34th Annual INCOSE international symposium

hybrid event

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Model-Based Trade Studies to Inform Decision-Making

Introductions

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Deloitte Digital Engineering

Kasey is a Systems Engineer at Deloitte with over 10 years of experience working in the defense industry. She has supported systems engineering and test programs for a variety of systems including Radars, Drones, and IoT. With specialties in Model Based Systems Engineering and Test and Evaluation, she enjoys optimizing tools and processes to make Systems Engineering and Testing more accurate and efficient.

Devon Clark

Deloitte Digital Engineering

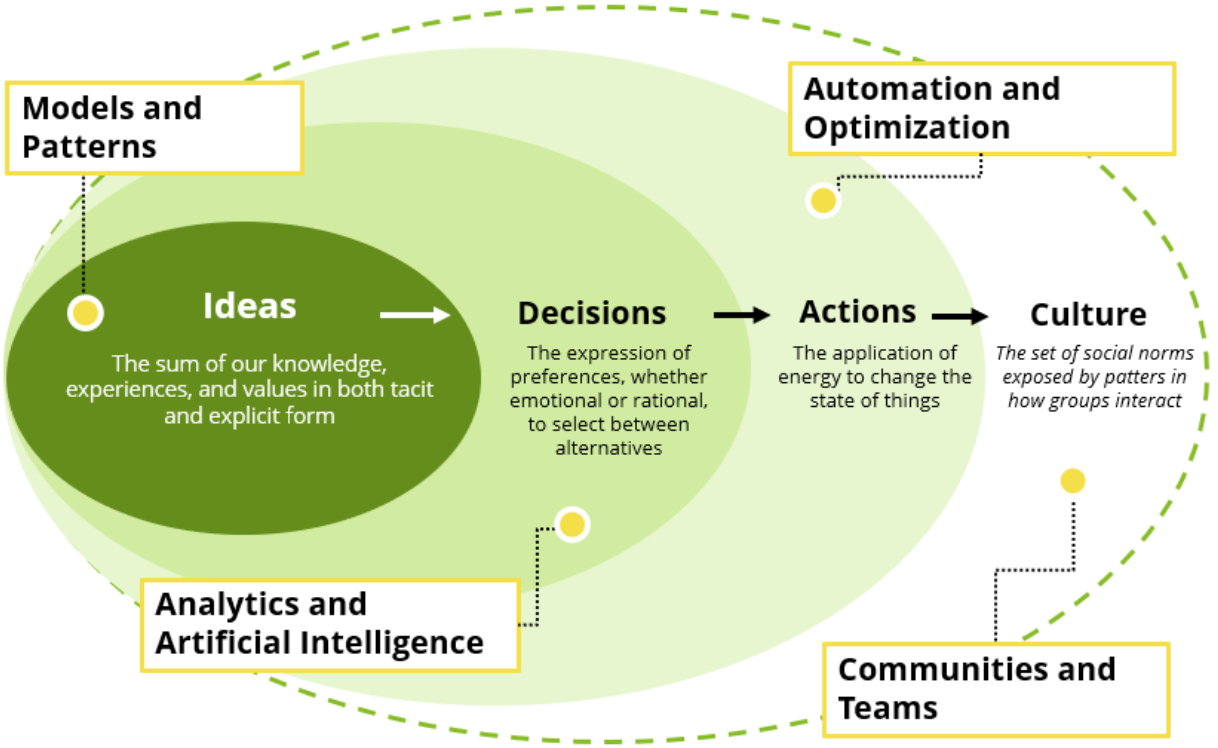
Devon is a Systems Engineer at Deloitte with 20 years of experience in Systems Engineering, Integration, and Test supporting government agencies in (primarily) DS&J sector to solve their System of Systems problems by connecting data. He currently leads our Model-Based Systems Engineering (MBSE) capability for GPS as part of our investment into Digital Engineering and Digital Transformation.

David Hetherington

SSI

David is a Principal at SSI with over thirty years of experience in Software and Systems Engineering in the Automotive, Semiconductor, Oil and Gas, Enterprise IT, Server Computer, Telecom, and Electronic Publishing sectors. David has experience in automotive radar design, software safety for offshore oil rigs, infotainment software design, and ISO 26262 functional safety for automotive “System on Chip” products. David is the author of the Simple SysML for Beginners book series and received a BA in Mathematics from the University of California San Diego and an MBA from the University of Texas McCombs School of Business.

Why it Matters



Decisions Transform Ideas into Actions

SYSTEMS ENGINEERING

VISION 2035

ENGINEERING SOLUTIONS FOR A BETTER WORLD

*"**Knowledge** engineering, **information** representation, **model curation**, and **data** analytics will **underpin the way decisions are made** and collaborative work is accomplished."*

*"**Highly connected data** with integrated AI/ML-based data segmentation, object labelling, and temporal scenario – ontology mapping supports automated digital twin creation, model correlation, verification and validation and **seamless systems engineering trade studies**."*

INCOSE Vision35

Background

IS23 Presentation: On Model Re-Use: Best Practices for the Application and Configuration of Model-Based Patterns

- IS23 presentation on Model-Based Patterns used the Trade Study Pattern as an example
  - Focused on how to build a pattern, best practices, and lessons learned from applying patterns
  - There was interest in learning more about how the trade study pattern works
- This presentation will deep-dive on the trade study pattern model. We will explore:
  - "Under the hood" and how the model works
  - How we interpreted the results and conducted sensitivity analysis

Background & Approach

Deloitte developed a model-based trade study for a DoD client to help them make some important decisions about the future of their enterprise architecture.

PROJECT BACKGROUND

Supporting the Commander, Navy Installations Command (CNIC) Public Safety Systems (PSS) Program

- Program is responsible for the Navy's Public Safety Systems Enterprise Architecture including systems such as alarm systems, gates, emergency dispatch, etc.
- Team had existing SysML models of the enterprise architecture

Leadership needed to make a decision on what to do about aging computing hardware that was reaching end of life

- Replace hardware in existing architecture?
- Develop entirely new architecture (e.g., cloud based)?
- Shut down some systems to prolong life of current hardware?

APPROACH

Develop a reusable model-based analysis of alternatives

- Make a model-based trade study pattern that can score alternatives based on a set of stakeholder criteria
- Use this to make a decision about the current question, but also to help answer future questions about the architecture

Gather stakeholder input throughout the entire trade study process

- The team gathered stakeholder inputs throughout the entire trade study process, from the development of criteria, to the development of alternative options and the scoring of those options
- Validated trade study methodology with key stakeholders to get their buy-in

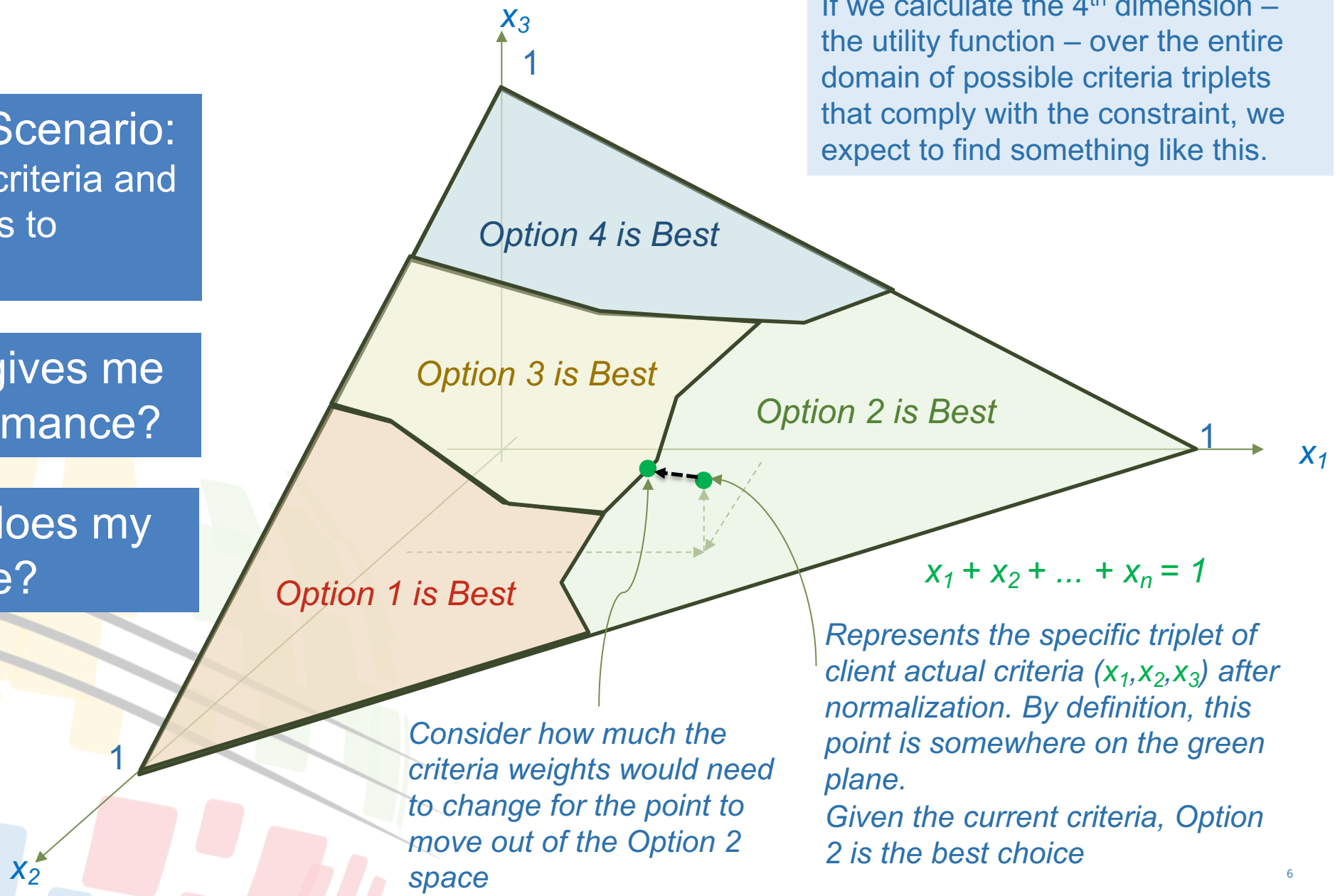
The Decision Space

Consider this Scenario:
- I care about 3 criteria and I have 4 options to choose from

Which option gives me the best performance?

At what point does my answer change?

If we calculate the 4th dimension – the utility function – over the entire domain of possible criteria triplets that comply with the constraint, we expect to find something like this.



$x_1 + x_2 + \ldots + x_n = 1$

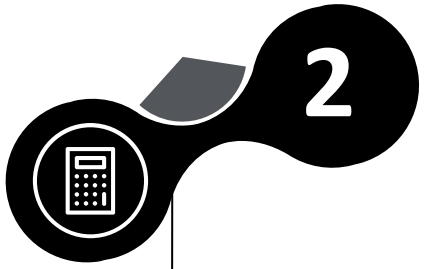
Represents the specific triplet of client actual criteria (x_1,x_2,x_3) after normalization. By definition, this point is somewhere on the green plane.
Given the current criteria, Option 2 is the best choice

Consider how much the criteria weights would need to change for the point to move out of the Option 2 space

Trade Study Methodology Overview

These steps summarize the methodology for the trade study:

Determine **what the stakeholders care about** and **how to measure** it

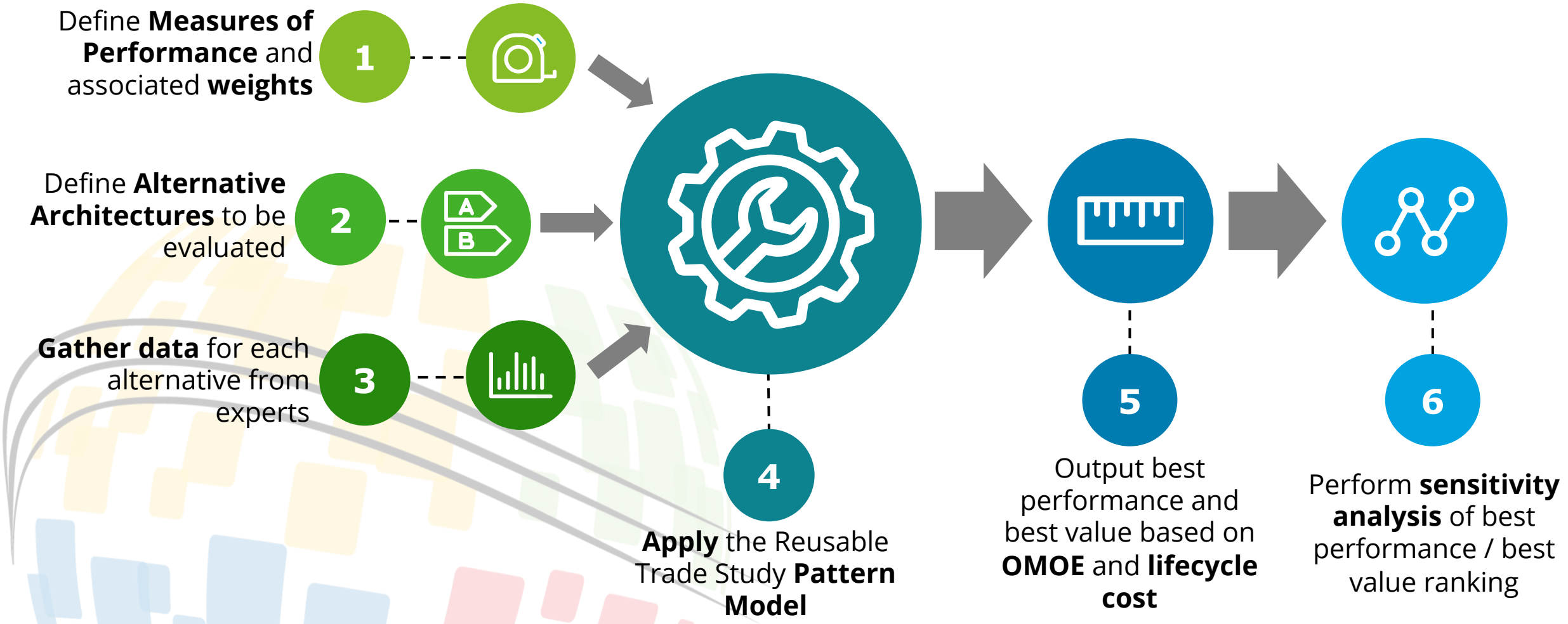


Generate a **single Overall Measure of Effectiveness** (OMOE) for each alternative

Perform **Cost As Independent Variable** (CAIV) analysis to identify the alternatives that provide the **most benefit for the cost**

Trade Study Process Overview

We will apply the Trade Study Pattern Model to assess multiple criteria to get 1 Overall Measure of Effectiveness (OMOE) for each alternative. To analyze the results, we will look at performance vs. cost and perform sensitivity analysis.

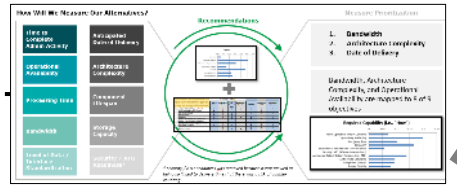


Trade Study Process Application

This presentation will focus on **how the trade study pattern model works** and **how to analyze the trade study results**.

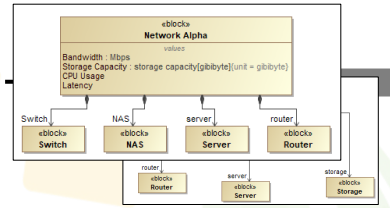
Survey Stakeholders to Define **Measures of Performance** and associated **weights**

1



Gather/build models for **Alternative Architectures** to be evaluated*

2

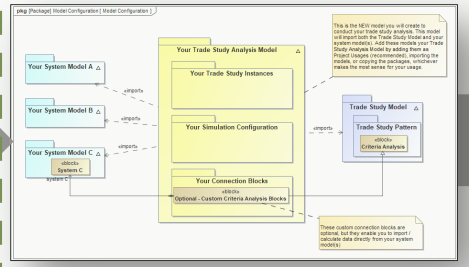


Gather data for each alternative from experts*

3

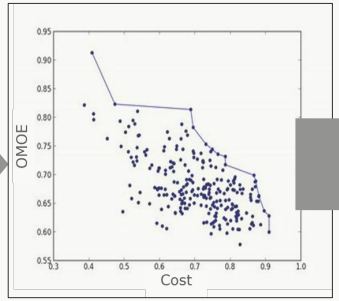
Name	Normalized_Score : Real	Weighted_Score : Real
Network Alpha - Bandwidth Analysis	0.5	0.15
Network Alpha - Data/Interface Standardization Analysis	1	0.2
Network Alpha - Op Availability Analysis	0.5	0.25
Network Bravo - Bandwidth Analysis	0.6667	0.2
Network Bravo - Data/Interface Standardization Analysis	0.6	0.12
Network Bravo - Op Availability Analysis	0.75	0.375
Network Charlie - Bandwidth Analysis	0.3333	0.1
Network Charlie - Data/Interface Standardization Analysis	0.2	0.04
Network Charlie - Op Availability Analysis	1	0.5

Focus for this Presentation



4

Apply the Reusable Trade Study **Pattern Model**



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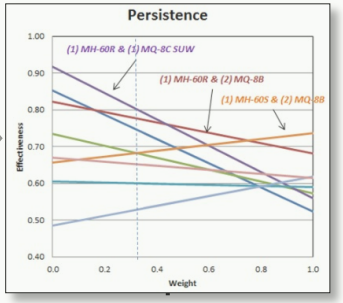
Output best performance and best value based on **OMOE** and **lifecycle cost**



6

Perform **sensitivity analysis** of best performance / best value ranking

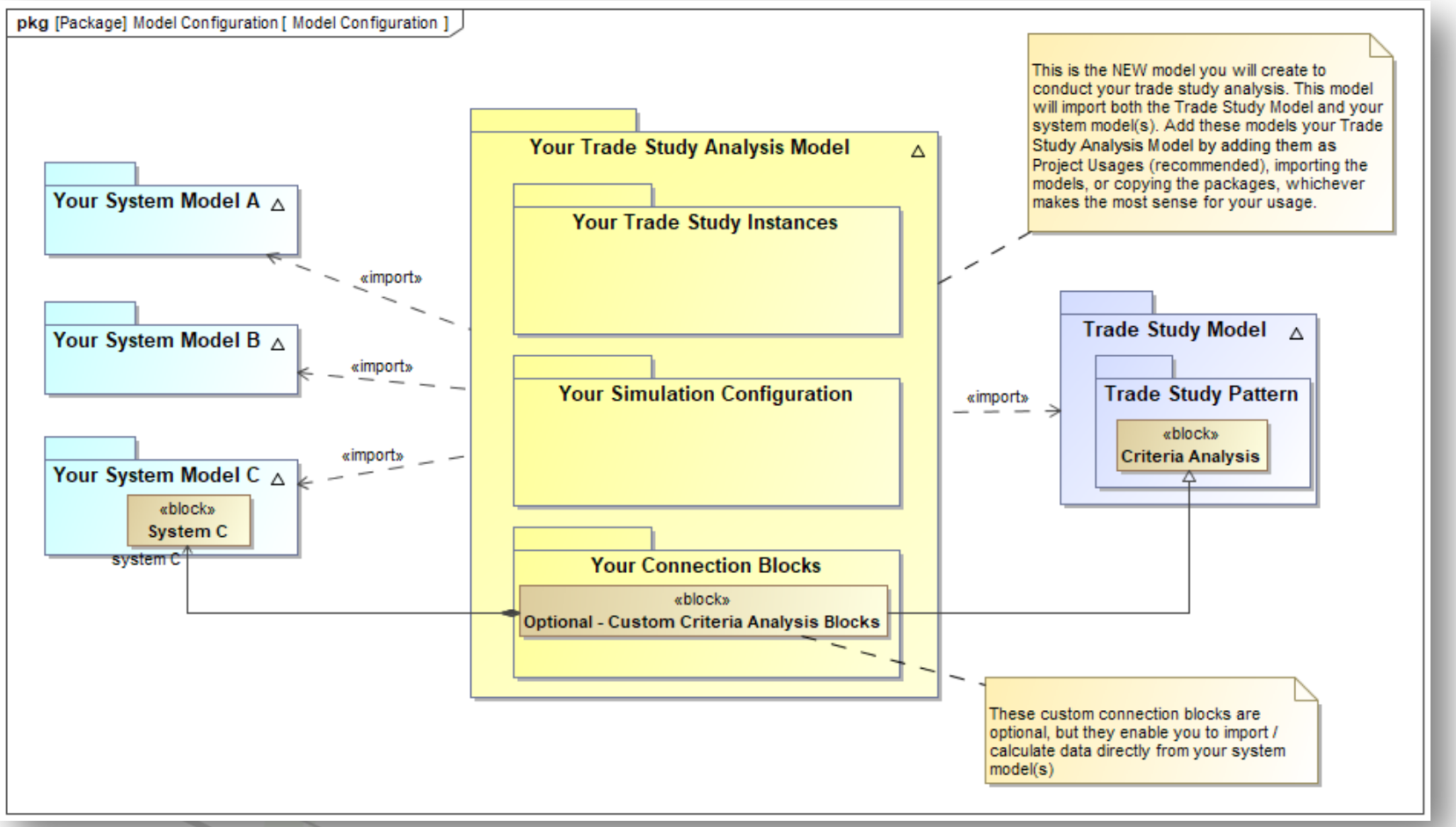
*Model will validate inputs for consistency

Trade Study Model Configuration

The Trade Study Analysis Model applies the Reusable Pattern Model to analyze the System Model. With this model configuration, neither the System Models nor the Trade Study Pattern Model will need to be modified to execute the analysis.

3 Models are used to conduct the Trade Study Analysis

- The **Trade Study Pattern Model** defines the reusable pattern model for analysis
- The **System Model(s)** define the architecture(s) to be analyzed
- The **Trade Study Analysis Model** uses the Trade Study Model as a pattern to analyze the System Model(s). **Instances** form the basis for the analysis.



Trade Study Pattern Structure

A structure of interconnected instances forms the basis for doing the trade study calculations

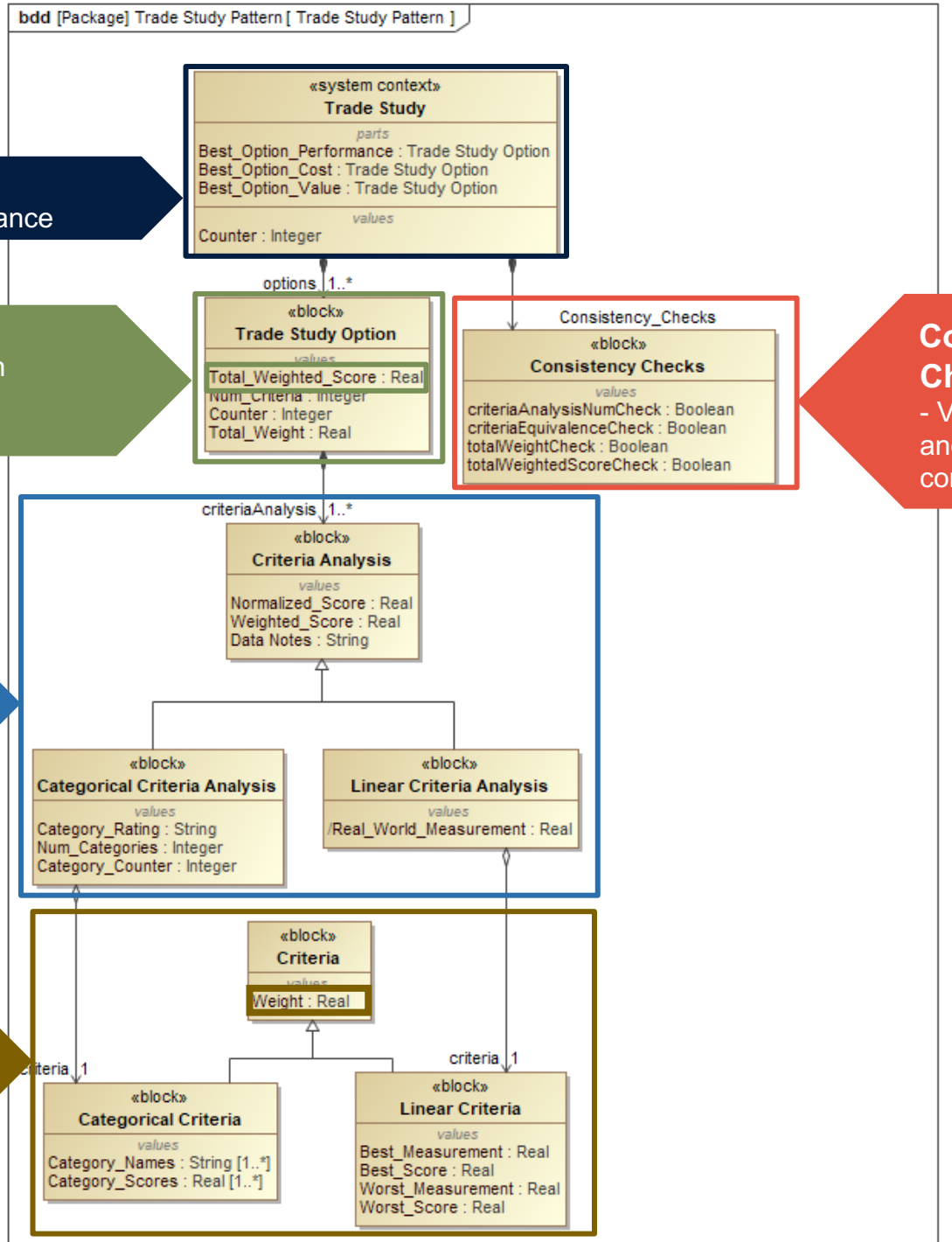
Trade Study Instance
- Rolls up all options into one top-level instance

Trade Study Option Instances
- Calculates total weighted score for each alternative (all criteria added together)
- Total Weighted Score = OMOE

Criteria Analysis Instances
- Calculates an individual alternative's normalized & weighted score for one criteria
- Can be linear or categorical

Criteria Instances
- Stores data for how to score the criteria
- Stores criteria weighted based on stakeholder input
- Can be linear or categorical
- Common across all alternatives

Consistency Checks
- Validate inputs and check for common errors



Calculating Scores in the Model: Version 1

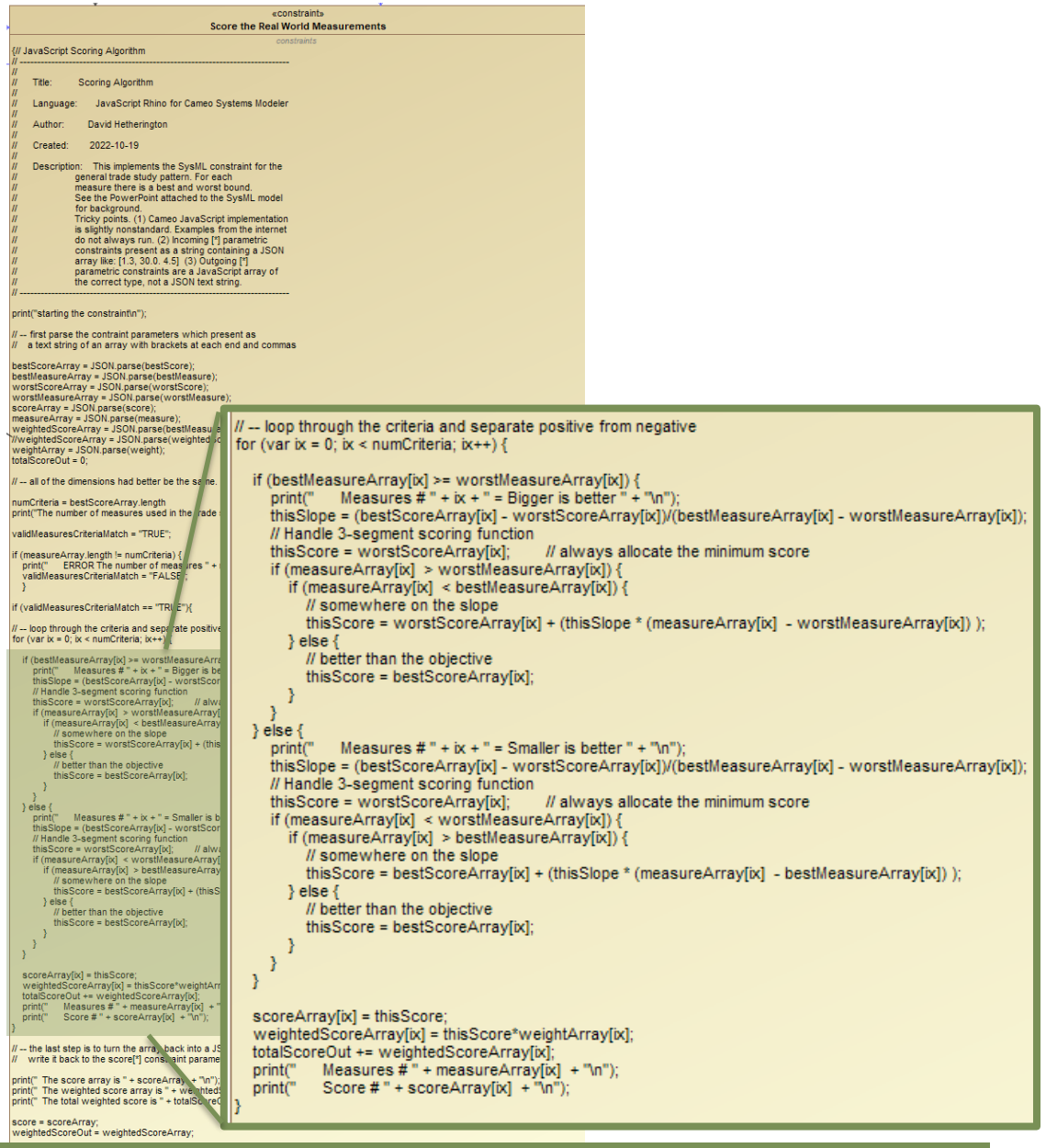
- First version of the model used **JavaScript code** inside one large **constraint block** to calculate the weighted scores

Pros:

- Faster to code for developers
- Easy for developers to understand

Cons:

- Difficult for non-developers to understand the process
- Hard to debug in Cameo
- Challenging to maintain code



While this method did objectively work, the difficulty of maintenance and debugging led us to try another approach for the calculations…

Calculating Scores in the Model: Version 2

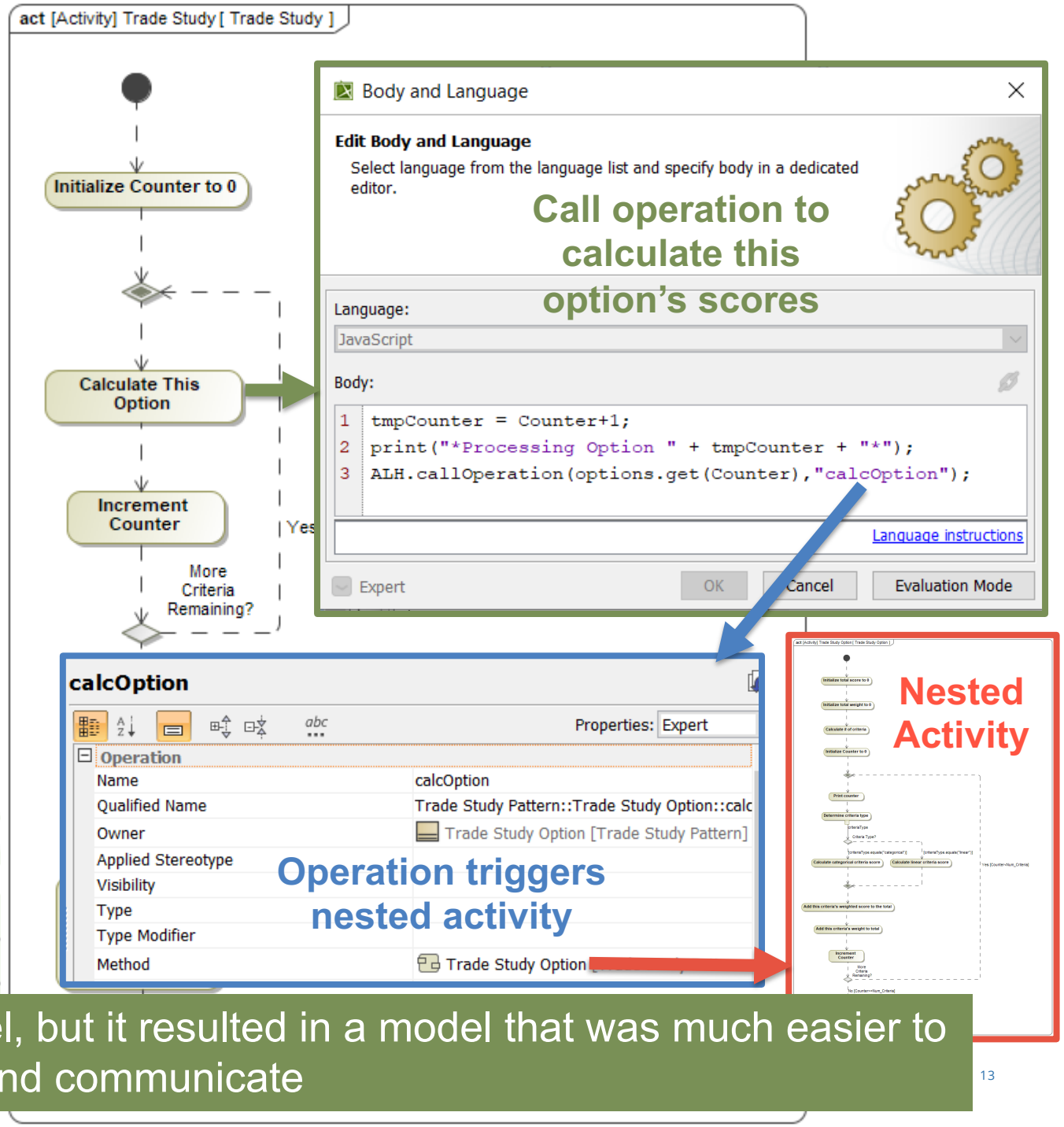
- Second version of the model used a series of **nested activity diagrams** with **JavaScript-based Opaque Actions** to calculate the scores

Pros:

- Easier for non-developers to understand
- Visualize loops and if statements
- Easier to debug at the step-level

Cons:

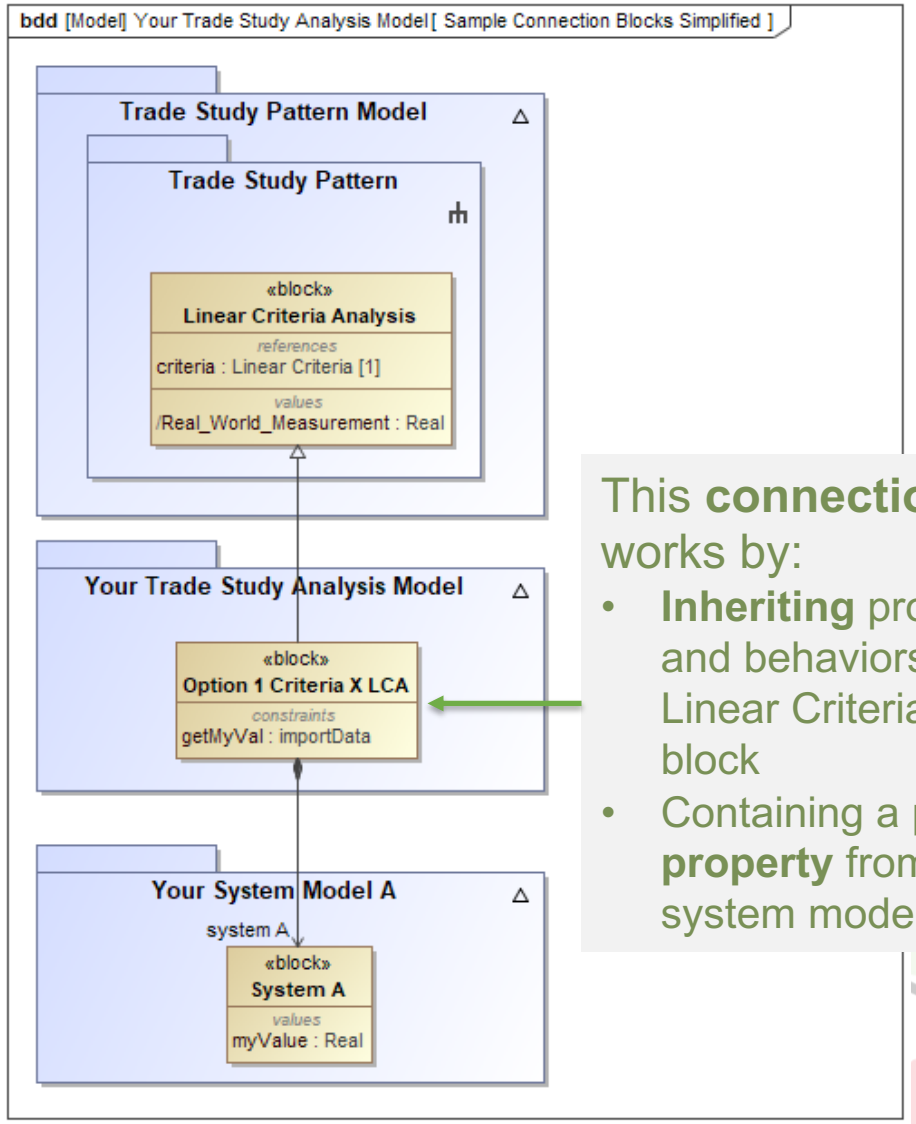
- More difficult to code and build the model



This approach took longer to build the model, but it resulted in a model that was much easier to explain and communicate

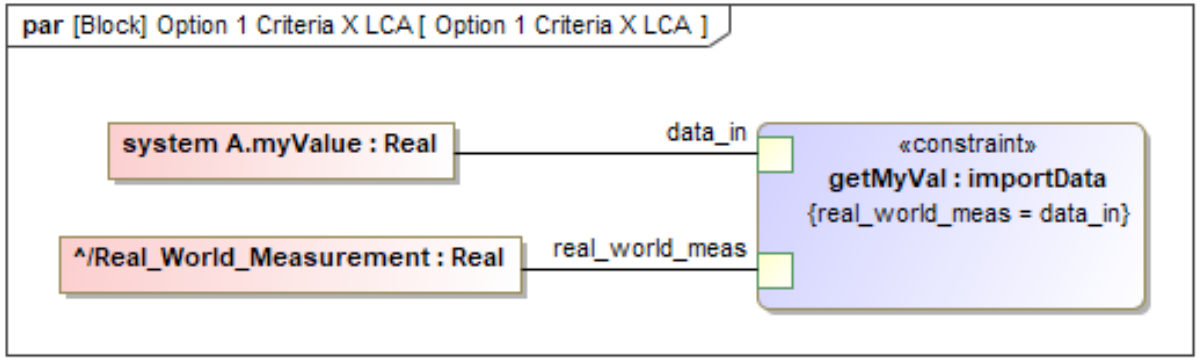
Connecting Models with Parametrics to Input Data

We developed "Connection Blocks" to input data from the system model into the trade study analysis model without modifying the original system model or trade study pattern model



This **connection block** works by:

- **Inheriting** properties and behaviors from the Linear Criteria Analysis block
- Containing a **part property** from the system model



This parametric diagram takes the **"myValue" value property** from the System A model and **plugs it into** the **"Real_World_Measurement"** value property in the Trade Study Analysis Model

Example Implementation – Network Model Trade Study (1 of 2)

The team implemented a network trade study analysis* as a testing tool. Three criteria were generated for testing and sample data was input into the trade study analysis model. One sample parametric diagram shows an example of model analysis to generate trade study data.

Three Criteria define how to evaluate the alternatives

Categorical Criteria

Name	Weight : Real	Category_Names : String	Category_Scores : Real
Level of Data / Interface Standardization	0.2	High	1
		Medium	0.6
		Low	0.2

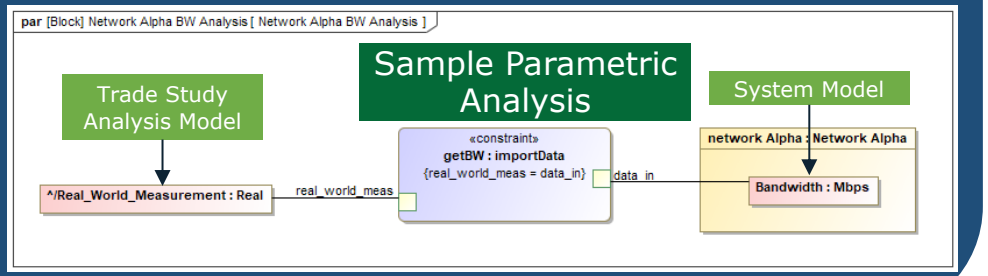
Linear Criteria

#	Name	Best_Measurement : Real	Best_Score : Real	Worst_Measurement : Real	Worst_Score : Real	Weight : Real
1	Bandwidth	2000	1	500	0	0.3
2	Operational Availability	0.999	1	0.995	0	0.5

Input Data into the trade study analysis model using either **model analysis** (parametrics or activities) or manual fill-in

Name	Classifier	Real_World_Measurement : Real	Data Notes : String
Network Alpha - Op Availability Analysis	Linear Criteria Analysis	0.997	Analysis by Bob Smith
Network Bravo - Op Availability Analysis	Linear Criteria Analysis	0.998	Calculated from Network Alpha Model
Network Charlie - Op Availability Analysis	Linear Criteria Analysis	0.9999	Data from spec sheet dated 20221030
Network Alpha - Bandwidth Analysis	Network Alpha BW Analysis	1250	Imported from Network Alpha Model
Network Bravo - Bandwidth Analysis	Linear Criteria Analysis	1500	Data from spec sheet dated 20220901
Network Charlie - Bandwith Analysis	Linear Criteria Analysis	1000	Data from spec sheet dated 20221030

Name	Category_Rating : String	Data Notes : String
Network Alpha - Data/Interface Standardization Analysis	High	Analysis by Bob Smith
Network Bravo - Data/Interface Standardization Analysis	Medium	Analysis by Karen Johnson
Network Charlie - Data/Interface Standardization Analysis	Low	Analysis via survey conducred 20221030

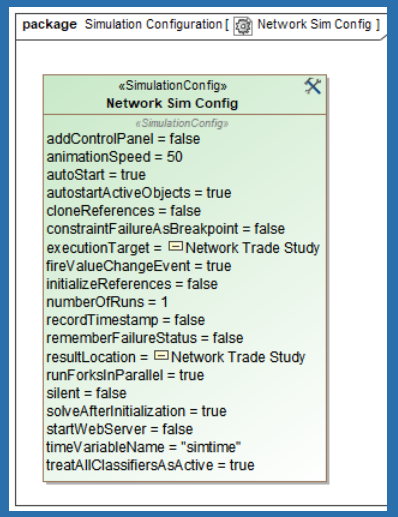


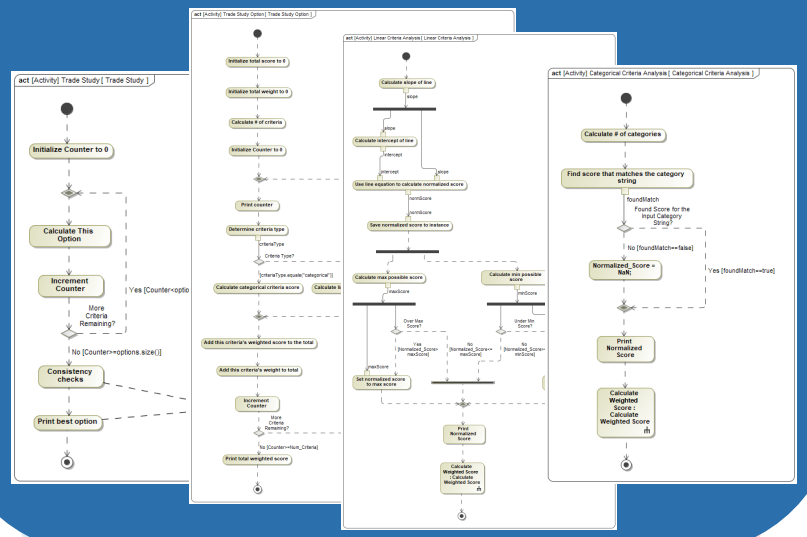
*This is a sample analysis based on synthetic data

Example Implementation – Network Model Trade Study (2 of 2)

The simulation will calculate the individual scores for each criteria/alternative, which are then tallied into a total weighted score for each alternative representing the overall measure of effectiveness (OMOE)

Simulation Configuration triggers a cascading sequence of **activities** that calculate the trade study scores





Individual Scores calculated for each criteria / alternative pairing

- **Normalized Score** – score between 0 and 1 calculated based on guidelines set in the criteria
- **Weighted Score –** normalized score multiplied by the criteria weight

Name	Normalized_Score : Real	Weighted_Score : Real
Network Alpha - Bandwidth Analysis	0.5	0.15
Network Alpha - Data/Interface Standardization Analysis	1	0.2
Network Alpha - Op Availability Analysis	0.5	0.25
Network Bravo - Bandwidth Analysis	0.6667	0.2
Network Bravo - Data/Interface Standardization Analysis	0.6	0.12
Network Bravo - Op Availability Analysis	0.75	0.375
Network Charlie - Bandwith Analysis	0.3333	0.1
Network Charlie - Data/Interface Standardization Analysis	0.2	0.04
Network Charlie - Op Availability Analysis	1	0.5

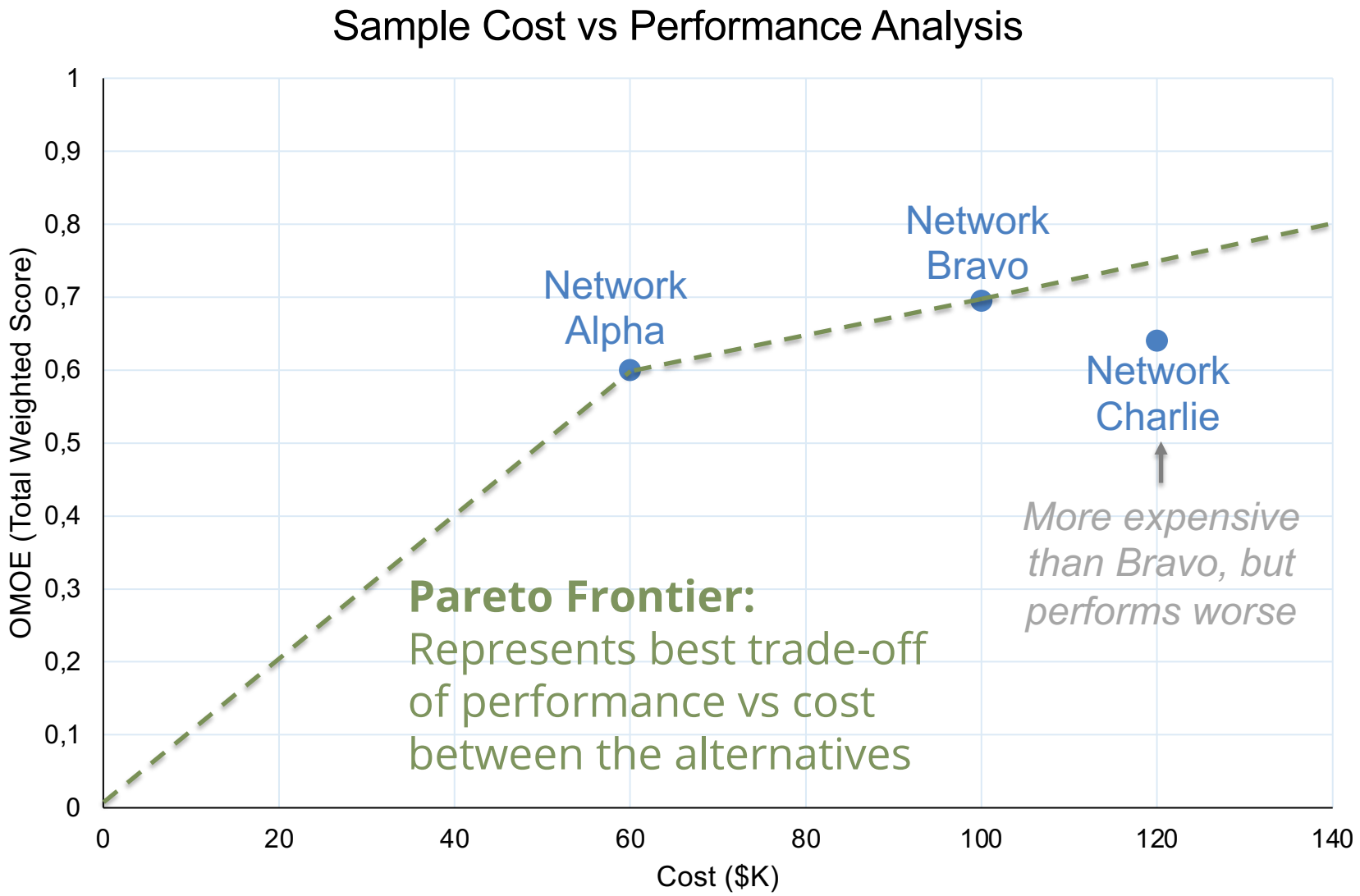
Final Scores – Total Weighted Score indicates best alternative (OMOE)

Name	options : Trade Study Option	options.Total_Weighted_Score : Real
Network Trade Study	Network Alpha : Trade Study Option	0.6
	Network Bravo : Trade Study Option	0.695
	Network Charlie : Trade Study Option	0.64

*This is a sample analysis based on synthetic data

Cost vs. Performance Analysis

Next, we input the data from the trade study model into Excel to generate a graph of cost vs. performance



- Network Alpha is the cheapest option
- Network Bravo is the highest scoring option
- Network Charlie is below the Pareto frontier, and therefore should not be considered

*This is a sample analysis based on synthetic data

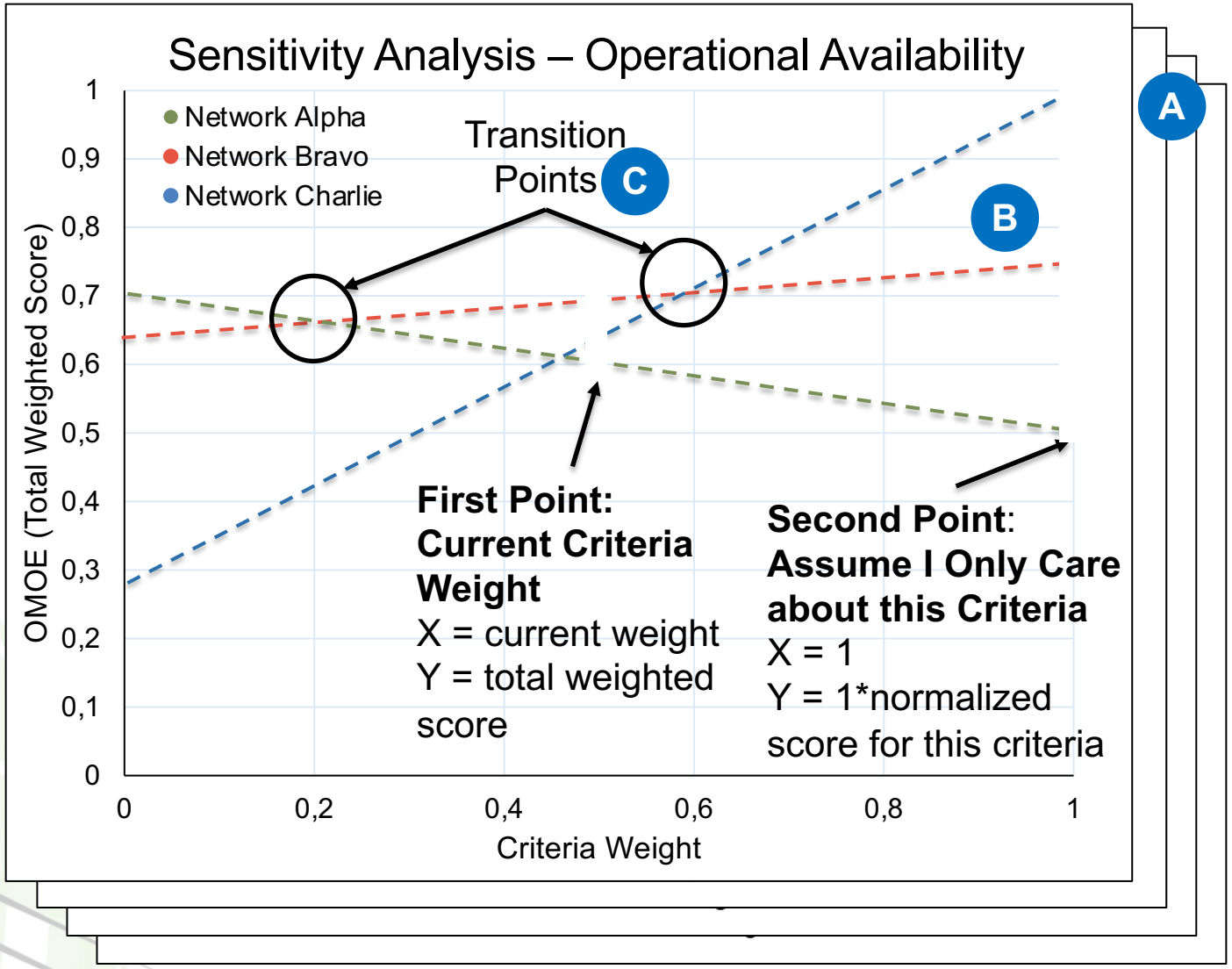
Linear Sensitivity Analysis

Assertion: If we care more about one feature, the amount we care about the other features must go down proportionally.

A **Individual Measure Analyses:** analyze 1 criteria at a time

B **Draw a Line for Each Alternative**: Each evaluated alternative receives its own line that identifies how the OMOE increases or decreases as we care more or less about the individual measure

C **Analyze Transition Points:** Given that each line will have a different slope, there are points where your top line will change. These "transition points" are what we're looking for.



Transition points indicate how much stakeholder priorities have to change to result in a different ranking of alternatives

*This is a sample analysis based on synthetic data

Benefits and Impact

Repeatable

- Generic pattern can be applied to **any type of analysis of alternatives** with **any criteria of interest**
- **How-To Guide** included with **Trade Study Pattern model** to help new users
- Team is **ready to generate future trade studies** as-needed

Dynamic and Flexible

- Dynamic model-based trade studies can be **updated as alternative architecture definitions change**
- Once the trade study analysis model is configured, **updating the trade study requires only a couple button clicks to re-run the simulation** if the linked architecture model(s) have changed

Data-Driven

- **Modeling** the trade study adds **engineering rigor** to the decision-making process
- **Stakeholder priorities** and **system performance** are documented in the model, formally capturing data inputs and trade study results

Model-Based Trade Studies enable dynamic evaluation of multiple alternative system models to inform decision-makers

Thank You

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