Bridging the Gap Between MBSE and RAM Using Parametric Diagrams

Keith Zook

INTUITIVE[®], IT'S...INTUITIVE[®], and our lighthouse logo are all Registered Trademarks of Intuitive Research and Technology Corporation. © 2022 Intuitive Research and Technology Corporation. All Rights Reserved.

NTUITIVE

Purpose and Topics

Purpose

Describe how RAM analyses can be performed within a system's Model Based Systems Engineering (MBSE) environment

• Topics

- Introduction to MBSE
- Model and tool description
- MBSE language and diagram types
- Modeled behavior, requirements, and structure
- A simple Reliability analysis
- Correlation to requirement verification
- Other potential application areas
- Summary



MB<u>SE</u> – Model Based <u>SYSTEMS ENGINEERING</u>



We use models that aid us in performing the Systems Engineering 'V' process

INTUITIVE

INTUITIVF

Today's Model and MBSE Tool

- MBSE Tool
 - Cameo Enterprise Architecture
 - aka MagicDraw
 - Cameo Simulation Toolkit
- Notation
 - SysML
- System of Interest
 - System X
 - Completely notional
 - It could be anything ...





2021x

SYSTEMS

MODELING LANGUAGE

The MBSE Language

We use the Systems Modeling Language (SysML)

- 3 diagram categories; 9 diagram types
- Defined element types and relationships between elements (the metamodel)
- Everything on the diagram has semantic meaning; not just a ppt shape or line
- Customize as necessary
- Other notations and frameworks exist; SysML is foundational





System X Behavior

System Use Cases – identify top-level functions and external interactions



Activity Diagrams elaborate each Use Case with detailed functional flow



Basis for the system's functional requirements; supports Functional Hazard Analyses (FHA)

INTUITIVE

INTUITIVE

Expanded to show actual

Requirement elements

System X Requirements

Model organization – reflects standard specification content (MIL-STD-961, DI-IPSC-81431A)



Reliability Requirement Element Specification

Pro



What's a Value Properties System Reliability Requirement Type - Threshold What's a Value Properties System Reliability Requirement Type - Threshold What's a Value System Reliability System Reliability Requirement - CDD-3 Requirement for - System X Requirement - CDD-3 Requirement for - System X Requirement for - System X What's a Value System Reliability (3. System X Logicalis). Requirement Class) (3. System X Logicalis). Requirement for - System X Requirement for - System X Property? The system Reliability (3. System X Logicalis). Requirement for - System X Requirement for - System X Requirement for - System X System Reliability (3. System X Logicalis). Requirement X Requirement for - System X	🗉 te 🖸 💈	System Reliability		All IDULES Dequirement Text The system shall	
What's a Value What's a Value Property Traceability What's a Value Property Traceability Usage in Diagrams System X Requirements System X Requirements System X Legicali3. Requirement [Class] [System X Logicali3. Requirement X:3.1 System X:3.0 Re Navigation/Hyperinks Requirements System X Requirements System X Requirement System X Requirements System X Requirement Type - Threshold Requirement Type - Threshold Requirement Type - Threshold Requirement Type - Threshold Requirement Verification Method Analysis Perding What's a Value Property Threshold Verified By System X Logicali3. Requirement. Statified By Sithed Reliability (S. System X Logicali3. Requirement. Property Traceability Parent Requirement - CDD-3 Requirement for - System X Requirement for - System X Verified By System X Logicali3. System X Logicali3. System X Property - required reliability Verification I System X Logicali3. System X Requirement for - System X	System Reliability	💼 2; 🥫 🕫 🖾	Properties: Expert 🗸 🗸	kequirement lext – The system shall	
Wind's a Value Property? Verification Method What's a Value Property? Threshold Basic Requirement (Class) System Reliability (3. System X Logicals). Requirements:::1. System X:3.0 Requirement ID – 562 Requirement ID – 562 Requirement ID – 562 Requirement ID – 562 Requirement ID – 562 Requirement Type = Threshold Source Rick System Reliability Approval Pending Input Source Note: Requirement Type = Threshold Requirement Verification Method Value Connents Property? Threshold Value Connents Property? Threshold What's a Connents Value Connents Property? Threshold What's a Connents Value Connents Property? Threshold Value Connents Property? System Reliability (3. System X Logicals). Requirement - CDD-3 Requirement for - System X Requirement for - System X Value System X		System X Requirement		have a reliability of no less than .925.	
What's a Value Property? What's a Value Property? Traced To Statified By Sta	🗈 Usage in Diagrams	Applied Stereotype	«» System X Requirement [Class] [System X Profile]		
Qualified Name 3. System X Logical:3. Requirements::31 System X::30 Re Requirement::10 = 362 Navigation/Hyperinks Text The system shall have a reliability of no less than .925. Requirement Name – System Reliability 4 = '562' Source Signem X::00 (cal::3. Requirements::31 System X::30 Re Requirement Name – System Reliability 4 = '562' Source Signem X::00 (cal::3. Requirements::31 System X::00 (cal::3. Requirement X::00 (cal::3. System X::00 (Tags	Verify Method		Boquiromont ID E62	
Text The system shall have a reliability of no less than .925. Requirement Name – System Reliabilitit Is proved in the system of Regulation Comments system Reliability of no less than .925. Requirement Type - Threshold Is proved in the system shall have a reliability of no less than .925. Requirement Type - Threshold Is proved in the system shall have a reliability of no less than .925. Requirement Type - Threshold What's a Value Provid input Source Requirement Type - Threshold Is the system shall have a reliability of no less than .925. Requirement Type - Threshold What's a Value Pre-formets Requirement Type - Threshold Is raceability Input Source Requirement Type - Threshold Verification Method = Analysis Requirement Type - Threshold Parent Requirement - CDD-3 Requirement Type - Threshold Input Source Requirement Test Case - how will verification be performed? Requirement for - System X System X Logical:3. Requirement. Requirement for - System X Owner System X Logical:3. Requirement. Required System X Reliability Verification [3. System X Logical:3. Requirement. Derived From System X Logical:3. Sequirement. Requirement for - System X If raced To System Reliability Verificatin [3. System X Logical:3. Se	Sub Requirements	Qualified Name	3. System X Logical::3. Requirements::3.1 System X::3.0 Re	Kequirement ID – 562	
Id 562 System Reliability is/k System Reliability is/k Name System Reliability is/k Name System Reliability is/k Name System Reliability is/k Name System Reliability is/k What's a Value Property? What's a Value Property? What's a Value Property? What's a Value Property? What's a Value Property? What's a Value Property? What's a Value Property? What's a Value Property? Value Property Water Out of the distance Out of the distance Drived From	Documentation/Comments	Text	The system shall have a reliability of no less than .925.		
Cystem X Requirements System Reliability System Reliability Source Risk Nome System Reliability Approval Input Source Notes/ Comments Requirement Type - Threshold Approval Input Source Notes/ Comments Requirement Verification Method - Analysis What's a Value Poroperty? Value Poroperty? What's a Value Poroperty? Owner Satified By Master Owner Derived From Derived From By Object Arman Derived From Derived From Derived From Derived From Derived Trom Derived Trom <tr< td=""><td>Language Properties</td><td>Id</td><td>562 🚽</td><td> Requirement Name – System Reliability</td></tr<>	Language Properties	Id	562 🚽	Requirement Name – System Reliability	
eSystem X Requirements System Reliability Rak Requirement Type - Threshold 1= "562" requirement Type = Threshold ext = The system Stall have a liability of no less than .925." erification Method = Analysis Requirement Type - Threshold Requirement Type - Threshold - Analysis What's a Value Property? Value Drived Refined By Master Traceability Between the system X logical:3. Requirement CDD-3 Operational Reliability (3. System X logical:3. System X logical:5.		Source			
System Reliability System Reliability Requirement Type Threshold approval Pending Requirement Verification Method - Analysis What's a Value Period Tracebility - Analysis Requirement Type - Analysis What's a Value Tracebility - Analysis Requirement - CDD-3 Property? Fried By	«System X Requirement»	Risk		Requirement Type - Threshold	
Approval Pending Requirement Type = Threshold ext = The system shall have a eliability of no less than .925* (erification Method = Analysis What's a Value Property? What's a Value Property? Fraceability Derived Refined By Satisfied By Master Derived From Derived Fr	System Reliability	▶ Name	System Reliability 🚽	Requirement type threshold	
input Source input Source Requirement Vermitcation Method Notes/Comments Notes/Comments - Analysis What's a Verification Method Analysis - Analysis What's a Verification Text - - General - - - - Drived - - - - Value - - - - Derived - - - - Master - - - - - Owner - 3.11.1 Reliability [3. System X Logical:3. Requirement. - Requirement for - System X Verified By - System Reliability Verification [3. System X Logical:3. Structure] - Required System X Reliability Value Property – required reliability value - Required System X Reliability value Property – required reliability value	a = "562" Requirement Type = Threshold	Approval	Pending	Paguiroment Varification Mathed	
Peliability of no less than .925." What's a Value Property? Owner Derived Refined By Owner Derived From Verification [Ast by] Master Owner Derived From Verification [S system X Logical:3. Requireme.theliability [2. Operational Reliability [2. Operational Context] Verified By System X [3. System X Logical:1. Structure] Traced To System X [3. System X Logical:1. Structure] Property - required reliability value	ext = "The system shall have a	Input Source			
erification Method = Analysis Requirement Type Threshold What's a Value Property? Verification Text General Relations I Traceability Derived Refined By Satisfied By Master Inteshold Requirement Type Owner 3.11.1 Reliability [3. System X Logical:3. Requireme Derived From Required System X Logical:3. Requireme Derived From Required System X Logical:1. Structure] Verified By Traced To System X [3. System X Logical:1. Structure] Required System X Reliability Value Property - required reliability value	eliability of no less than .925."	Notes/ Comments		- Analysis	
Verification Method Analysis Relations What's a Value General Parent Requirement – CDD-3 Property? Refined By Requirement Test Case – how will verification be performed? Nater Owner 3.11.1 Reliability [3. System X Logical:3. Requireme Derived From © CDD-3 Operational Reliability (2. Operational Context Requirement for - System X Verified By System X Logical:1. Structure] Required System X Reliability Value Traced To System X Logical:1. Structure] Property – required reliability value	erification Method = Analysis	Requirement Type	Threshold		
What's a Value Verification Text Parent Requirement – CDD-3 Property? Traceability Requirement Test Case – how will verification be performed? Naster Owner 3.11.1 Reliability [3. System X Logical:3. Requireme Derived From © CDD-3 Operational Reliability (2. Operational Context Required System X Logical:1. Structure] Verified By System X [3. System X Logical:1. Structure] Required System X Reliability Value Traced To System Kibility: Real = .925 [3. System X] Required System X Reliability value		Verification Method	Analysis ┥	Polations	
What's a Value General Parent Requirement – CDD-3 Property? Derived Refined By Satisfied By Master Requirement Test Case – how will verification be performed? Owner 1.11.1 Reliability [3. System X Logical:3. Requireme Derived From Derived Trom Verified By System Reliability [2. Operational Context Werification [3. System X Logical:1. Structure] Traced To Required System X Logical:1. Structure] Traced To		Verification Text		Relations	
Value Derived Requirement Test Case – how will Property? Naster Naster Naster Owner Derived From CDD-3 Operational Reliability [2. Operational Context Requirement for - System X Verified By System X [3. System X Logical: 1. Structure] Required System X Reliability Value Traced To Traced To Required System X [3. System X Logical: 1. Structure] Property – required reliability value	What's a	General		Parent Requirement – CDD-3	
Value Derived Refined By Satisfied By Satisfied By Master Owner 3.11.1 Reliability [3. System X Logical::3. Requireme Derived From CDD-3 Operational Reliability [2. Operational Context Verified By System Reliability Verification [3. System X Logical::5. Traced To System X [3. System X Logical::1. Structure] Mequired System Reliability: Real = .925 [3. System X] Property – required reliability value	Value	Traceability			
Property? Refined By Satisfied By Master Owner In 1.1 Reliability [3. System X Logical::3. Requireme Derived From CDD-3 Operational Reliability [2. Operational Context Verified By System Reliability Verification [3. System X Logical::5. Traced To System X [3. System X Logical::1. Structure] Traced To Required System Reliability : Real = .925 [3. System X I	value	Derived		Requirement Test Case – how will	
Satisfied By Master Owner 1.11.1 Reliability [3. System X Logical:3. Requireme Derived From CDD-3 Operational Reliability [2. Operational Context Verified By System Reliability Verification [3. System X Logical:5. Traced To System X [3. System X Logical:1. Structure] Wertin Cation be performed? Required System X Reliability Verification [3. System X Logical:5. Wertin Cation be performed? Required System X Reliability Verification [3. System X Logical:5. Wertin Cation be performed? Property – required reliability Value	Property?	Refined By			
Master Owner 1.1.1 Reliability [3. System X Logical::3. Requireme Derived From CDD-3 Operational Reliability [2. Operational Context Verified By System Reliability Verification [3. System X Logical::1. Structure] Traced To System X [3. System X Logical::1. Structure] Required System Reliability : Real = .925 [3. System X]		Satisfied By		verification be performed?	
Owner 3.11.1 Reliability [3. System X Logical::3. Requireme Derived From Image: CDD-3 Operational Reliability [2. Operational Context Verified By System Reliability Verification [3. System X Logical::5. Traced To System X [3. System X Logical::1. Structure] Image: Required System Reliability : Real = .925 [3. System X] Property – required reliability value		Master			
Derived From Im CDD-3 Operational Reliability [2, Operational Context Verified By System Reliability Verification [3, System X Logical::5, Traced To System X [3, System X Logical::1, Structure] Image: Required System Reliability : Real = .925 [3, System X]		Owner	3.11.1 Reliability [3. System X Logical::3. Requireme	Requirement for - System X	
Verified By O System Reliability Verification [3. System X Logical::5.] Traced To System X [3. System X Logical::1. Structure] Traced To Required System Reliability : Real = .925 [3. System X I]		Derived From	R CDD-3 Operational Reliability [2. Operational Context]		
Traced To System X [3. System X Logical::1. Structure] Image: Comparison of the system Reliability : Real = .925 [3. System X logical::1. Structure] Image: Comparison of the system Reliability : Real = .925 [3. System X logical::1. Structure] Image: Comparison of the system Reliability : Real = .925 [3. System X logical::1. Structure] Image: Comparison of the system Reliability : Real = .925 [3. System X logical::1. Structure] Image: Comparison of the system Reliability : Real = .925 [3. System X logical::1. Structure] Image: Comparison of the system Reliability : Real = .925 [3. System X logical::1. Structure] Image: Comparison of the system Reliability : Real = .925 [3. System X logical::1. Structure] Image: Comparison of the system Reliability : Real = .925 [3. System X logical::1. Structure] Image: Comparison of the system Reliability : Real = .925 [3. System X logical::1. Structure] Image: Comparison of the system Reliability : Real = .925 [3. System X logical::1. Structure] Image: Comparison of the system Reliability : Real = .925 [3. System X logical::1. Structure] Image: Comparison of the system Reliability : Real = .925 [3. System X logical::1. Structure] Image: Comparison of the system Reliability : Real = .925 [3. System X logical::1. Structure] Image: Comparison of the system Reliability : Real = .925 [3. System X logical::1. Structure] Image: Comparison of the system Reliability : Real = .925 [3. System X logical::1. Structure] Image: Comparison of the system Reliability : Real = .925 [3. System X logical::1. Structure] Image: Comparison of the system Reliability : Real = .925 [3. System X logical::1. Structure] Image: Comparison of the system Reliability : Real = .925 [3. System X logica		Verified By	System Reliability Verification [3. System X Logical::5.	Poquirad System X Poliability Value	
Index No Image: A state of the state		Traced To	System X [3. System X Logical::1. Structure]	Required System A Reliability value	
			Required System Reliability : Real = .925 [3. System X I]	Property – required reliability value	
Will We Make Draw article and Leave to Develop this Discussion of Owned by System X			and have to Demonstrate Discussion	owned by System X	

INTUITIVE

System X Structure



INTUITIVE®

Reliability Calculations

We're going to calculate the reliability of System X

- Based on the reliability of its subsystems
- Simple series and parallel system configurations
- Compare calculated reliability against the Required System Reliability

We can mechanize all these calculations, and tie them directly to System X elements, within the model Series: System 'success' depends on the success of every individual component



System X Series Reliability

= Subsystem 1 * Subsystem 2 * Subsystem 3

System X Reliability > Required System Reliability ?



System X Parallel Reliability = 1 - (1 - Subsystem 1) * (1 - Subsystem 2) * (1 - Subsystem 3)

System X Parallel Reliability > Required System Reliability ?

INTUITIVE®

Mechanizing MBSE Parametric Analyses

4 primary steps:



Step 1: Establish the Analysis Context

Context diagram is represented as a Block Definition Diagram (BDD)

A SysML Structure Diagram

The Context is comprised of:

- The System of Interest (System X)
- System X Subsystems
 - and their Reliability Value
 Properties
- Constraint Block
 - Constrains System X
 - Defines the Reliability equations and parameters
 - Defines Reliability equation parameters as Real

How do we associate equation parameters to System X values?



INTUITIV



Step 3: Execute the Simulation



INTUITIVE

Step 4: Analyze and Refine the Results

🗄 Variables ×	
	Ö -
Name	Value
🖃 🔜 System Reliability Analysis Context	System Reliability Analysis Context@3710880b
🖻 🖻 System X : System X	System X@25a772f3
System Reliability {CalcRelSeries = System X.Subsys1.Subsystem 1 Reliabil	System Reliability@400dda23
🗖 CalcRelParallel : Real	1.0000
··· 🔲 CalcRelSeries : Real	0.9448
🗖 ReqRelSYS : Real	0.9250
🗔 Subsystem1 : Real	0.9650
🗔 Subsystem2 : Real	0.9990
🛄 🗔 Subsystem3 : Real	0.9800
🗄 🖸 System Reliability : System Reliability {CalcRelSeries = Subsystem1 * Subsys	System Reliability@7f4e46e

The simulation has completed execution and...

INTUITIVE

Green: Both parallel and series calculated values exceed System X required reliability!

路 Variables ×			
	Ö -		
Name	Value		
🗗 🔜 System Reliability Analysis Context	System Reliability Analysis Context@3710880b		
🕀 🖃 System X : System X	System X@25a772f3		
🗄 🖸 : System Reliability {CalcRelSeries = System X.Subsys1.Subsystem 1 Reliabil	System Reliability@400dda23		
🗖 CalcRelParallel : Real	0.9111		
🗖 CalcRelSeries : Real	0.1637		
🗖 ReqRelSYS : Real	0.9250		
- 🗔 Subsystem1 : Real	0.4800		
🗔 Subsystem2 : Real	0.5500		
🛄 🗔 Subsystem3 : Real	0.6200		
🗈 📧 System Reliability : System Reliability {CalcRelSeries = Subsystem1 * Subsys System Reliability@7f4e46e			

We can actually change values directly within the Variables pane

• further 'what-if' analyses, so...

Tweaking the Subsystem reliability values...

Red: Neither calculated value exceeds System X required reliability

INTUITIVE®

External Evaluator Capability

Cameo math functions are fairly robust; however, 'external evaluator' capability exists

- More custom/intense analyses
- Several external evaluator platforms supported
 - Matlab
 - MapleTM
 - Mathematica
 - more
- Custom coding
 - Python
 - Ruby
 - more

Fundamental premise is ability to 'expose' constraint parameters to external evaluator platforms

- Results come back to the model
- Key is still associating analysis parameters to System of Interest Value Properties





INTUITIVE

Reliability Requirement Verification



NTUITIVE

Other Potential Applications

- Other RAM calculations
 - Availability
 - MTBF
 - etc.
- System physical aspects
 - Aircraft weight rollup
 - Aircraft center of gravity
 - etc.
- Risk calculations
- Anything that can be represented as a value, owned by the system, can be used in a Parametric Diagram analysis!





Summary

- MBSE directly supports the Systems Engineering process
- Parametric Diagrams provide a robust analysis capability within the MBSE model environment
- RAM activities can leverage a model's Parametric Diagram capability for an integrated model-centric approach





Wrap Up and Discussion

- Questions?
- Comments?

Contact: Keith Zook
 <u>Keith.Zook@IRTC-HQ.com</u>