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

CIMdata PLM Leadership Webinar Series
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#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
Our Mission...

_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_
PLM Transformation

Services for Industrial Organizations—Improving your PLM-Related Processes

CIMdata’s PLM consulting methodology—transforming your business for a competitive advantage!

A comprehensive set of services tailored to fit your specific needs...

Our PLM Transformation Clients...

A sampling of CIMdata’s international industrial clients (1 of 2)
Our PLM Transformation Clients...
A sampling of CIMdata’s international industrial clients (2 of 2)

Questions?
Please use the GoToMeeting chat panel

- We’re hoping that the anonymity of the chat window might help participants ask more questions
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Failure Knowledge Capture and Reuse for Designing Dependable Software-Intensive Products

Agenda

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

Smart, Connected Products

Functions, Enablers, and Challenges

Information

Sensor Analytics
Data Fusion

Scenario Recognition
Scenario Updating

Connection

Internet
Cellular
Wireless
Combination

Decision
Planning
Action
Correction

Control

Complexity, Software

Connection

Engineering Intuition

Smart Connected Products
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Quality & Reliability Risks Today

Complexity of Electronically Controlled, Software-Intensive Products

Auto. SW Related Recalls
- 0.3% of recalls in 2005
- 4.3% of recalls in 6 months of 2015

NHTSA’s Safety Complaints
- 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

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Learning System Based Design-for-Reliability

Connecting three main elements of robust design

- Technical Processes used in Systems Engineering
- Failure modes knowledge storage and retrieval
- Reliability Engineering Tools
- Failure Knowledge Capture & Reuse System
- Failure modes knowledge storage and retrieval

Benefits to OEMs & Suppliers

- 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
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 Analysis
- System Elements Definition
- System Elements Realization
- System Elements Integration
- System Design Verification
- 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
- Graphical Analysis
- Kepner-Tregoe Analysis (KTA)
- Fault Tree Analysis (FTA)
- Reliability Block Diagrams (RBD)
- FRA/CAS
- 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

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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 and Reuse for Designing Dependable Software-Intensive Products

Ontology is an Explicit Specification of a Conceptualization

Level of Abstraction

- Meta-Meta-Level
- Meta-Level
- Class Level
- Instance Level

Application Area
Perception
Mental Model
Formalization

Inside Computer

Failure Knowledge Capture & Reuse
Modeling Framework for Ontology Based Knowledge System


Failure Knowledge Capture & Reuse
Concepts and Relations in FMEA Domain (Meta Level & Class Level)

ROOT_CONCEPT

fmea

examines

component

fulfills

function

has_failure

mode

has_rpn

risk_priority_number

has_containment

action

mechanical_component

hydraulic_component

electrical_component

transform

transmit

join

each


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PLM Leadership

Failure Knowledge Capture & Reuse

*Instantiation of an Ontology based FMEA (Instance Level)*

- **FMEA Lamp Moon** (fmea)
  - Examines component
  - **Lamp Moon** (electric_light_component)
    - Illuminates with electricity (electric_illumination_function)
    - Has function
  - **Electric Components** (lamp_electric_component)
    - Has function
  - **Illuminates environment** (illumination_function)
    - Has failure_mode
  - **Lamp does not illuminate** (failure_mode)
  - Causes
  - **Bulb is broken** (failure_mode)
  - Causes
  - **Broken bulb containment action** (containment_action)
  - Has containment_action
  - **Broken bulb RPN** (risk_priority_number)
  - Has RPN
  - **Has control method**
  - **New broken bulb RPN** (risk_priority_number)


**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[]. 
  ```

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Failure Knowledge Capture & Reuse

Ontology based SW FMEA

SW FMEA Stages Mapped on Development Lifecycle Activities

- TOP LEVEL FUNCTIONAL FMEA
- DETAILED FUNCTIONAL FMEA
- SW Requirements Analysis
- SW Design
- SW Coding
- HIL Testing
- SW DEVELOPMENT ASSURANCE LEVEL VERIFICATION


Failure Knowledge Capture & Reuse

UML Representation of Intensional Part of Ontology

Top Level Functional FMEA

- CSCI
- Functional Requirement
- Failure Mode
- Operation Mode
- Failure Effect


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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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