PLM Leadership

Failure Knowledge Capture and Reuse for Designing Dependable Software-Intensive Products

CIMdata PLM Leadership Webinar Series

11 August 2016

#cimdatawebinar

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CIMdata® | Global Leaders in PLM Consulting
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Venki Agaram, Ph.D., MBA

Director, Quality & Reliability Engineering Practice

- 25+ years of experience from industry & academia
- 16 years at Fiat Chrysler Automobiles
- Growing the Quality & Reliability Engineering Practice
- R&D, virtual engineering, complex material systems, controlled mechanical systems, design-for-six-sigma, structured innovation, regulatory compliance, process modeling, market strategy, and business transformation
- Technical & business background: ideally suited for leading industry transformation to improve the robustness of smart, connected products and processes
- Education: aerospace engineering, business strategy

Our Mission...

Strategic management consulting for competitive advantage in global markets

CIMdata is the leading independent global strategic management consulting and research authority focused exclusively on the PLM market.

We are dedicated to maximizing our clients' ability to design and deliver innovative products and services through the application of PLM.

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Our Services...

Creating, Disseminating, and Applying our Intellectual Capital

Research
- *Market research & analysis*
- *Technology research & analysis*
- *Reports & publications*
- *Market news*
- *Member services...*

Education
- Executive seminars
- PLM Certificate Programs
- Technology seminars
- Int'l conferences & workshops
- Best practices training...

Consulting
- Strategy & vision
- Needs assessment
- Solution evaluation
- Best practices
- Quality assurance
- Program management
- Market planning...

Delivering strategic advice and counsel through a comprehensive, integrated set of research, education, and consulting services

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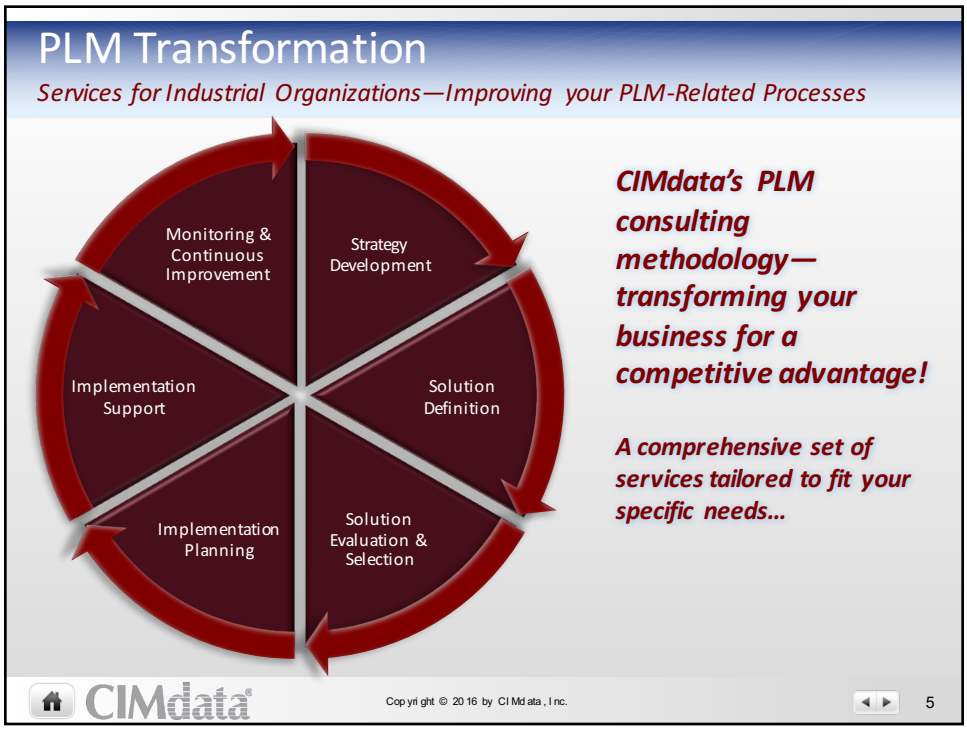

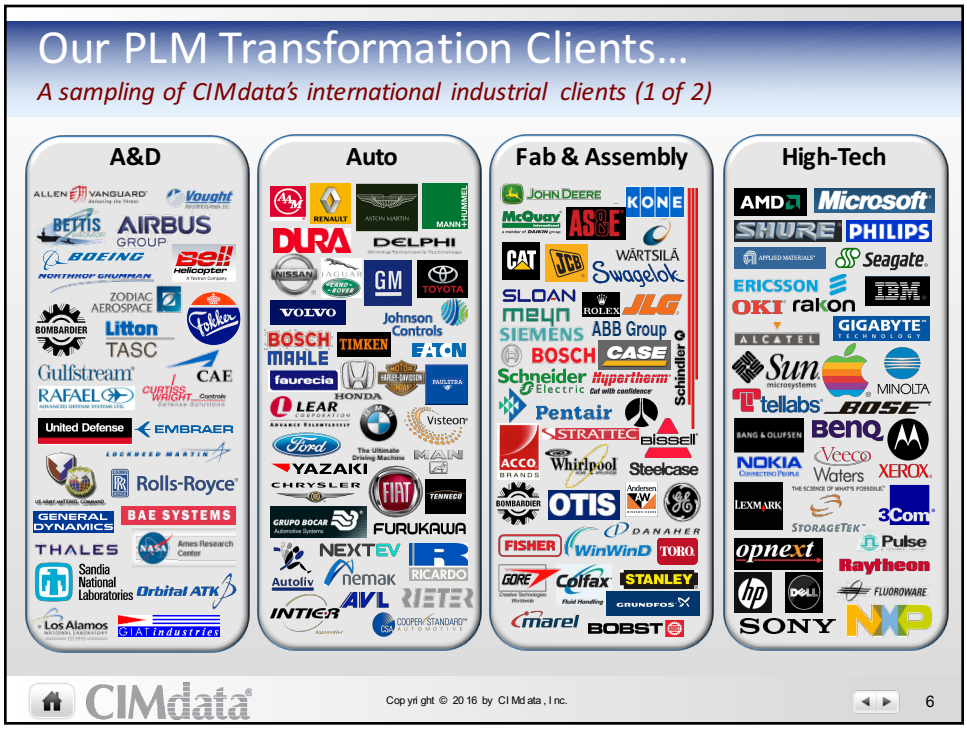

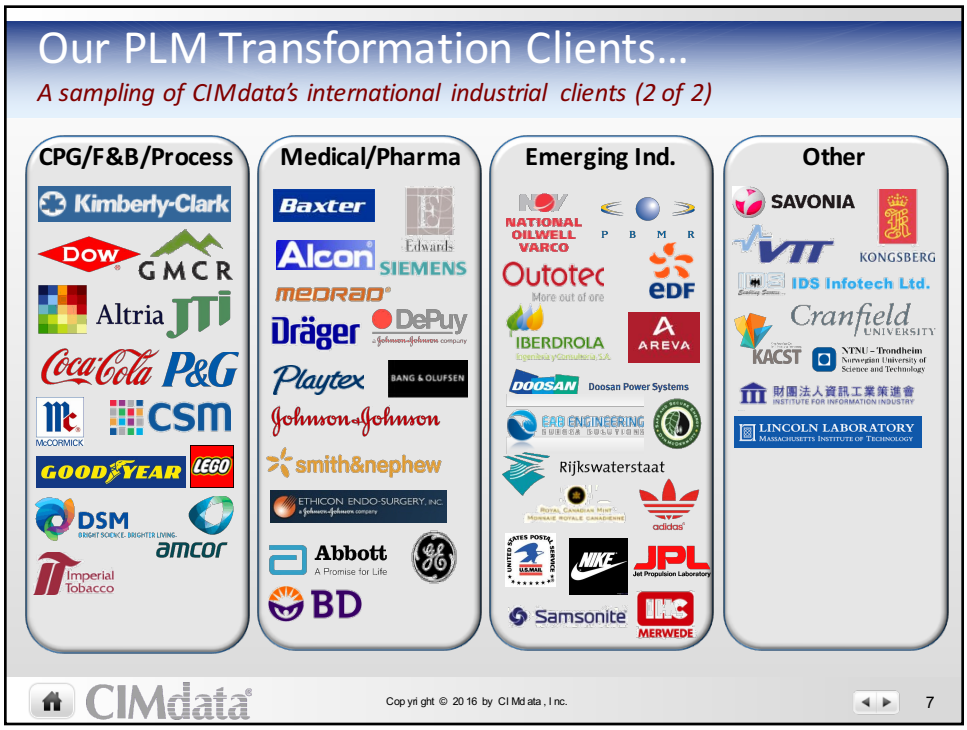

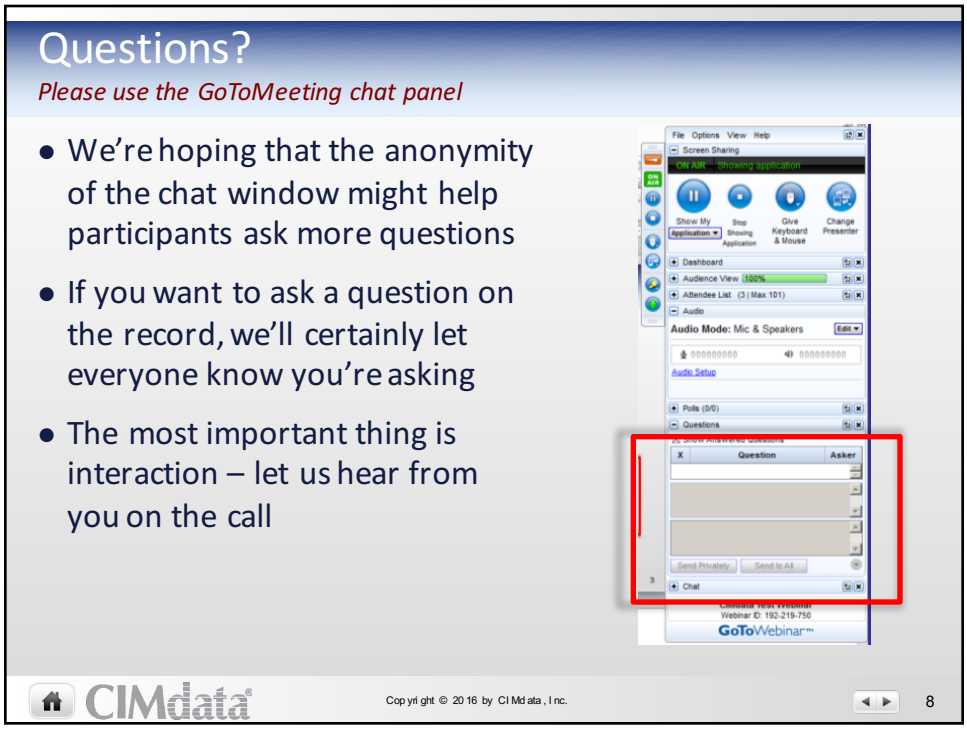

Agenda

- Smart, Connected Products
- Quality & Reliability Risks Today
- Learning System Based Design-for-Reliability
- Failure Knowledge Capture & Reuse
- Exploring the Business Opportunity
- Q&A

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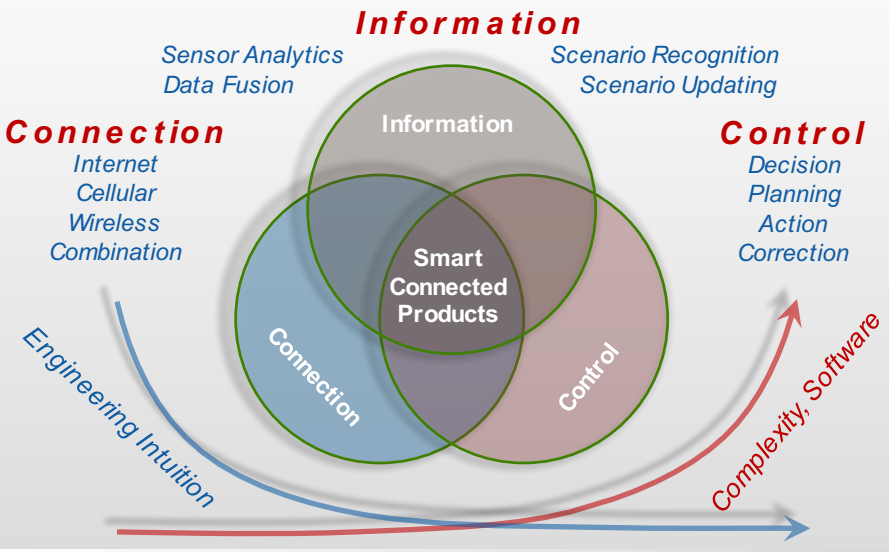
Smart, Connected Products

Functions, Enablers, and Challenges



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Quality & Reliability Risks Today

Complexity of Electronically Controlled, Software-Intensive Products

Auto. SW Related Recalls

- *2005 – 2012: 32 recalls, 3.6 mn. veh.*
- *2013 – 2015: 63 recalls, 6.4 mn. veh.*
- *0.3% of recalls in 2005*
- *4.3% of recalls in 6 months of 2015*

NHTSA's Safety Complaints

- *2005 – 2009: 55 SW related*
- *2010 – 2014: 197 SW related*

Med. Dev. SW Related Recalls

- *2005: 14% of recalls*
- *2011: 25% of recalls*

Trending upward since 1983

- *1983 - 1991: 6% of recalls*
- *1992 – 1998: 8% of recalls*
- *1999 – 2004: 11% of recalls*
- *2005 – 2011: 19% of recalls*

Aerospace SW Related Issues

- *Boeing 787: generator control unit (GCU) SW counter overflow after 248 days of continuous power resulting in loss of all electrical power regardless of flight phase*
- *F-35 Joint Strike Fighter: RADAR SW vulnerability to cyber-attacks, requires system reboot every 4 hrs of flight time while desired interval is 8 – 10 hrs of flight time*

Source(s): Automotive Warranty & Recall Blog 2015, USFDA Study 2013, https://www.engadget.com/2015/05/01/boeing-787-dreamliner-software-bug/, https://www.rt.com/usa/335318-f35-radar-reboot-required/

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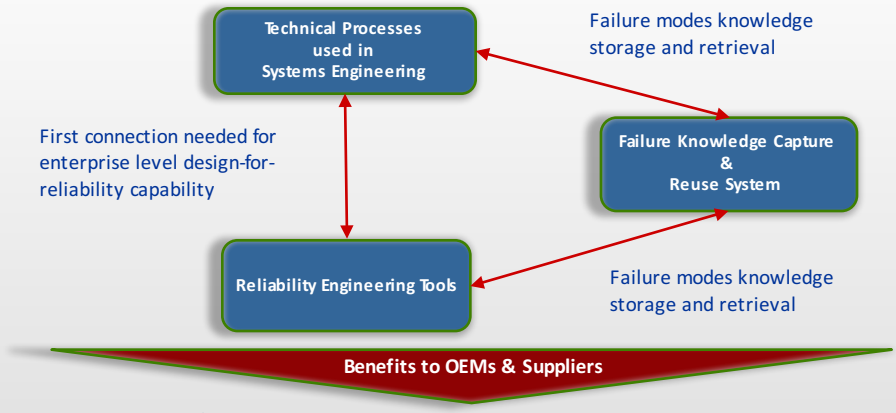
Learning System Based Design-for-Reliability

Connecting three main elements of robust design



- ❖ Avoid repeat product issues and costly product recalls
- ❖ Improve the capability for root cause analysis of complex systems
- ❖ Increase breakthrough innovation probability through superior problem solving capability
- ❖ Improve collaboration between systems engineers and reliability engineers

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First Connection for Design-for-Reliability

Towards building a learning system based design-for-reliability

Seamless integration of reliability engineering tools with systems engineering technical processes is imperative

Systems Engineering Technical Processes

- *Stakeholders' Requirements Identification*
- *System Requirements Definition*
- *System Architectural Design*
- *System Elements Definition*
- *System Analysis*
- *System Elements Realization*
- *System Elements Integration*
- *System Design Verification*
- *Verified System Transition*
- *System Performance Validation*
- *System Operation*
- *System Maintenance*
- *System Disposal*

Reliability Engineering Tools

- *Affinity Diagrams (KJ Analysis)*
- *Quality Function Deployment (QFD)*
- *Kano Analysis*
- *FMECA*
- *TRIZ*
- *Robust Optimization*
- *Design of Experiments (DOE)*
- *Monte Carlo Simulations*
- *Conjoint Analysis*
- *Kepner-Tregoe Analysis (KTA)*
- *Fault Tree Analysis (FTA)*
- *Reliability Block Diagrams (RBD)*
- *FRACAS*
- *CAPA*
- *Markov Analysis*
- *Weibull Analysis*
- *System Maintainability Analysis*
- *System Availability Analysis*
- *Accelerated Life Testing (ALT)*

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First Connection for Design-for-Reliability

Towards building a learning system based design-for-reliability

Relationship between Reliability Tools and Systems Engineering Processes

Systems Engineering Technical Processes		1 Affinity Diagrams	2 QFD (HOQ)	3 Kano Analysis	4 Functional Flow Block Diagram	5 SysML Diagrams	6 IDEF	7 N² Charts	8 Specification Tree	9 FMECA	10 TRIZ	11 Physics of Failure Analysis	12 Robust Optimization	13 Design of Experiments (DOE)	14 Response Surface Analysis	15 Monte Carlo Simulations	16 Conjoint Analysis	17 Kepner-Tregoe Analysis	18 Analytic Hierarchy Process (AHP) Models	19 Multi-Attribute Utility Analysis (MAUA)	20 Fault Tree Analysis (FTA)	21 Event Tree Analysis (ETA)	22 Reliability Block Diagrams (RBD)	23 FRACAS	24 CAPA	25 Markov Analysis	26 Weibull Analysis	27 System Maintainability Analysis	28 System Availability Analysis	29 Asset Performance Management	30 Accelerated Life Testing
Stakeholders' Requirements Definition	1	■		■	■	■			■					■			■							■	■					
System Requirements Definition	2		■		■	■			■	■	■	■		■	■	■								■	■			■	■	■
System Architectural Design	3				■	■			■	■	■		■	■	■	■				■			■	■	■	■	■			
System Elements Definition	4		■		■	■	■		■	■	■	■	■	■	■	■				■	■	■	■	■		■	■	■		
System Analysis	5				■	■	■		■	■	■	■	■	■	■		■	■	■											
System Elements Realization	6								■	■	■		■	■	■								■	■						
System Elements Integration	7				■	■	■		■	■	■		■	■	■					■	■		■	■			■	■	■	■
System Design Verification	8				■	■	■	■	■	■	■	■	■	■	■					■	■		■	■						
Verified System Transition	9				■	■	■	■	■	■	■		■	■	■					■	■	■	■	■			■			
System Performance Validation	10				■	■	■	■	■	■	■	■	■	■	■					■	■	■	■	■						
System Operation	11				■	■	■	■	■	■	■	■	■	■	■					■	■	■	■	■	■		■	■		
System Maintenance	12				■	■	■	■	■	■	■	■	■	■	■	■							■	■		■	■	■		
System Disposal	13				■	■	■		■	■	■																			

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- Failure Knowledge Capture & Reuse
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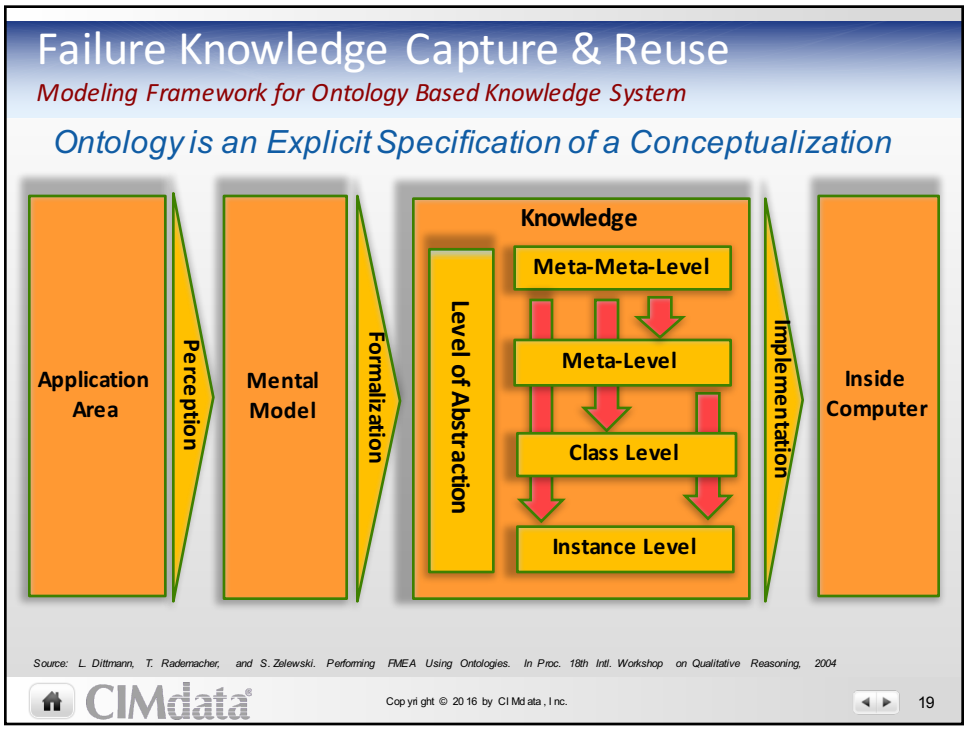
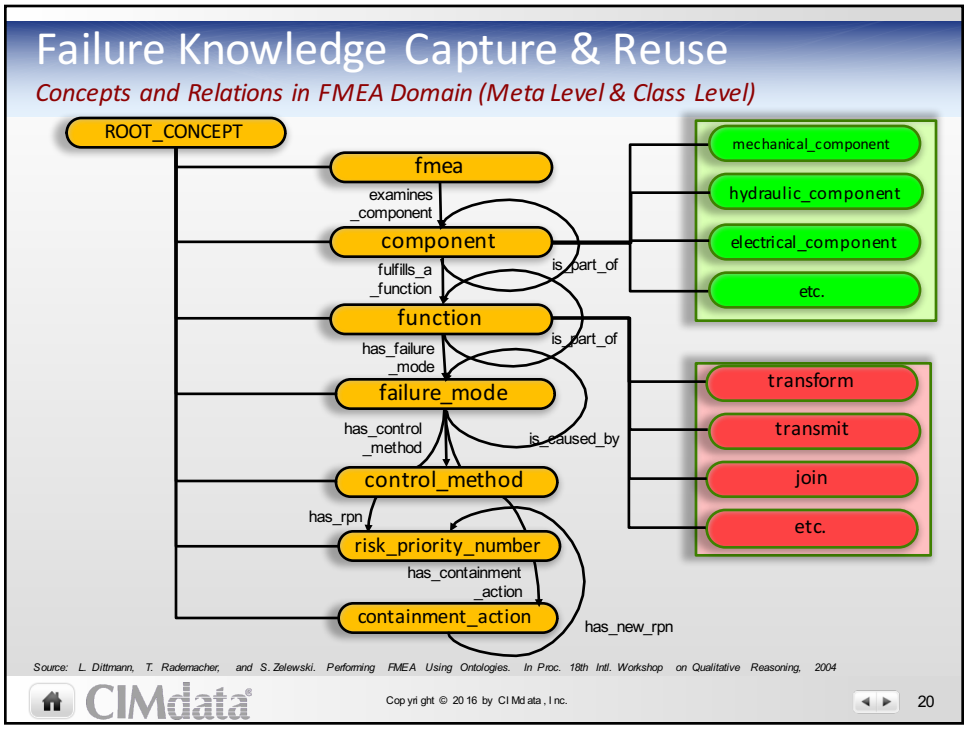
Failure Knowledge Capture & Reuse

Developing machine-readable failure knowledge

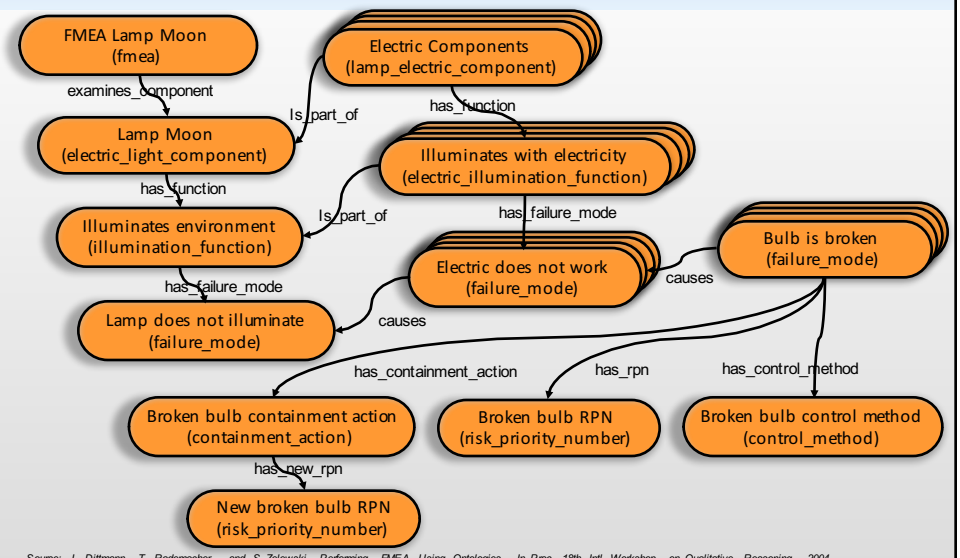
- Problems posed by complex, software-intensive products:
  - Root causes of failures are hard to find because they exist at the interfaces between different subsystems, and at the intersection of different disciplines of engineering
  - Prior knowledge about failure modes often exists in the language of the expert community, not immediately accessible, and in particular, cannot be acquired from conventional databases
- Potential Solution:
  - Step I: Establish a common understanding of domain specific failure modes without need for interpretation. Example – Ontology applied to failure knowledge
  - Step II: Make failure knowledge explicit, machine-readable/-searchable.
  - Step III: Establish enterprise level connection between the machine-readable/-searchable failure knowledge capture and reuse system, the systems engineering technical processes, and the reliability engineering tools





Failure Knowledge Capture & Reuse

Instantiation of an Ontology based FMEA (Instance Level)



Source: L. Dittmann, T. Rademacher, and S. Zelewski. Performing FMEA Using Ontologies. In Proc. 18th Intl. Workshop on Qualitative Reasoning, 2004

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Failure Knowledge Capture & Reuse

FMEA queries using F-Logic

- Find all instances of the concept component that are part of any instance of the concept *electric_light_component*.

```
FORALL    Subcomponent, Component <-
          Subcomponent [is_part_of->>Component] AND
          Component: electric_light_component AND
          Subcomponent: Concept
```

- Find all instances of the concept function that are functions of any instance of the concept *electric_light_component*.

```
FORALL    Function, Component <-
          Function: function AND
          Function[is_fulfilled_by->>Component] AND
          Component:electric_light_component.
```

- Find all instances of the concept *failure_mode* that are failure modes of functions of instance *Lamp Moon*.

```
FORALL    Mode, Function <-
          Mode: failure_mode AND
          Mode[interferes_function->>Function] AND
          Function:function AND
          Function[is_fulfilled_by->>
          lamp_moon:electric_lighting_component]].
```

Source: L. Dittmann, T. Rademacher, and S. Zelewski. Performing FMEA Using Ontologies. In Proc. 18th Intl. Workshop on Qualitative Reasoning, 2004

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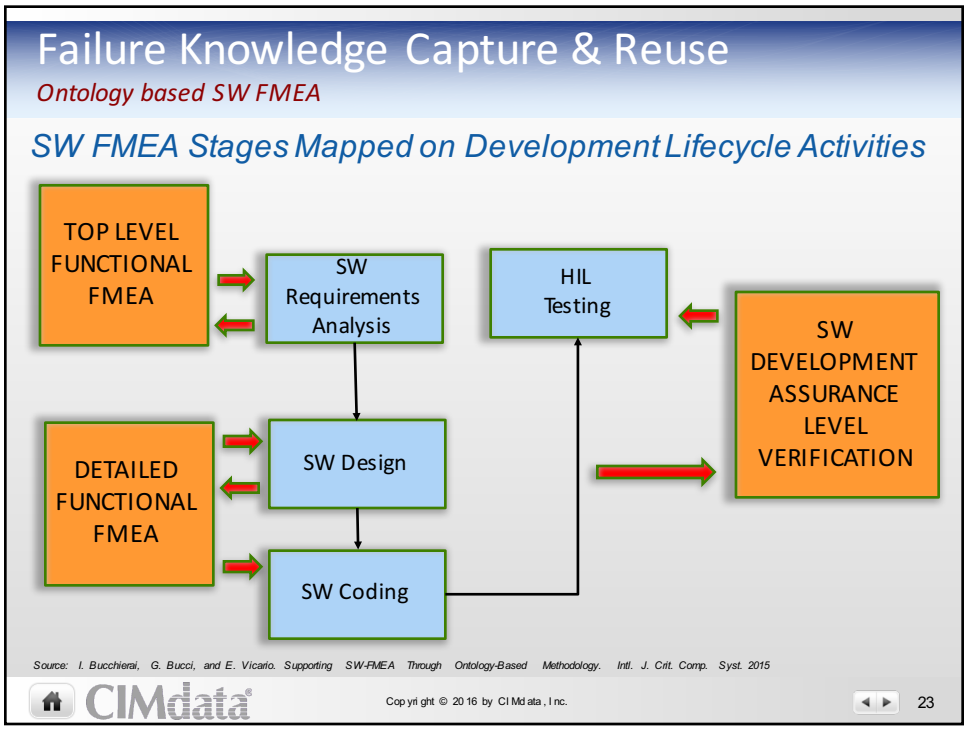

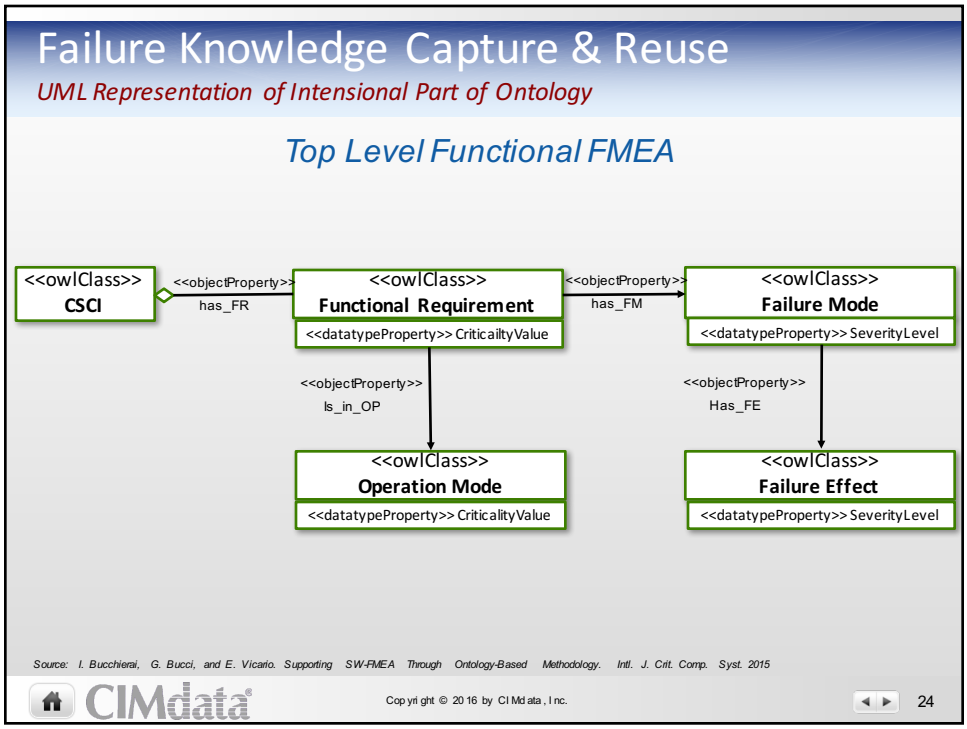

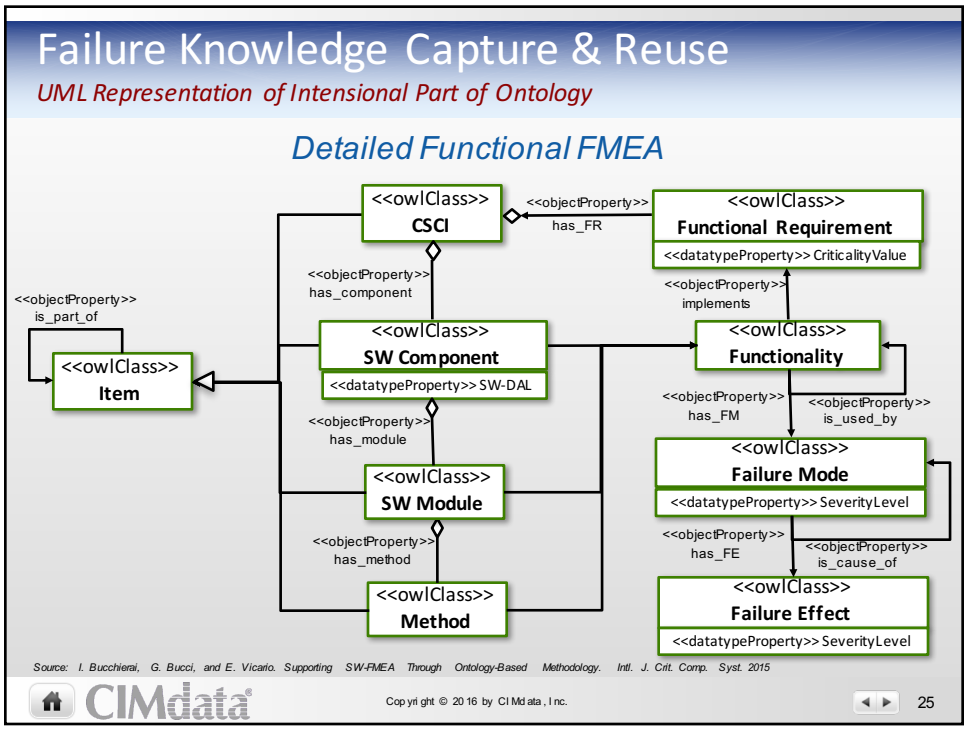

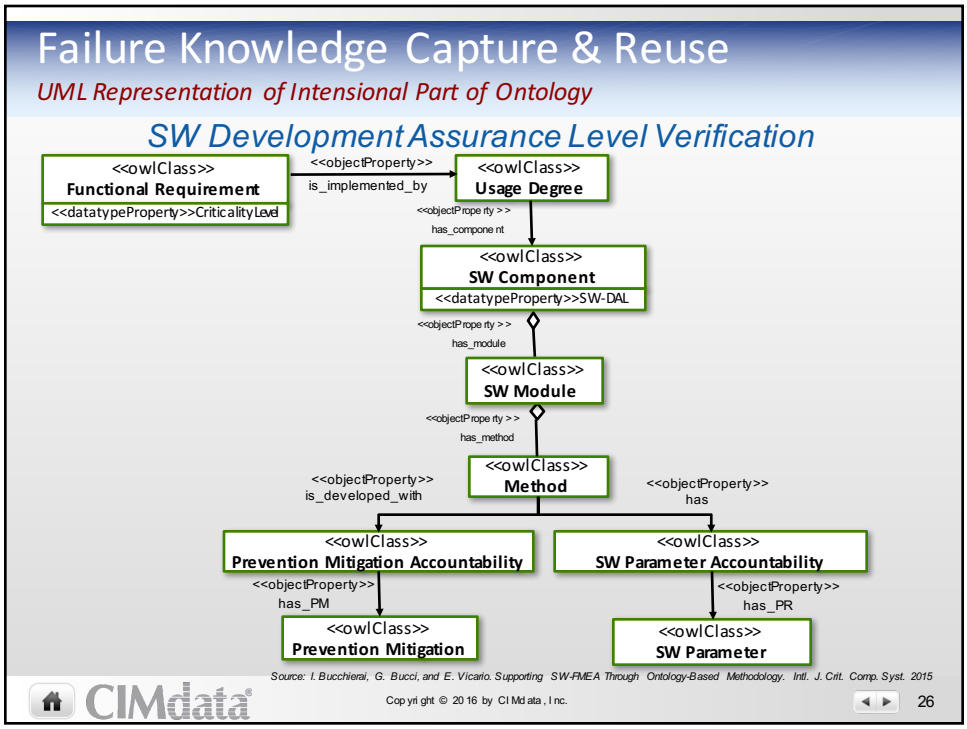

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Exploring the Business Opportunity

Realizing enterprise learning system based design-for-reliability

- Systems engineering helps in dealing with product complexity of intelligent, connected products
- Verification and validation iterations in systems engineering are opportunities for new learning about the failure modes of complex, intelligent, connected products
- Reliability engineering tools are needed to leverage product failure knowledge and they are mostly disconnected from systems engineering tools
- Bridging the tools and processes used in systems engineering and reliability engineering while leveraging failure knowledge capture and reuse is imperative to minimize recall and launch risks

Exploring the Business Opportunity

Realizing enterprise learning system based design-for-reliability

- All tools used in systems engineering, reliability engineering, and failure knowledge capture and reuse will not likely be provided by a single software provider
- System integrators are likely to play a major role in closing the loop between reliability engineering, systems engineering, and knowledge capture and reuse
- CIMdata believes that connected products will enable closed-loop quality based product development but will additionally need failure knowledge capture and reuse
- CIMdata would like to collaboratively explore with OEMs, suppliers, and solution providers, a maturity model pertaining to "learning systems based design-for-reliability"

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Quality & Reliability Engineering Output

What is coming from CIMdata's QRE Consulting Practice?

- Survey to be filled by OEMs/Suppliers, SIs and SW Providers
  - Topic: Learning System Based Design-for-Reliability, August 2016
- Whitepaper:
  - Quality & Reliability Engineering – Learning Systems based Design-for-Reliability
  - August 2016
- Knowledge Council Kick-off:
  - October 2016
- Education Webinars
  - October 22, 2016, December 15, 2016

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Questions?

Please use the GoToMeeting chat panel

- We're hoping that the anonymity of the chat window might help participants ask more questions
- If you want to ask a question on the record, we'll certainly let everyone know you're asking
- The most important thing is interaction – let us hear from you on the call