PLM Leadership

Why Connected Intelligent Products need Semantic Web Technology?

CIMdata PLM Leadership Webinar Series
9 February 2017
#cimdatawebinar

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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

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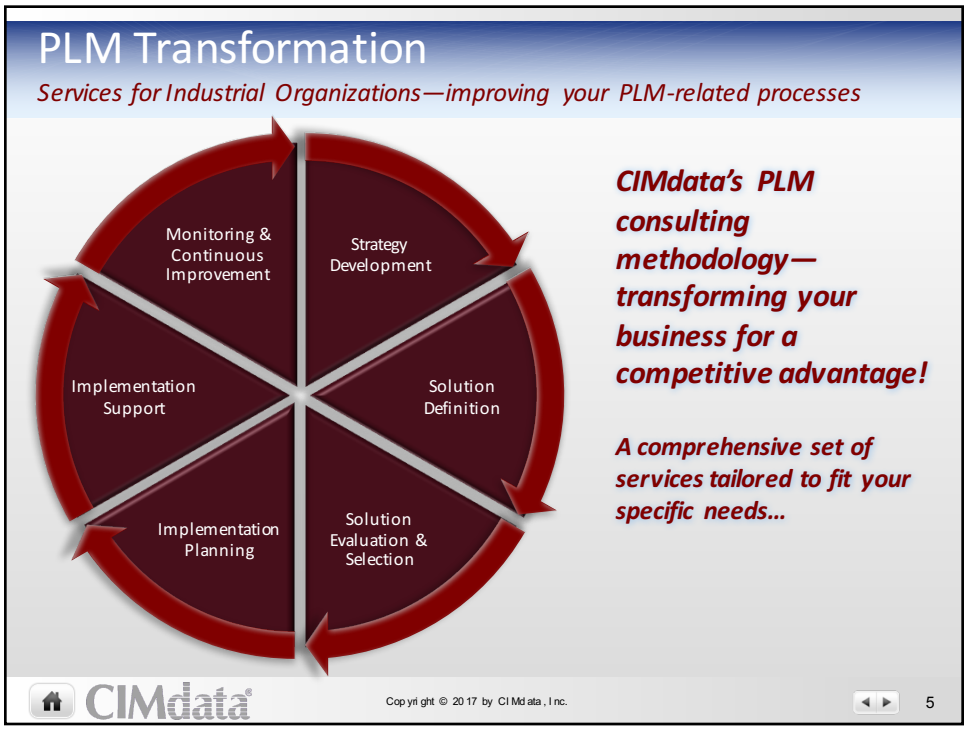
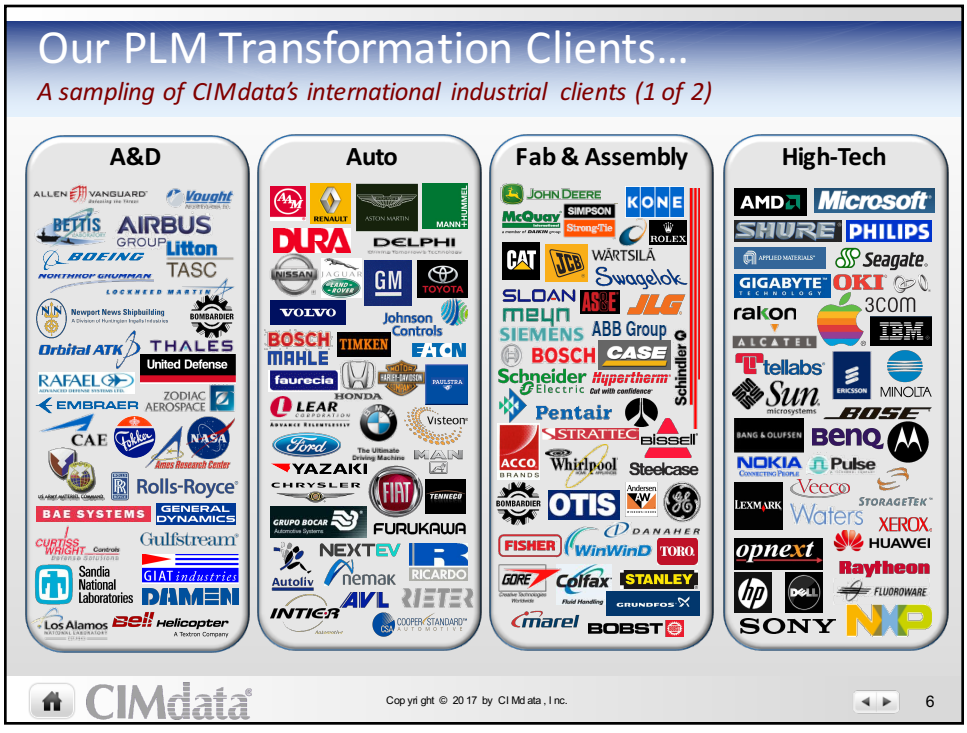
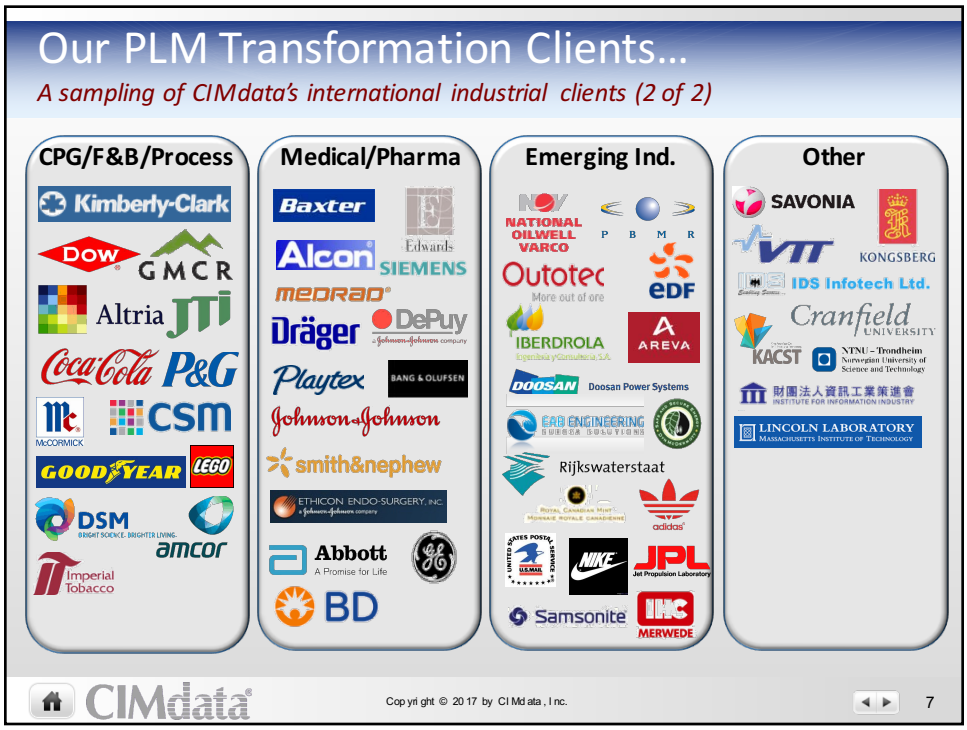
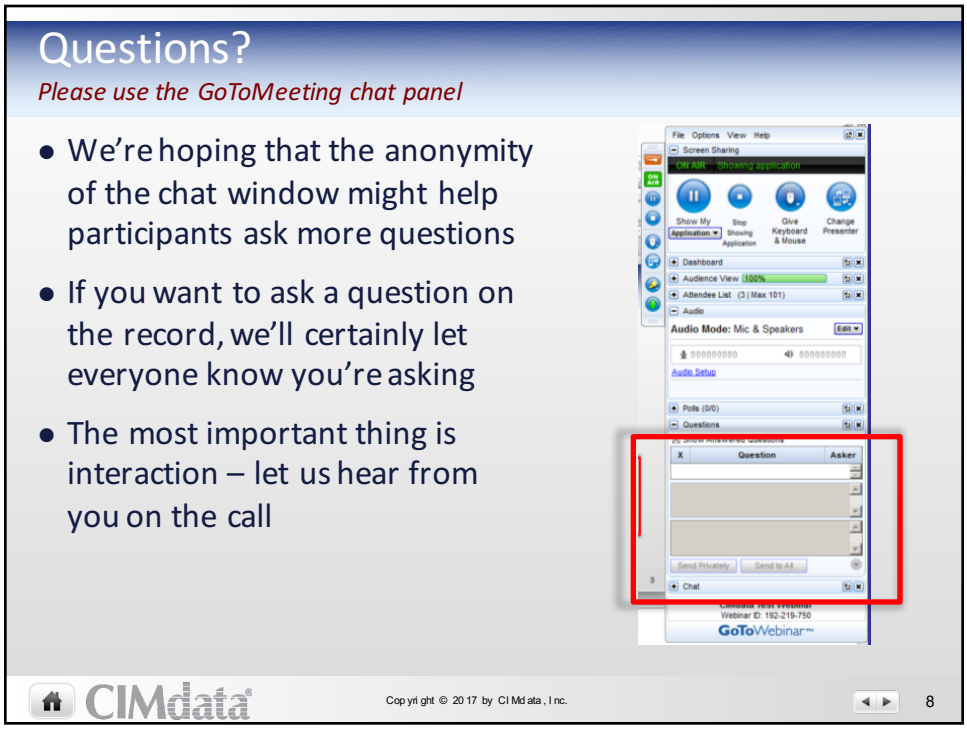
4









Agenda

Semantic Web Technology for Dependable Connected Intelligent Products

- Brief Overview of Semantic Web Technology
- Applying Semantic Web Technology in Reliability Engineering
- Complexity Challenge of Connected Intelligent Products
- Leveraging Semantic Web Technology in Reliability Engineering and Systems Engineering
- Summary & Next Steps
- Q&A

 9

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 10

Enablers of Ontology-Based Knowledge Systems

Semantic Web Technology Elements for Ontology Development

The Semantic Web is envisioned as an extension of the World Wide Web in which knowledge is described (through ontologies) in such a way that the computer can process and understand it.

The computer would then be able to draw conclusions from the given knowledge (in ontologies) using processes similar to human reasoning and inference.

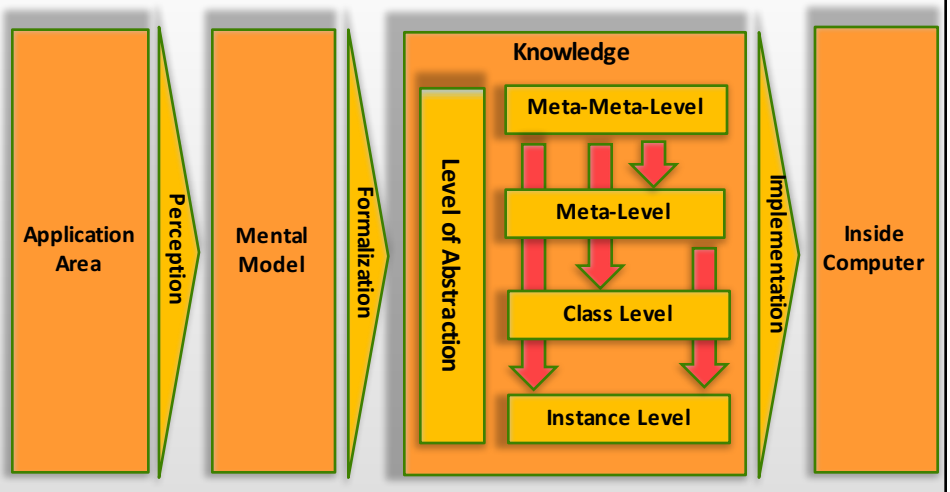
- RDF
- OWL
- Jena
- SPARQL
- F-LOGIC
- .....

Source: I. Herman, Introduction to Semantic Web Technologies, Semantic Technology Conference, San Francisco, CA, June 2010

 11

Ontology-Based Knowledge System

Modeling Framework for Explicit Specification of a Conceptualization



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

 12

Steps for Developing an Ontology

Iterative Design of Ontology

- Step 1. Determine the domain and scope of the ontology
- Step 2. Consider reusing existing ontologies
- Step 3. Enumerate important terms in the ontology
- Step 4. Define the classes and the class hierarchy
  - Top-Down, Bottom-Up, Combination
- Step 5. Define the properties of classes—slots
- Step 6. Define the facets of the slots
  - Slot Cardinality, Slot Value Type, Domain & Range of Slot
- Step 7. Create instances

Source: N. F. Noy and D. L. McGuinness, Ontology Development 101: A Guide to Creating Your First Ontology, Stanford University, http://protege.stanford.edu

 13

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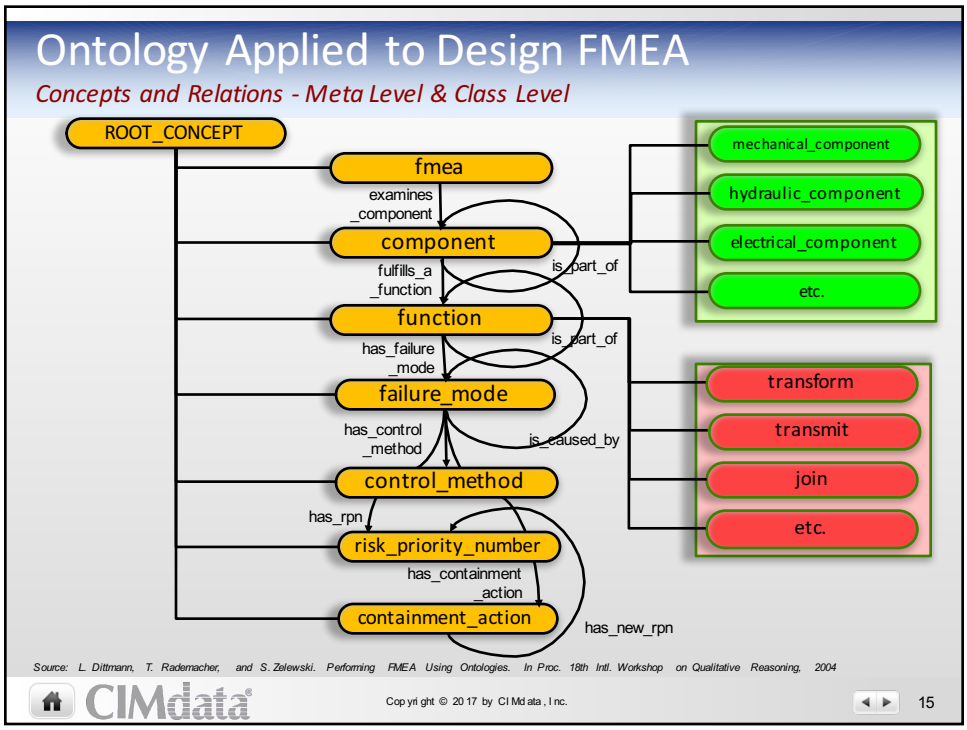
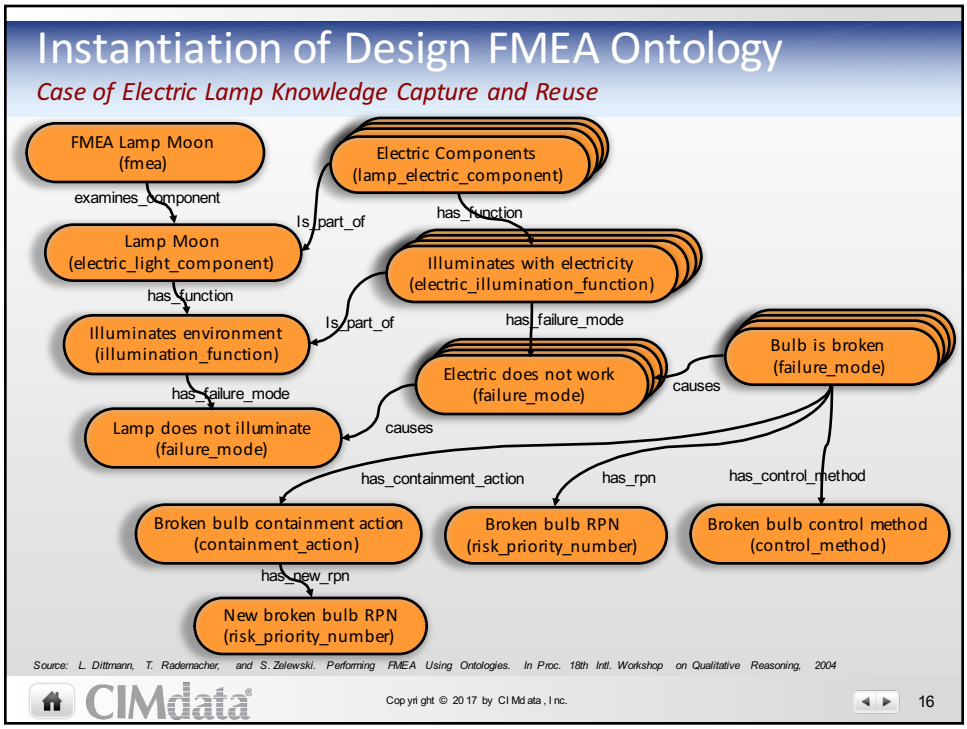
 14





FMEA Queries using F-Logic

Case of Electric Lamp Knowledge Capture and Reuse

- 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*.

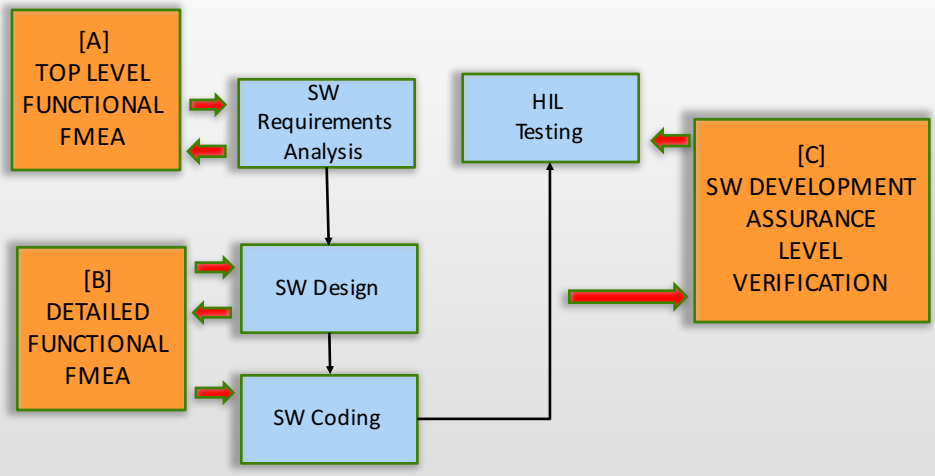
```
FORALL    Mode, Function <-
          Mode: failure_mode AND
          Mode[interferes_function->>Function]  AND
          Function:function AND
          Function[is_fulfilled_by->>
          lamp_moon:electric_lighting_component].
```

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

 17

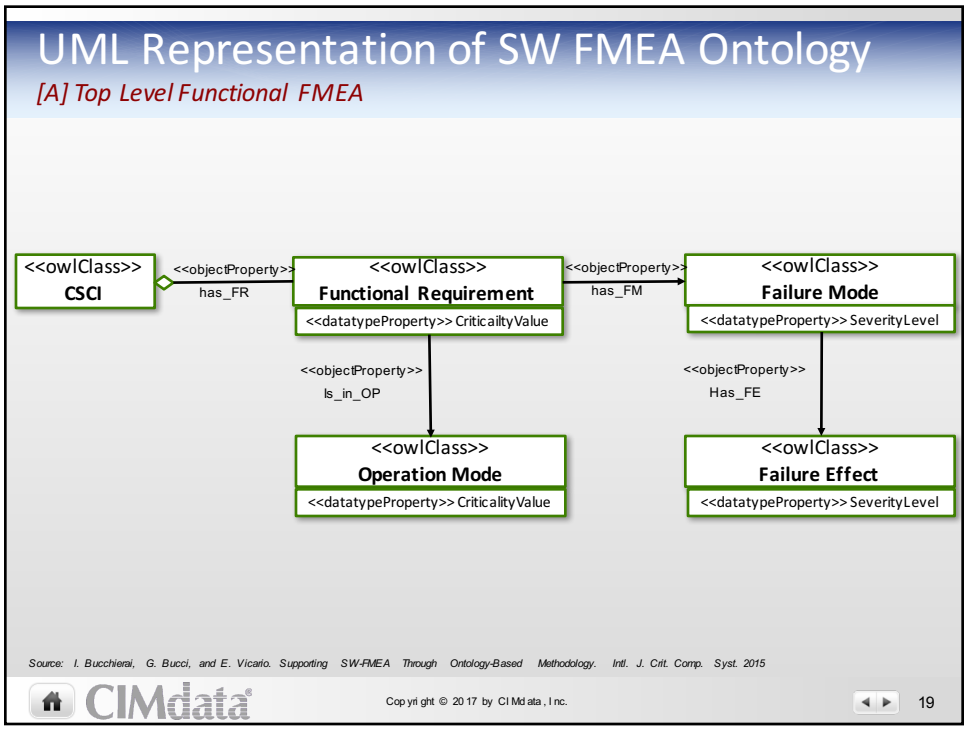
Ontology Applied to Software FMEA

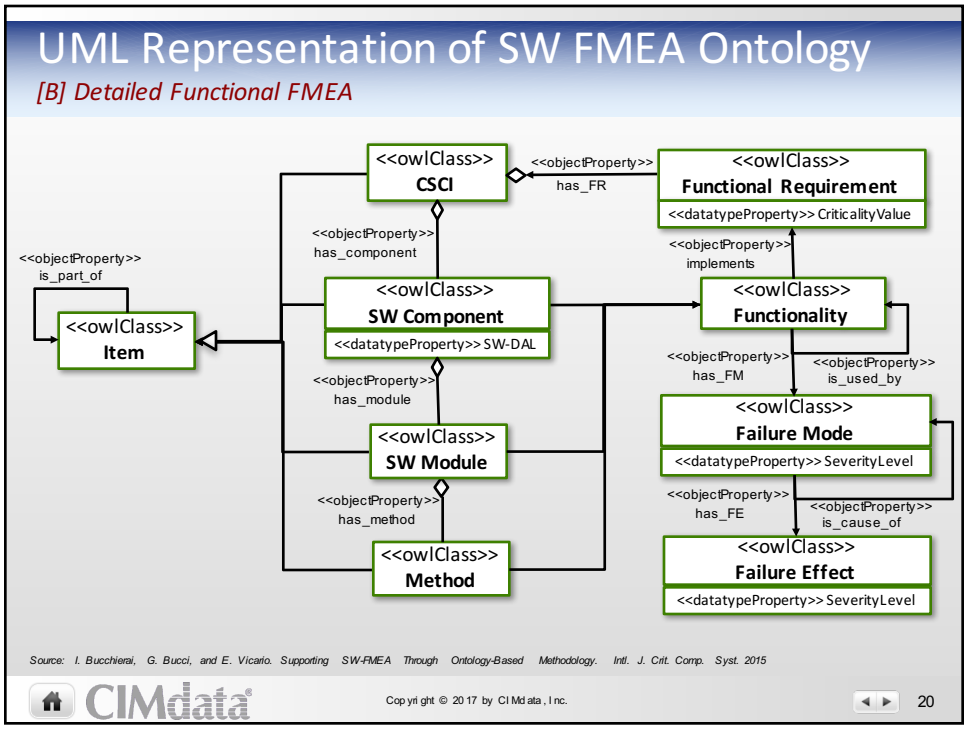
SW FMEA Stages Mapped on Development Lifecycle Activities

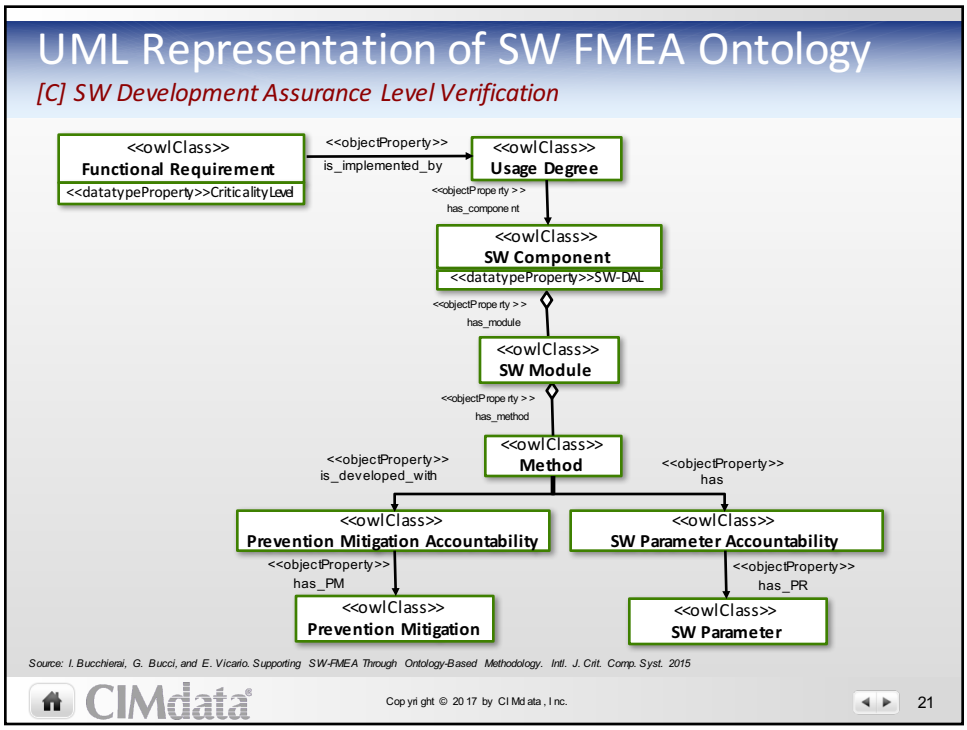


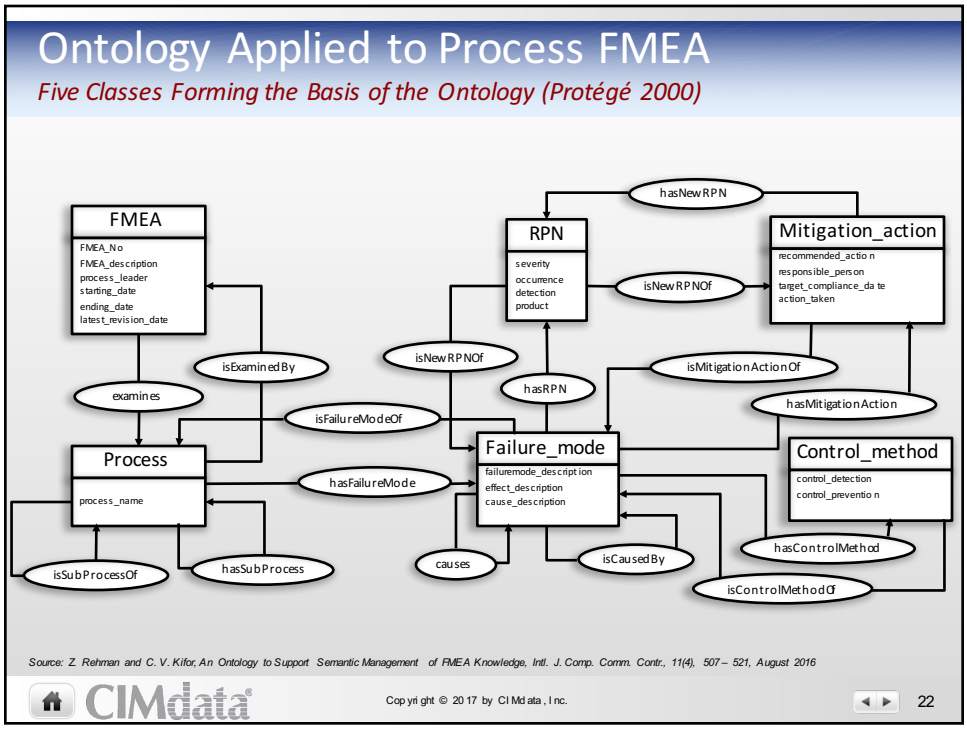
Source: I. Bucchierai, G. Bucci, and E. Vicario. Supporting SW-FMEA Through Ontology-Based Methodology. Intl. J. Crit. Comp. Syst. 2015

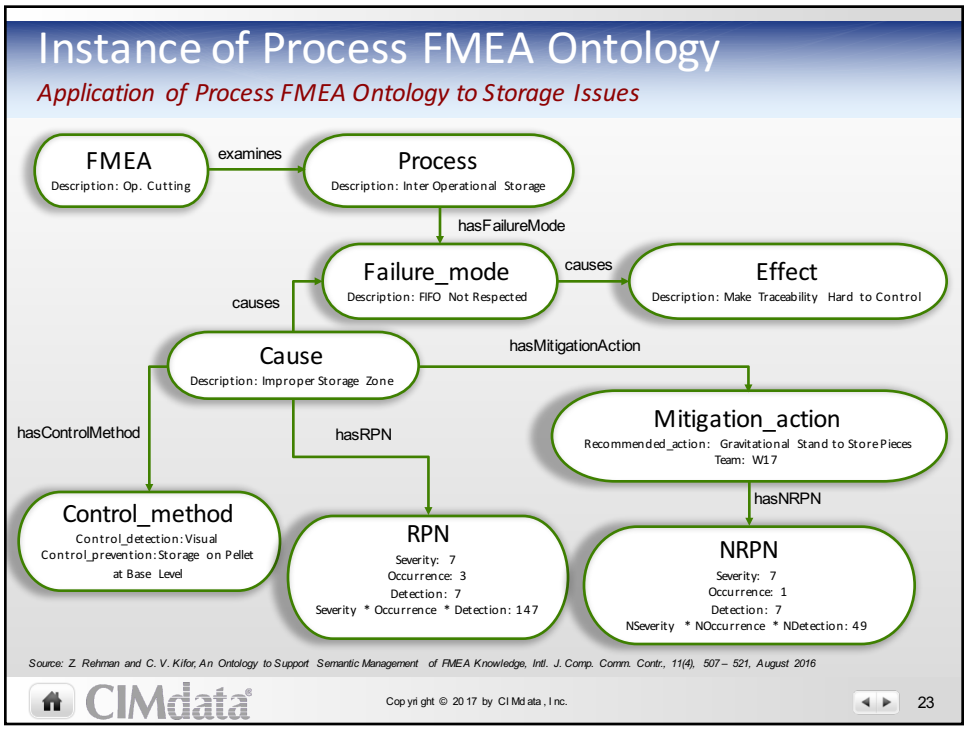
 18

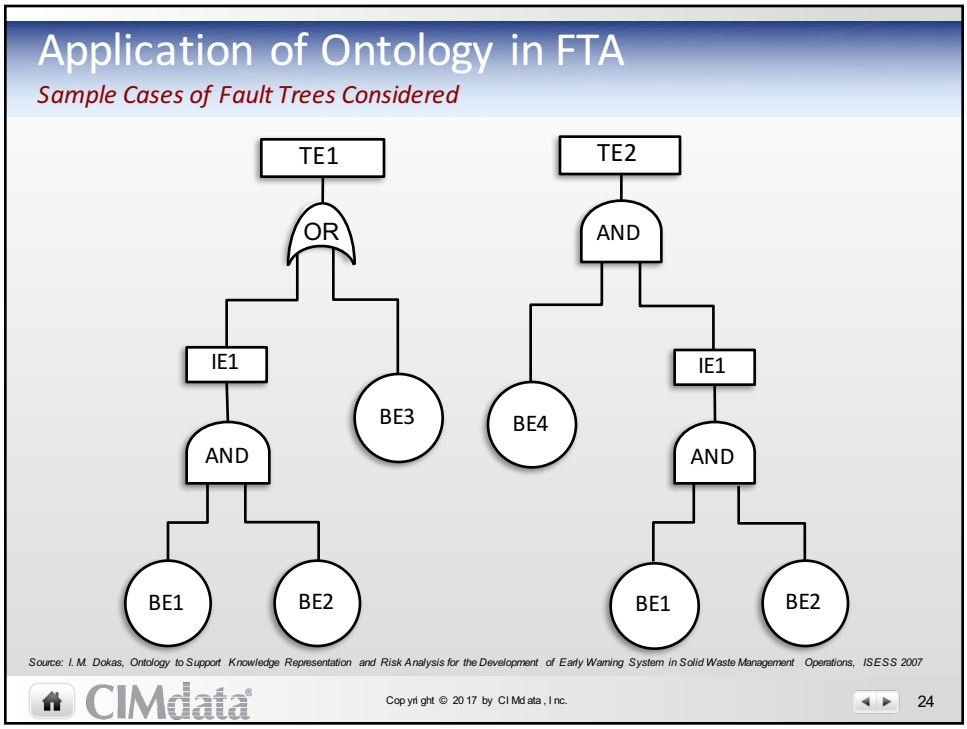












Representation of Fault Tree in OWL DL

First Step for Automatic Generation of Large Fault Trees

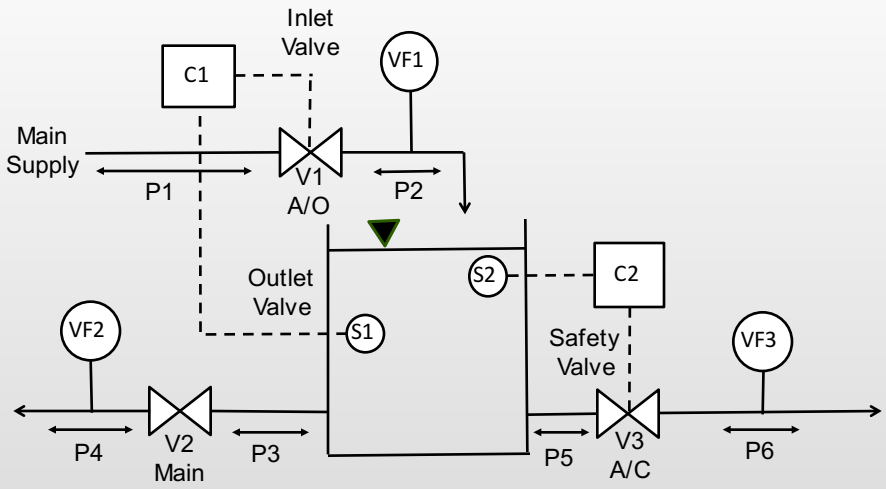
```
<owl:Class rdf:ID="FT_1">
 <rdfs:subClassOf>
  <owl:Class rdf:ID="Mrf_FTA_Diagrams"/>
 </rdfs:subClassOf>
 <owl:disjointWith>
  <owl:Class rdf:ID="FT_2"/>
 </owl:disjointWith>
 <rdfs:subClassOf>
  <owl:Restriction>
   <owl:someValuesFrom>
    <owl:Class rdf:ID="TE_1"/>
   </owl:someValuesFrom>
   <owl:onProperty>
    <owl:ObjectProperty rdf:ID="hasTopEvent"/>
   </owl:onProperty>
  </owl:Restriction>
 </rdfs:subClassOf>
 <rdfs:subClassOf>
  <owl:Restriction>
   <owl:someValuesFrom>
    <owl:Class rdf:ID="BE_3"/>
   </owl:someValuesFrom>
   <owl:onProperty>
    <owl:ObjectProperty rdf:ID="hasBasicEvent"/>
   </owl:onProperty>
  </owl:Restriction>
 </rdfs:subClassOf>
 <rdfs:subClassOf>
  <owl:Restriction>
   <owl:onProperty>
    <owl:ObjectProperty rdf:about="#hasIntermediateEvent"/>
   </owl:onProperty>
   <owl:someValuesFrom>
    <owl:Class rdf:about="#IE_1"/>
   </owl:someValuesFrom>
  </owl:Restriction>
 </rdfs:subClassOf>
 <rdfs:subClassOf>
  <owl:Restriction>
   <owl:allValuesFrom>
    <owl:Class rdf:about="#TE_1"/>
   </owl:allValuesFrom>
    <owl:onProperty>
     <owl:ObjectProperty rdf:about="#hasTopEvent"/>
    </owl:onProperty>
   </owl:Restriction>
 </rdfs:subClassOf>
 <rdfs:subClassOf>
  <owl:Restriction>
   <owl:onProperty>
    <owl:ObjectProperty rdf:about="#hasBasicEvent"/>
   </owl:onProperty>
   <owl:allValuesFrom>
    <owl:Class rdf:about="#BE_3"/>
   </owl:allValuesFrom>
  </owl:Restriction>
 </rdfs:subClassOf>
 <rdfs:subClassOf>
  <owl:Restriction>
   <owl:onProperty>
    <owl:ObjectProperty rdf:ID="hasIntermediateEvent"/>
   </owl:onProperty>
   <owl:allValuesFrom>
    <owl:Class rdf:ID="IE_1"/>
   </owl:allValuesFrom>
  </owl:Restriction>
 </rdfs:subClassOf>
 <rdfs:subClassOf>
  <owl:Restriction>
   <owl:hasValue
rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
   >BE_3 OR (BE_1 AND BE_2)</owl:hasValue>
   <owl:onProperty>
    <owl:DatatypeProperty rdf:ID="hasStructure"/>
   </owl:onProperty>
  </owl:Restriction>
 </rdfs:subClassOf>
</owl:Class>
```

Source: I. M. Dokas, Ontology to Support Knowledge Representation and Risk Analysis for the Development of Early Warning System in Solid Waste Management Operations, ISESS 2007

 25

Ontology for Fault Tree Generation

Application to Water Tank Flow Control System Example



Source: A.. Venceslau, R. Lima, L. A. Guedes, and I. Silva, Ontology for Computer-Aided Fault Tree Synthesis, Emerg. Tech. Fact. Autom. September 2014

 26

Automatically Generated Fault Tree

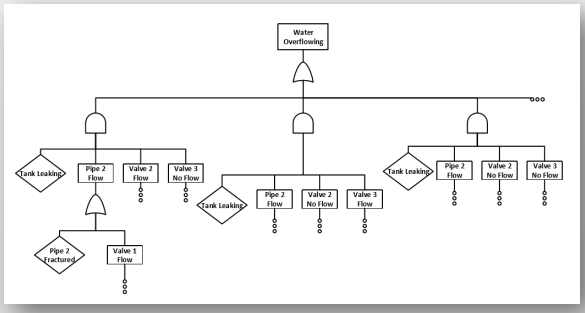
Application to Water Tank Flow Control System Example

Controller 1 Function Table

Input 1	Functional Condition	Output 1
Below	OK	1
Above	OK	0
-	Failed Low	1
-	Failed High	0

Valve 1 State Transition Table

Input 1	Initial Sate	Functionality	Final State
1	-	OK	Open
0	-	OK	Close
0	Open	Failed to Close	Open
1	Close	Failed to Open	Close



Source: A.. Venceslau, R. Lima, L. A. Guedes, and I. Silva, Ontology for Computer-Aided Fault Tree Synthesis, Emerg. Tech. Fact. Autom. September 2014

 27

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 28

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, US FDA 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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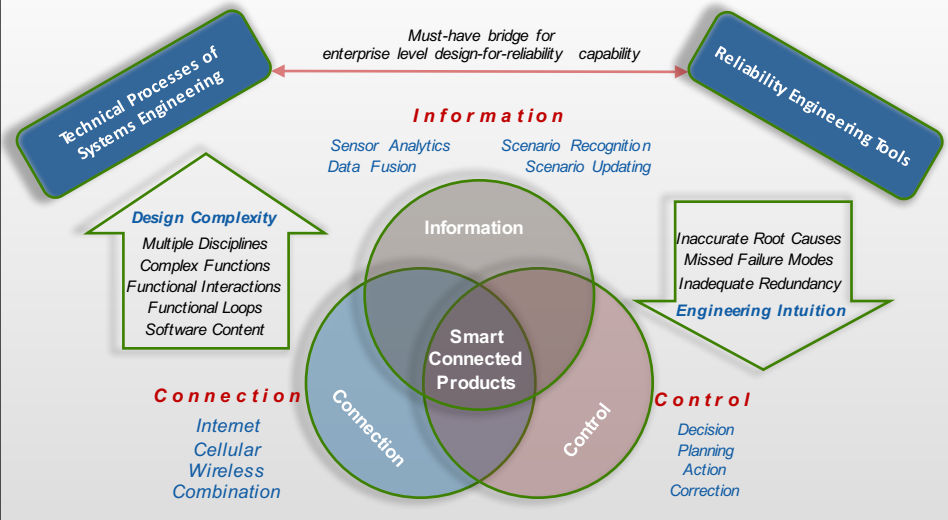
Complexity of Connected, Intelligent Products

Need to Bridge Reliability Engineering and Systems Engineering



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Bridging Reliability Eng. & Systems Eng.

First step towards building a Knowledge System-based Design-for-Reliability

Relationship between Reliability Tools and Systems Engineering Processes

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

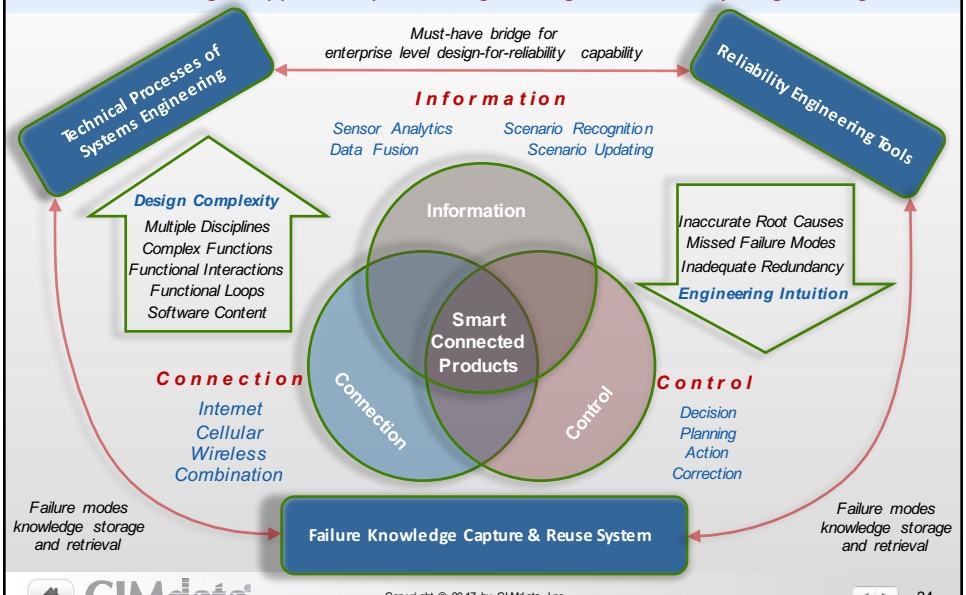
Developing Machine-Readable Failure Knowledge for Reuse

- 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

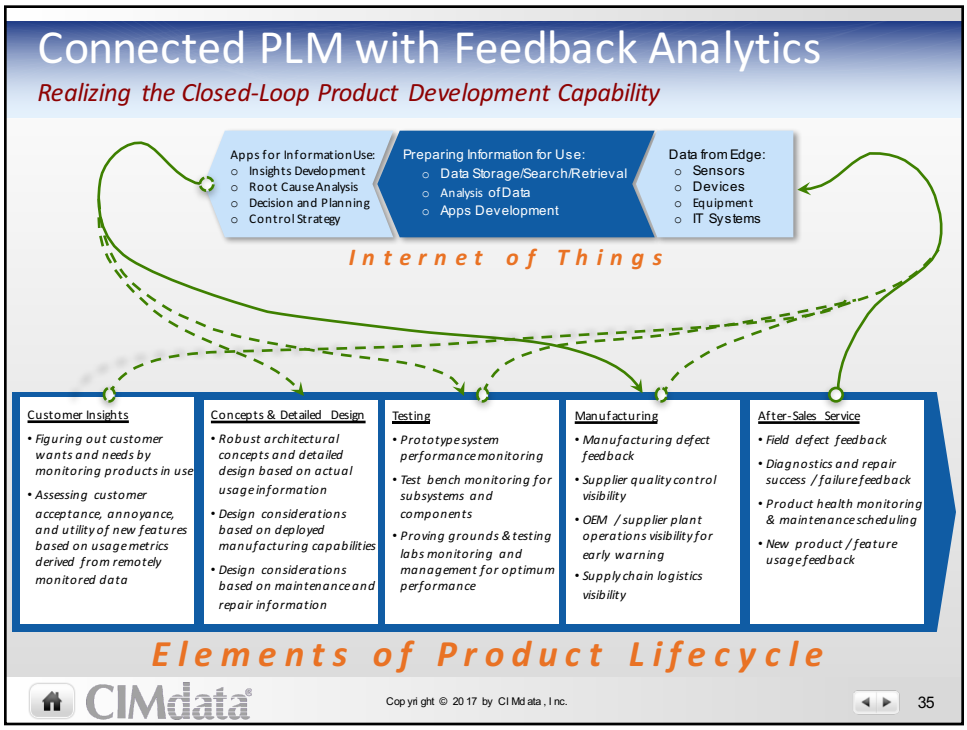
 33

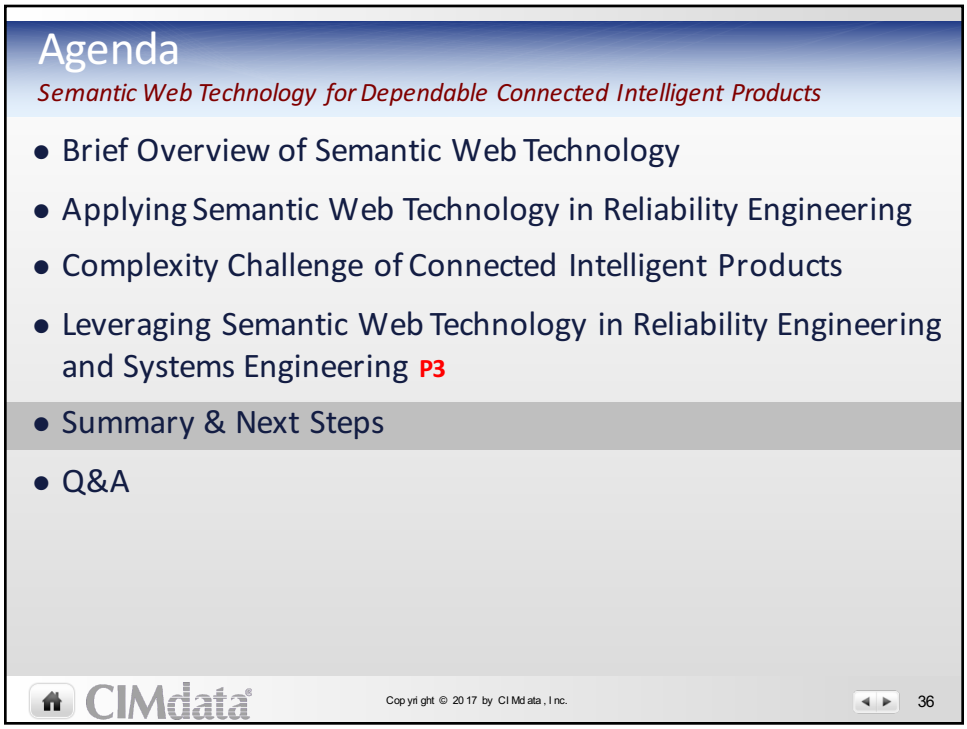
Complexity of Connected, Intelligent Products

Failure Knowledge Support to Systems Engineering and Reliability Engineering



 34





Summary & Next Steps

Realizing Enterprise Knowledge System-Based Design-for-Reliability (1 of 2)

- Systems engineering technical processes help dealing with product complexity of intelligent, connected products but they cannot be pursued in isolation from reliability engineering
- Reliability engineering tools are needed to leverage product failure knowledge and they must be seamlessly bridged with the systems engineering technical processes
- Both the systems engineering technical processes and the reliability engineering tools must leverage failure knowledge capture and reuse to minimize recall and launch risks
- All tools used in systems engineering, reliability engineering, and failure knowledge capture and reuse will not likely be provided by a single software provider

 37

Summary & Next Steps

Realizing Enterprise Knowledge System-Based Design-for-Reliability (2 of 2)

- 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 for dependability
- CIMdata would like support from OEMs, suppliers, and solution providers to further explore Semantic Web Technology in Reliability Engineering, e.g, FMEA, FTA
- CIMdata would like to collaboratively explore with OEMs, suppliers, and solution providers, a maturity model pertaining to "Knowledge Systems-Based Design-for-Reliability"

 38

Quality & Reliability Engineering Output

What is coming from CIMdata's QRE Consulting Practice?

- Request for Project Support
  - Topic: Semantic Web Technology in Reliability Engineering, February 2017
- Survey to be filled
  - Topic: Knowledge Systems-Based Design-for-Reliability, March 2017
- Whitepaper:
  - Quality & Reliability Engineering – Knowledge Systems based Design-for-Reliability, April 2017
- Knowledge Council Kick-off:
  - May 2017
- Education Webinars
  - July 13, 2017
  - November 9, 2017

 39

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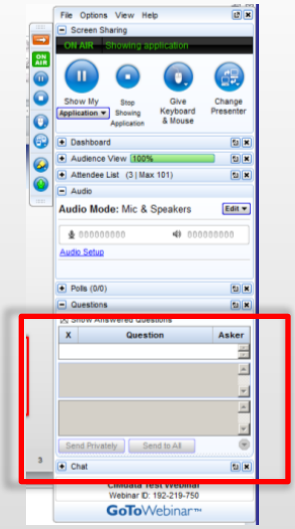
 40

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



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