Application of Systems Engineering to Regulatory Compliance Activities for Medical Devices

Presented by Apoorv Maheshwari

INCOSE Healthcare MBSE Challenge Team: Modeling for a Healthy Future

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Outline

• About the Challenge Team
• Why MBSE?
• Objectives
• Approach
• Demonstration
• Lessons Learned
• Future Work
About the Challenge Team

• **Mission**
  - Demonstrate value and utility of MBSE in biomedical programs
  - Provide INCOSE members reference design to adopt for specific drug, device, and/or biological product development efforts.

• In 2014, finalized reference architecture using MagicDraw to develop SysML-compliant model drug delivery system
  - Requirements, structure, behavior, interfaces, parametrics
  - Emphasis on assurance of safety, reliability, usability, interoperability, and compliance with standards and regulations

• In 2015, added product development process model described in this presentation
Why do we need MBSE?

- Improved communication
  - *Think about language barrier in a global team*

- Improved understanding through logical models
  - *Provide high level of abstraction*
  - *Reuse or design sharing*

- Improved design of test cases
  - *Weakness exposed in the model*

- Easier verification
  - *Model testing vs. just reviews*
  - *Leveling of requirements*
Objectives

- **High-level**
  - Demonstrate value and utility of MBSE in the biomedical-healthcare applications
  - Develop clear roadmap for biomedical device developers to integrate systems engineering activities with regulatory compliance activities

- **Project-specific**
  - **Break the mold**: Medical device industry is conservative, risk averse and continues to use well-established document-based processes
  - **Safety Assurance**: Demonstrate safety, addressing safety and addressing risk (pump recalls)
  - **Guidance Manual**: Assist user on key processes along with the reference pump model
Approach

• Follow Appendix B of Buede’s 2009 textbook, *The Engineering Design of Systems*

• Harmonize with
  • ISO 15288: Systems and software engineering - System life cycle processes
  • ISO 14971: Application of Risk Management to Medical Devices
  • IEC 62366-1: Application of Usability Engineering to Medical Devices

• Build on approach in 2015 INCOSE IS best paper “*SysML Activity Models for Applying ISO 14971 Medical Device Risk and Safety Management Across the System Lifecycle*”
Reference Model for Infusion Pump

• Existing model completed in 2014 represents a generic infusion pump (drug delivery system) depicting:
  • Drug Delivery Requirements
  • Drug Delivery Structure
  • Behavioral Use Cases

An infusion pump is a medical device that delivers fluids, such as nutrients and medications, into a patient’s body in controlled amounts.
Added Engineering Design of Systems

- Buede’s textbook model for engineering design of a system converted from IDEF0 to SysML activity diagrams and linked to existing model

- Model can be accessed anywhere with an internet connection (*read-only*)
## Example: Mapping ISO 14971

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<th>14971</th>
<th>Buede’s Diagrams</th>
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<tr>
<td><strong>Risk Analysis Step</strong></td>
<td><strong>Produced by</strong></td>
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<tr>
<td><strong>Intended Use</strong></td>
<td>A1111 Develop Operational Concept</td>
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<td>Identify characteristics related to safety</td>
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<tr>
<td>Identify characteristics related to safety</td>
<td>A112 Develop System Functional Architecture</td>
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<tr>
<td>Identify characteristics related to safety</td>
<td>A113 Design System Physical Architecture</td>
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<tr>
<td>Identify characteristics related to safety</td>
<td>A1142 Define &amp; Analyze Functional Activation &amp; Control Structure</td>
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<td>Risk estimation</td>
<td>A1143 Conduct Performance &amp; Risk Analyses</td>
</tr>
<tr>
<td>Risk Control</td>
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Demonstration

Can be accessed at:
This file (or website) contains examples of MBSE in the biomedical domain, using closed-loop drug delivery systems as the basis for the architectures.

The "Reference Architecture" may serve as the starting point for any drug delivery system. Two specific examples were created—"Contrast Media Delivery" and "TBD Delivery"—to illustrate particular benefits of MBSE to the biomedical community.

The "Product Development Process" has also been developed using the model given by Dennis Buede in his book The Engineering Design of Systems: Models and Methods. Buede's diagrams have been enhanced by integrating risk management in the development process.

Follow the links below or navigate in the containment tree to the left.

- Reference Architecture Navigation
- Product Development Process
- TBD Navigation
- CM Delivery Domain Navigation
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- Reference Architecture Navigation
- Product Development Process
- TBD Navigation
- CM Delivery Domain Navigation
This is the navigation diagram for the product development process models. The diagrams outside the green box represent the steps prior to the systems engineering processes. The Development Phases diagram lists different phases involved in the product development. The External Systems Diagram shows the information flow across different phases and classifies the activities based on the actors involved in the product development.

The above described Product Development Process has also been mapped to ISO 14971:2007 to make it easier to understand for Healthcare Community. The mapping can be found here.
Pre-Systems Engineering Processes
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System-level Design Activities

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Pre-Systems Engineering Processes

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Mapping Information
Main Navigation Page

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A-1: Development Phases Flow

- A-11: Perform Stakeholders’ Activities
- A0: Perform Systems Engineering
  - A1: Perform Design Activities
  - A2: Perform Qualification & Integration Activities
- A-12: Design & Test Configuration Items
- A-13: Design & Qualify the Qualification system

"System-of-interest" for this project.

Shows the information flow across the above mentioned development phases.

Back to overview

Product Development Process
A-1: Development Phases Flow

A-11: Perform Stakeholders’ Activities

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Shows the information flow across the above mentioned development phases.

Back to overview
Artifact 1: Compliance documents (internal to company - procedures, guidelines, management tools)
Artifact 2: System Architecture Document (High-level)
Artifact 3: Development Plan

"Built-to" Configuration Items & Pre-Production Prototypes

System Design & Integration Documentation
Lessons Learned

• Differences in the vernacular terminology

• Pick the right problem

• Define the problem right
Future Work

- Parametric Modeling
  - Connect the SysML model with MATLAB

- Emergency Department
  - Focus: Diabetes Problem
  - Integrate infusion pump model to deliver insulin
Questions?
Abstract

• The INCOSE Biomedical-Healthcare Model-Based Systems Engineering (MBSE) Challenge Team has developed a reference model that uses SysML to represent a generic infusion pump and a systems engineering process for planning, developing, and obtaining regulatory approval of a medical device. This presentation describes recent updates to the model that incorporates Buede’s textbook model for the engineering design of a system and harmonizes it with ISO 15288 and applicable medical device industry standards such as ISO 14971 Application of Risk Management to Medical Devices and IEC 62366-1 Application of Usability Engineering to Medical Devices. The model provides a clear roadmap that biomedical device developers can follow to integrate systems engineering activities with regulatory compliance activities to provide a more cohesive approach to developing effective and safe medical devices.
Application of Systems Engineering to Regulatory Compliance Activities for Medical Devices

Apoorv Maheshwari, Michelle Lott, Robert J. Malins, Christophe Waterplas, Jack Stein, Ajay Thukral, C. Robert Kenley, and Daniel DeLaurentis

Abstract
The INCOSE Biomedical-Healthcare Model-Based Systems Engineering (MBSE) Challenge Team has developed a reference model that uses SysML to represent a generic infusion pump and a systems engineering process for planning, developing, and obtaining regulatory approval of a medical device. This presentation describes recent updates to the model that incorporates Buede’s textbook model for the engineering design of a system and harmonizes it with ISO 15288 and applicable medical device industry standards such as ISO 14971 Application of Risk Management to Medical Devices and IEC 62366-1 Application of Usability Engineering to Medical Devices. The model provides a clear roadmap that biomedical device developers can follow to integrate systems engineering activities with regulatory compliance activities to provide a more cohesive approach to developing effective and safe medical devices.

Professional Biographies
Apoorv Maheshwari is a Graduate Research Assistant in Purdue’s School of Aeronautics and Astronautics and School of Industrial Engineering in West Lafayette, IN (US). He graduated from the Indian Institute of Technology, Mumbai (India) where he completed his Bachelor’s in Aerospace Engineering. He is currently a member of the Purdue System-of-Systems Laboratory and Product Lifecycle Management Center. He has been actively working with the INCOSE Biomedical-Healthcare Working Group for past 6 months. His primary research interests are in the areas of applying model-based systems engineering to product lifecycle management, agent-based modeling, network theory, and application of random-utility discrete-choice theory to air transportation system.

Michelle Lott is the Principal and Founder of Lean RAQA Systems, LLC. She has nearly 20 years of experience covering technical, scientific, engineering project management, quality, and regulatory fields in large medical device/pharmaceutical manufacturers and small entrepreneurial focused companies. She has worked directly with FDA and EU authorities to determine submission strategies and expedite product approval for a variety of products. In addition, she has successfully navigated product registration in international arenas. Michelle served as an expert witness in forensic toxicology prior to beginning her career in medical devices. She received her BS in chemistry from Troy State University in Troy, AL, and achieved the Regulatory Affairs Professionals Society (RAPS) Regulatory Affairs Certification (RAC). In addition Michelle completed the RAPS Executive Development Program at Northwestern’s Kellogg School of Management.
Robert J. Malins is the founder and owner of Eagle Summit Technology Associates, Inc. and has over 35 years of experience in R&D and system development in defense, aerospace, energy, and security fields as well as in commercial product development. Dr. Malins is a senior systems engineer skilled in both the technical and management functions of systems engineering. In addition, he has a strong background in numerous technologies and has been the concept integrator for many multi-disciplinary teams. For the past ten years, Dr. Malins has provided systems engineering, architecture development, and concept development support to Army programs in unmanned systems development, tactical network integration, and force basing architectures and to DOE National Laboratory programs to transfer DOE technologies to military systems. Prior to forming Eagle Summit, Dr. Malins worked in the aerospace industry supporting a broad range of advanced technology programs in directed energy, kinetic energy interceptors, command and control systems, and novel optical and RF sensors. Dr. Malins received his BS in chemistry from the University of Houston and his Ph.D. in physical chemistry from the University of Iowa.

Christophe Waterplas is a lead systems engineer at Resmed Ltd. with over 10 years of experience in the medical device industry. Mr. Waterplas graduated with a master degree in electromechanical engineering and telecommunication from Université libre de Bruxelles in Brussels, Belgium. He began his professional career as a software engineer in the telecommunication industry. In 2003, he changed fields, developing embedded software for mechanical ventilators at Resmed before becoming a systems engineer in 2005. He has worked on several projects providing his expertise in risk management, usability engineering, and alarm systems.

Jack Stein is a Systems Engineer, Co-Chair of the INCOSE Risk Management Working Group (WG), member of the INCOSE, Project Management Institute (PMI) Strategic Alliance WG, and member of the INCOSE Biomedical-Healthcare WG and Model-Based Systems Engineering (MBSE) Challenge Team. He also serves as Assistant Director of the INCOSE Americas Sector North-Central Region. Mr. Stein has over 25 years of experience in the Automotive and Medical Device industries, and more than 20 years of experience as a U.S. national technical expert in the development of a variety of industry standards (ISO, IEC, SAE, and ZVEI). Recently, he led the effort to complete the revision of the Risk Management section of the INCOSE Systems Engineering, Handbook Version 4.0. He is currently leading a collaborative effort between the INCOSE Risk Management WG and the PMI Risk Management Community of Practice in support of the INCOSE-PMI Strategic Alliance. Mr. Stein studied Systems, Reliability and Quality Engineering at the University of Arizona, Tucson, Arizona under the Ford Motor Company Fellowship Award, and has BSEE and Bachelor of Commerce Degrees from the University of Windsor, Ontario, Canada.

Ajay Thukral is co-founder of Cientive Group, Inc. and serves as the company’s Chief Technology Officer, in addition to sitting on the Board of Directors. Dr. Thukral has a background in aerospace engineering. He has been an integral part of the team that developed some of the core tools for Cientive’s proprietary transcription services. He leads the mathematical analysis, modeling of engineering and biomedical teams at Cientive. He is a former R&D mathematical and modeling specialist and continues to serve as a
consultant for Roche Diagnostics. Dr. Thukral received his BS degree from the Indian Institute of Technology and his MS and Ph.D. from Auburn University.

C. Robert Kenley is an Associate Professor of Engineering Practice in Purdue’s School of Industrial Engineering. He has over thirty years’ experience in industry, academia, and government as a practitioner, consultant, and researcher in systems engineering. He has published papers on systems requirements, technology readiness assessment and forecasting, Bayes nets, applied meteorology, and the impacts of nuclear power plants on employment.

Daniel DeLaurentis is a Professor in Purdue’s School of Aeronautics and Astronautics. He leads Purdue's Center for Integrated Systems in Aerospace and its largest recent project with the Missile Defense Agency's Enhanced C2BMC program that is developing agent-based modeling and simulation for development of advanced battle management architectures. His primary research interests are in the areas of problem formulation, modeling and robust system design, and control methods for aerospace systems and systems of systems. This includes agent-based modeling, network theory, optimization, and aerospace vehicle modeling. His research is conducted under grants from NASA, FAA, Navy, the DoD Systems Engineering Research Center UARC, and the Missile Defense Agency.