Document-based change process	Isolated models included in change	Change impact analysis & suspicion mgmt	Complete PLM configuration with models, parameters, history,...	Cross-project level reuse, starting point for next project
<b>Content Management</b>					
Requirements Analysis <i>Requirements engineering &amp; mgmt</i>	Uncontrolled spreadsheets & docs	Managed requirements docs	Disconnected RM tools with exchanges	Integrated requirements & traceability inside PLM	Continuous compliance thru connected, configured, cross-domain traceability & reuse
Behavior Model Management <i>System, performance, et al simulation</i>	Uncontrolled models on desktops	Version controlled models	SE artifacts linked into models	Integrated model & product configuration with simulation	Continuous, focused simulation & multi-domain optimization, dash boards
Verification Management & Governance <i>Product Test/V&amp;V</i>	Document-based test procedures	Managed test cases	SE artifacts linked to test	Devops-like V&V HIL/SIL simulation	Continuous, focused testing, reuse results, model swap out
Physical Design Management <i>CAD, CAE... control/mgmt</i>	Unmanaged CAx models	PDM controlled CAx	SE artifacts linked into CAD	Cross-domain fine-grained PLM integration	Continuous physical design verification (Digital Twin)

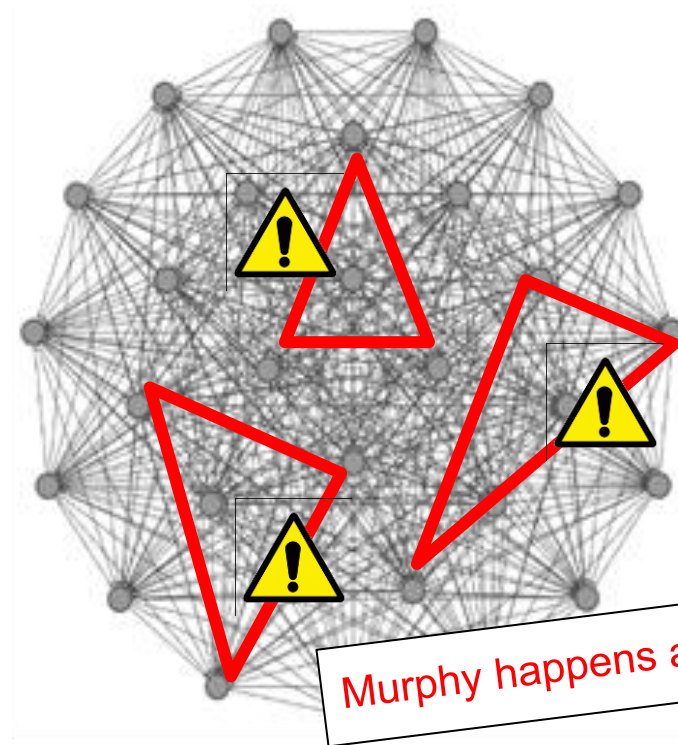
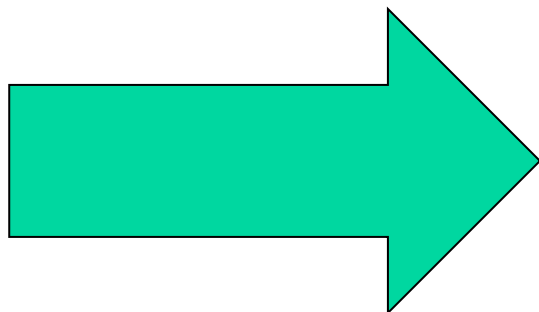




## Doing the math...



Nodes = 5  
Potential Links = 10  
Networks =  $2^{10}$  1024



Murphy happens at the interfaces

Nodes = 30, potential links = 435, unique configurations =  $2^{435}$   
Number of atoms in the universe est. between  $2^{158}$  and  $2^{246}$

Barriers to implementation

Problem is information exchange not data exchange

PLM is about information; managing the digital thread

Solution	(1) Initial	(2) Managed	(3) Defined	(4) Qualitative	(5) Optimizing
Product engineering	Uncontrolled	Controlled Documents	SysML	Enterprise Integration	Continuous Engineering
System Architecture Modeling <i>Product architecture definition</i>	PPT in docs	Disconnected Visio diagrams	SysML with simulations	Fine-grained integrated system architecture	Continuous integration via PLM-based architecture drives closed-loop MBDC
Planned Product Variability <i>PLE/Configuration/Variation</i>	None	Variation documents & spreadsheets	Disconnected variation rules	PLM Integrated variation rules	PLM variation definition architecture decisions
Reliability & System Safety Analysis <i>Technical Risk (RAMS)</i>	Risk documents & spreadsheets	Combined Risk Mgmt plans with manual RAMS artifacts (FMEA)	output artifacts (MECA ...)	RAMS analysis tools integrated with product architecture via PLM	Integrated risk analysis
Cross domain services					
System Definition & Design Integration <i>Logical modeling &amp; Interface mgmt</i>	ICD & logical documents	Interfaces & logical hierarchy	SE artifacts linked to Logical models & Std interface libraries	Integrated fine-grained arch with interfaces	
Integrated services					
Feature Engineering <i>Feature/Functional Modeling</i>	Feature/Functional description docs	Functional hierarchy	Isolated functional behavior models	Integrated functional models	
Parameter/Target Mgmt <i>Characteristic/Targets/TPM</i>	Uncontrolled Excel/Docs	Controlled spreadsheets/Docs	Project-based Parameter/Target links	Integrated Parameter/Target links	
Change management	Document-based change process	Isolated change			
Content Management					
Requirements Analysis <i>Requirements engineering &amp; mgmt</i>	Uncontrolled spreadsheets & docs	Managed requirements			
Behavior Model Management <i>System, performance, et al simulation</i>	Uncontrolled models on desktops	Versioned models			
Verification Management & Governance <i>Product Test/V&amp;V</i>	Document-based test procedures				
Physical Design Management <i>CAD, CAE... control/mgmt</i>	Unmanaged				

Where do we start?

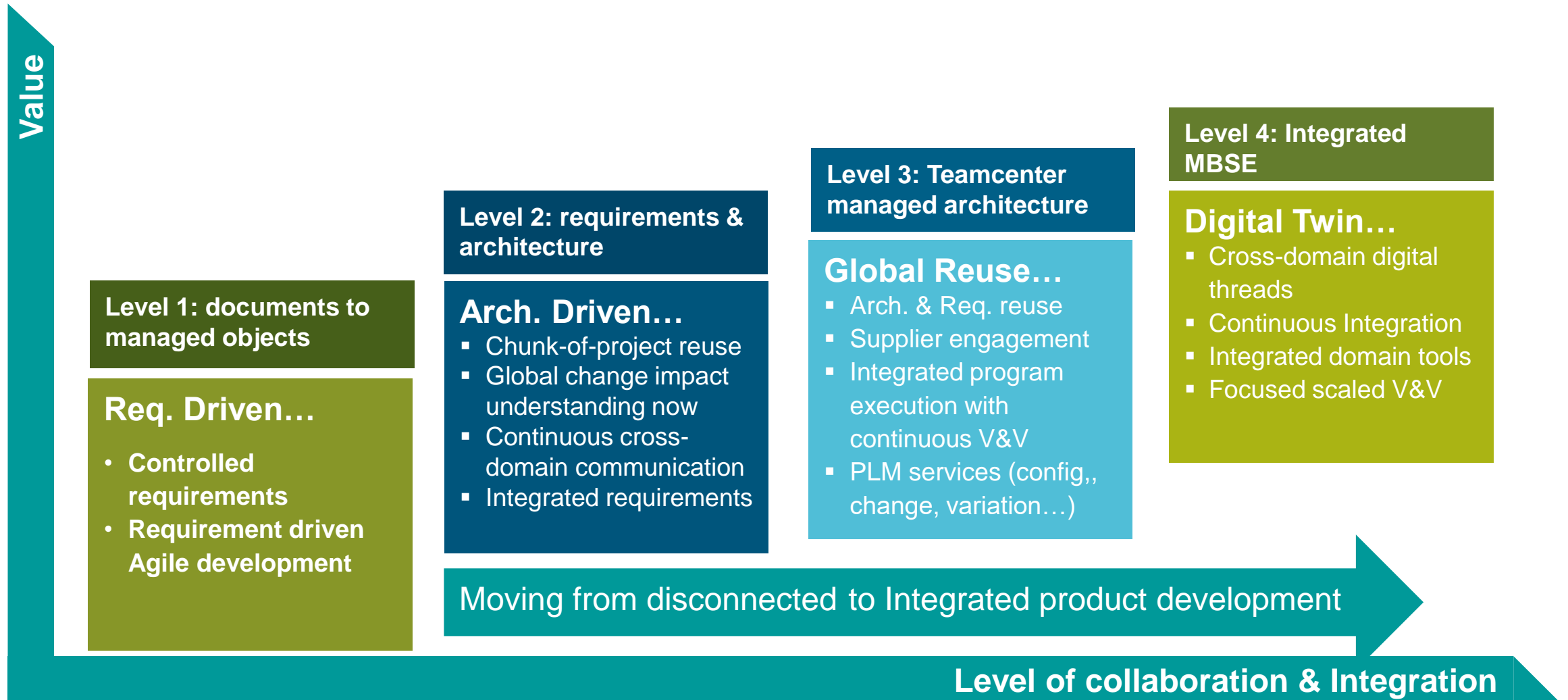
Target rich environment

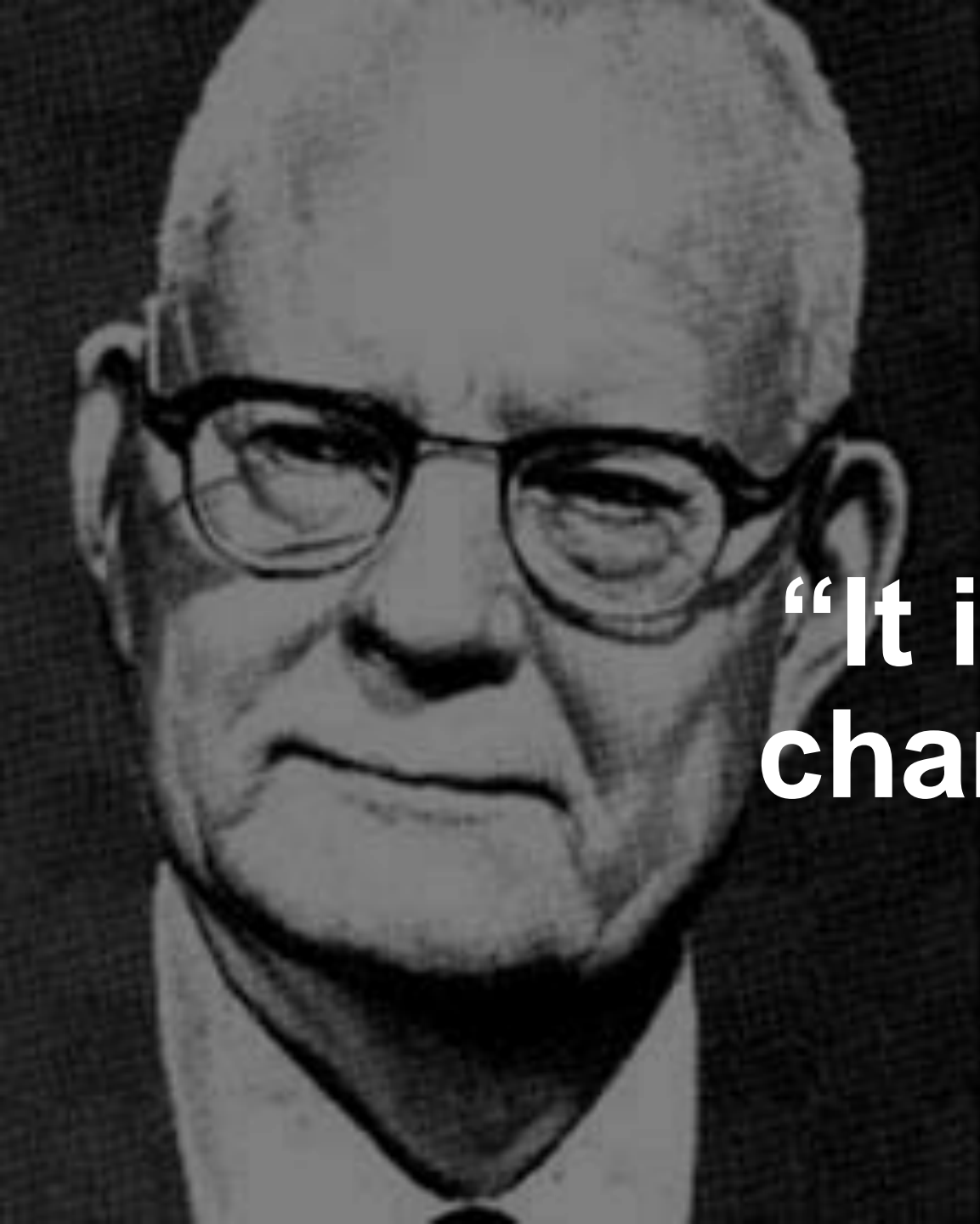
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Physcial Design Management <i>CAD, CAE,.. control/mgmt</i>	Unmanaged CAx models	RDM controlled CAx	SE artifacts linked into CAD	Cross-domain fine-grained PLM integration	Continuous physical design verification (Digital Twin)



# Integrated Systems Engineering

## Stair-steps to the right





**“It is not necessary to  
change, survival is not  
mandatory”**

- W. Edwards Deming,  
Data Scientist



# Thank You

Mark Sampson  
Systems Engineering Evangelist  
INCOSE MBSE Initiative Chair