International Council on Systems Engineering
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A Framework for Structuring Research Campaigns Leveraging Model Based Systems Engineering

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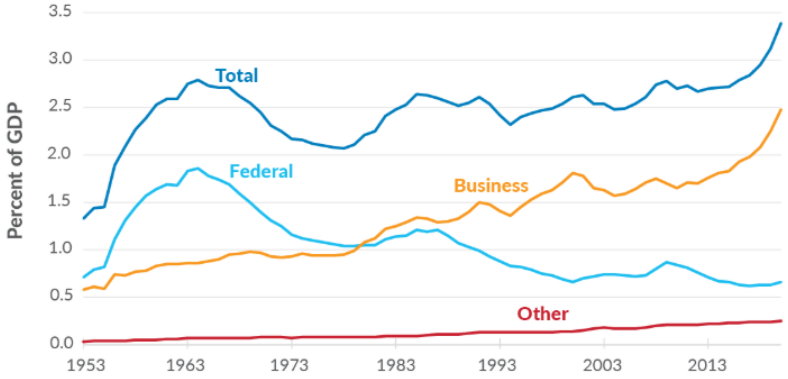
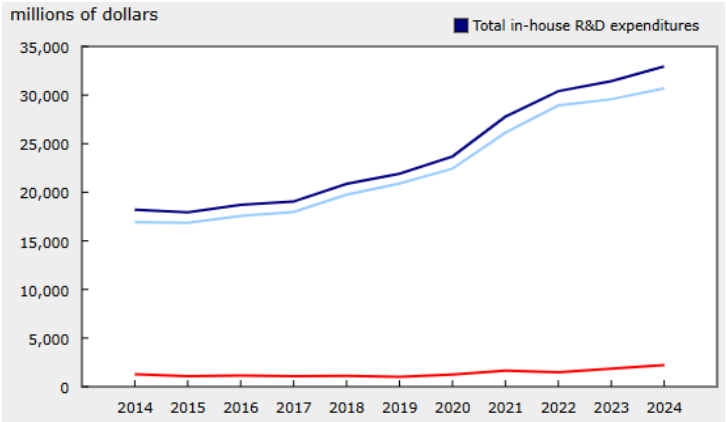
Introduction

- Expenditure in R&D is steadily increasing (and has been doing so for a while), especially within industry



Source: https://taxfoundation.org/blog/business-r-d-investment-trends/



Source: https://www150.statcan.gc.ca/n1/daily-quotidien/240905/dq240905a-eng.htm

- R&D is an investment, investments need to provide a return, the generation of innovative, or ambitions, systems or services (and their intellectual property)

Applying Structured approaches to R&D

- Organisations that apply structured approaches to their research are better placed to achieve success (Brennan et al., 2020), key challenges include:
  - Accelerated innovation cycles
  - R&D projects have few accountability metrics

- There is utility in applying Systems Engineering, and more specifically MBSE, to support early-stage R&D (Cook, 2024)
  - SE approaches can be used to provide structure to the **execution and planning** of R&D activities

The Framework

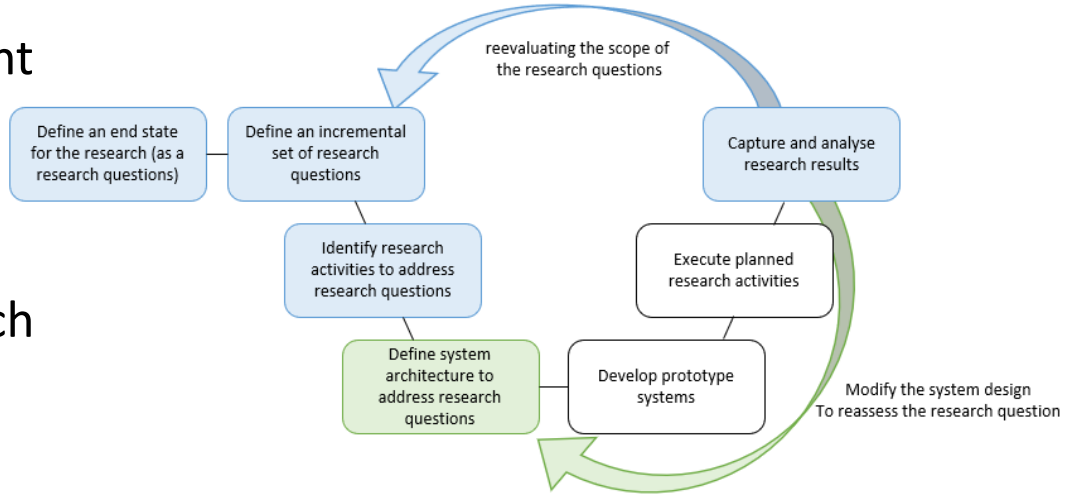
- A structured approach for the definition and execution of a campaign of research (R&D) aimed at addressing an ambitious system design end state

- The framework uses a novel MBSE approach to capture information about both the research campaign and the prototype system(s) developed within this campaign (the system model)
  - This was implemented in CATIA Magic (using a custom profile extension)

- To show the use of this framework a detailed example is presented

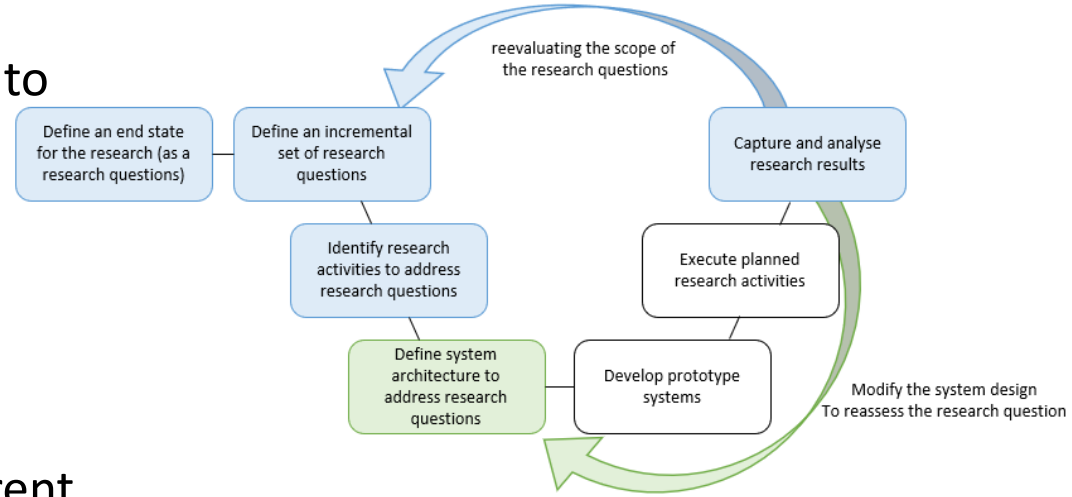
Methodology

- An iterative/evolutionary process
  - Define the desired end state (as best as possible)
    - High level, guiding statement
  - Identify incremental research questions
  - Identify research activities
    - How will we answer research questions
  - Define and develop prototype systems
    - Do R&D!!!



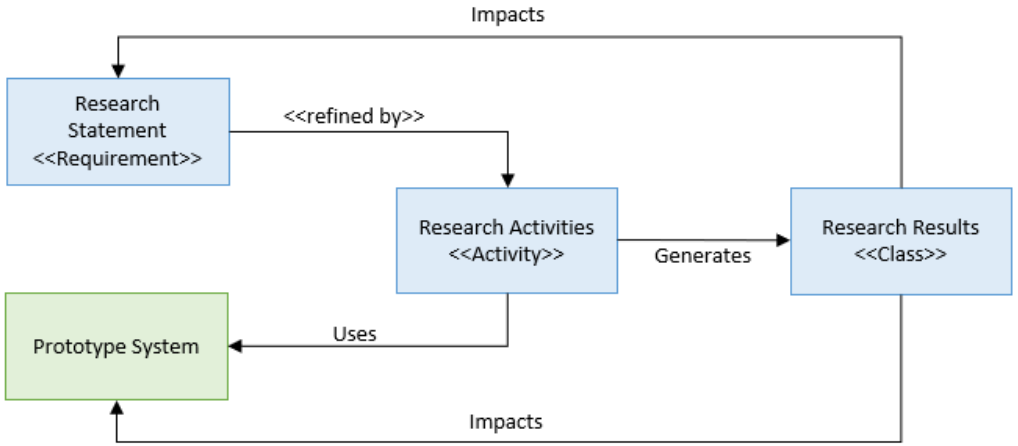
Methodology

- Iterate and evolve the research based on results
- Continue prototype development to better answer the questions
  - We're on the right track, but not quite there
- Redefine the question
  - We want to take this in a different direction



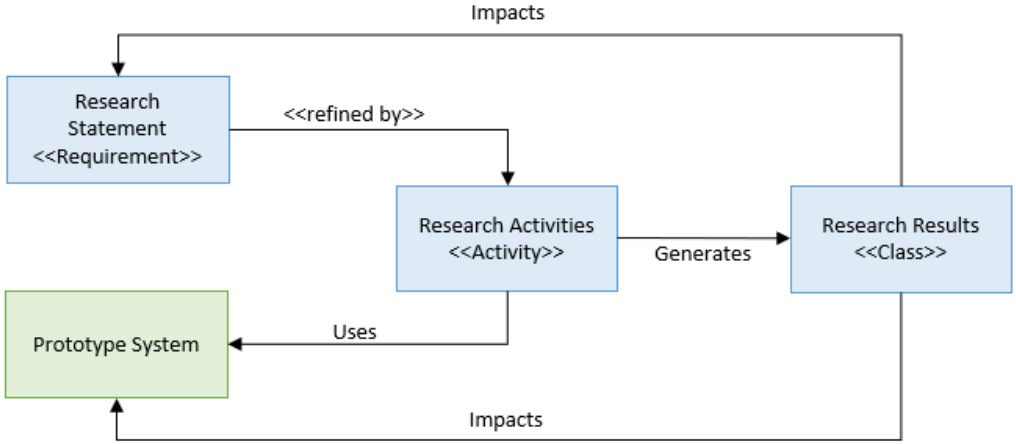
Metamodel

- Research Statement
  - Phrased as a question
  - Represents the high-level end-state and the incremental research questions
  - (generally) Arranged hierarchically



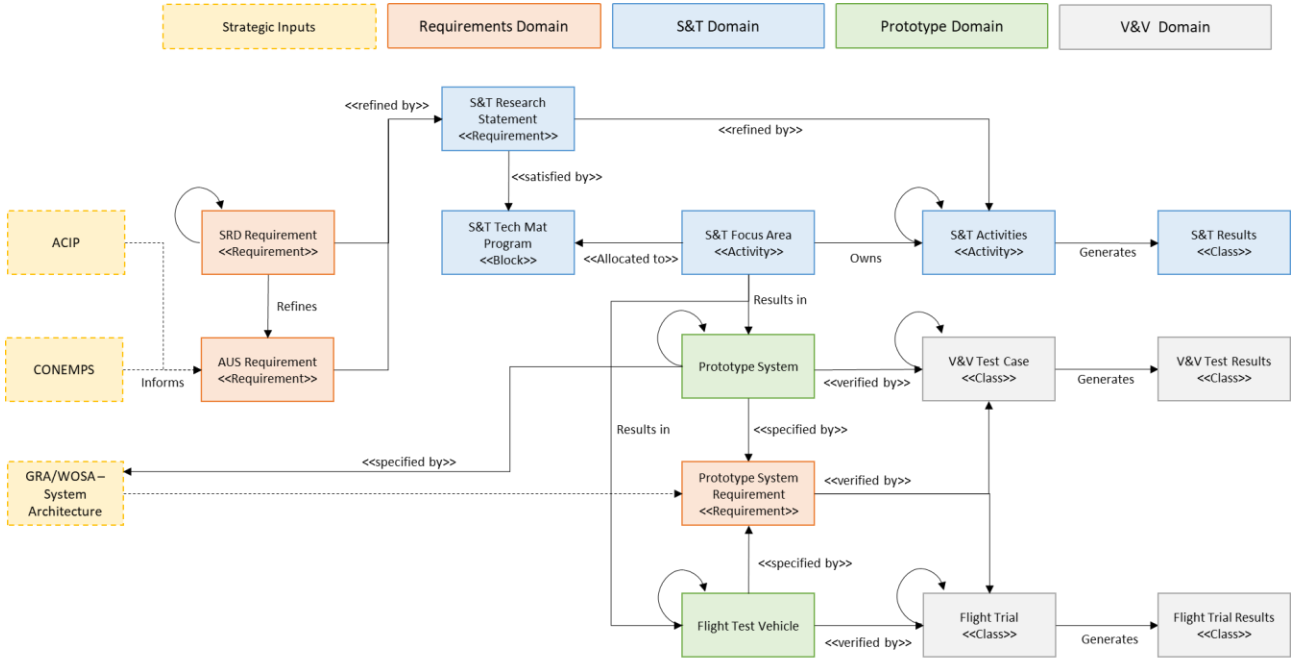
Metamodel

- Research Activity
  - Each activity includes a hypothesis, a description of the task, the equipment required, and the test steps to be executed
- Research Results
  - Captured summary of the completed research activity



A wider metamodel

- Worth noting, but not for this presentation, the framework presented fits within a larger, ongoing, set of activities



Aerial Refuelling Case Study

- Let's explore the framework through an example, an autonomous mid-air refuelling system using a thermal hyperspectral sensor
- Specifically:
  - A receiver aircraft, equipped with a thermal hyperspectral sensor, that can reliably detect, classify, and align with a tanker's refuelling boom in real-time under all environmental conditions

Source: https://en.wikipedia.org/wiki/Boeing_KC-135_Stratotanker

Developing End state and Research Questions

- Start with the end in mind, define the **ambitious** end state for the problem (be system focused, it is OK to be ‘in the weeds’)

> *“Can the thermal hyperspectral sensor system calculate and provide control inputs to the aircraft control system with low enough latency to guide the aircraft towards a moving refuelling boom?”*

- Research questions are then developed progressively, starting from the end state and decreasing in complexity **until an achievable initial research question is identified**
- Use workshops, Subject Matter Experts (SMEs), Technology Readiness Levels (TRLs), risks or any other structured approach

Example: Research Questions

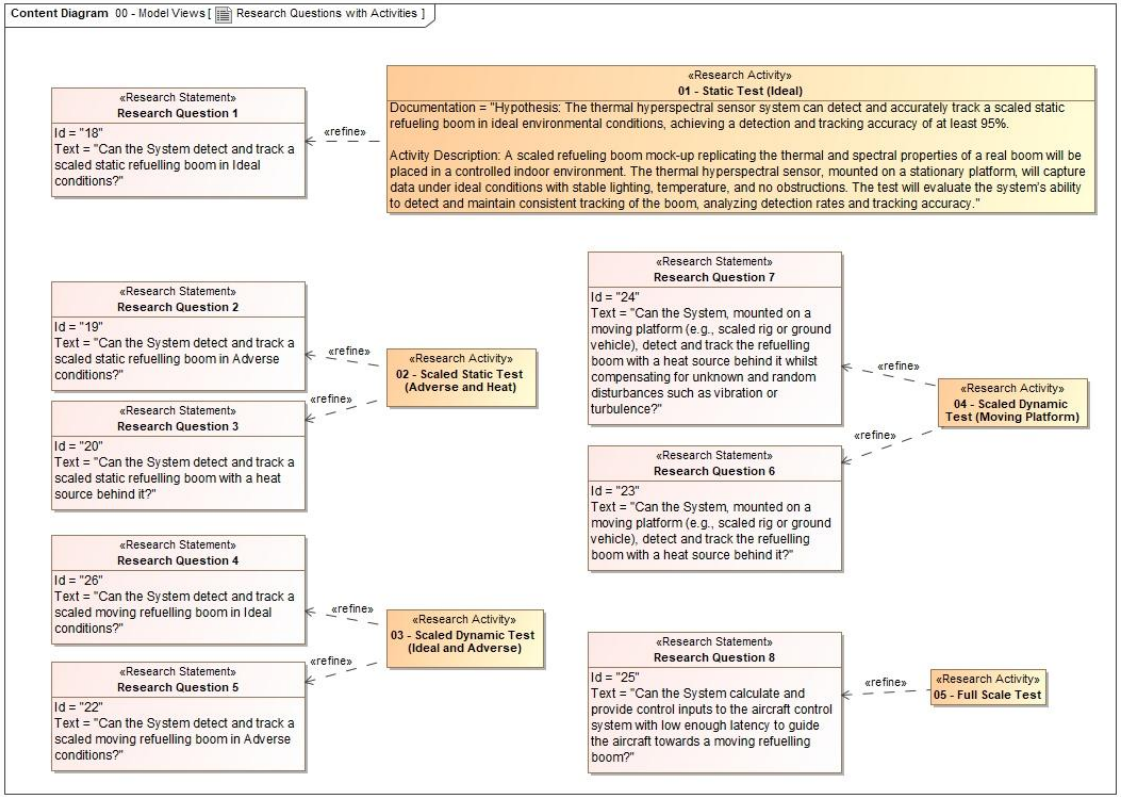
#	Name	Text
1	Research Question 1	Can the System detect and track a scaled static refuelling boom in Ideal conditions?
2	Research Question 2	Can the System detect and track a scaled static refuelling boom in Adverse conditions?
3	Research Question 3	Can the System detect and track a scaled static refuelling boom with a heat source behind it?
4	Research Question 4	Can the System detect and track a scaled moving refuelling boom in Ideal conditions?
5	Research Question 5	Can the System detect and track a scaled moving refuelling boom in Adverse conditions?
6	Research Question 6	Can the System, mounted on a moving platform (e.g., scaled rig or ground vehicle), detect and track the refuelling boom with a heat source behind it?
7	Research Question 7	Can the System, mounted on a moving platform (e.g., scaled rig or ground vehicle), detect and track the refuelling boom with a heat source behind it whilst compensating for unknown and random disturbances such as vibration or turbulence?
8	Research Question 8	Can the System calculate and provide control inputs to the aircraft control system with low enough latency to guide the aircraft towards a moving refuelling boom?
9	Research Question 99	Does a stabalisation platform on the System in motion improve performance?

Identifying Research Activities

- With a set of research questions that are defined, acceptable, and ‘sequenced’ we can define research activities
- Research Activities investigate one or more research questions, they are the used to test hypotheses, collect tangible data, and answer the research questions

- Aim to begin with simple and achievable activities that are still sufficiently complex to yield meaningful results (it is a balance)
  - Too ambitious and the research activity can suffer from schedule/budget issues, or just fail to deliver any results
  - Too simple and the knowledge gained does not advance the R&D

Example: Research Activities

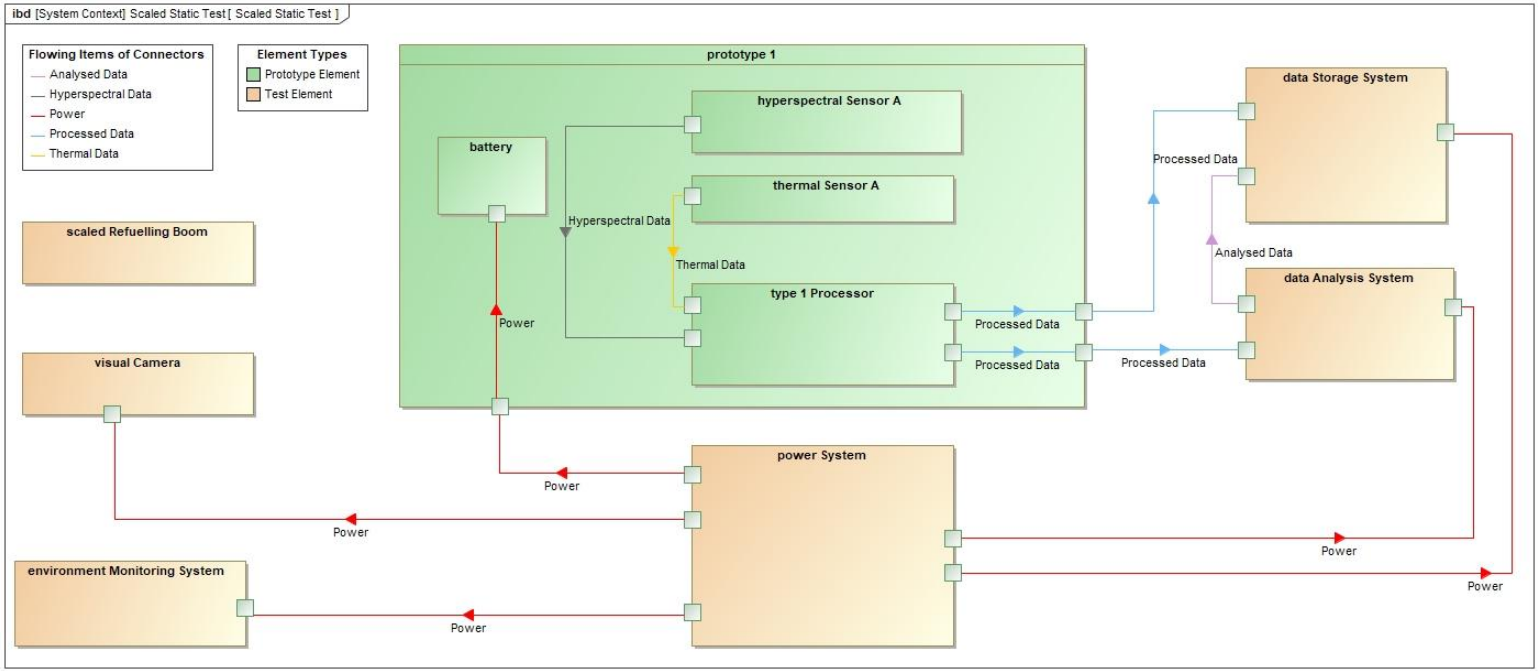


Defining System Architecture

- Defining the system architecture of the prototype system returns to ‘Classis Systems Engineering’
  - Understanding the context in which the system will exist which will be the **test configuration** not a deployed system in operations
  - Break the system down into subsystems to a level of definition required by the task
  - Define interfaces (as much as is needed)
  - (maybe) Identify behaviour

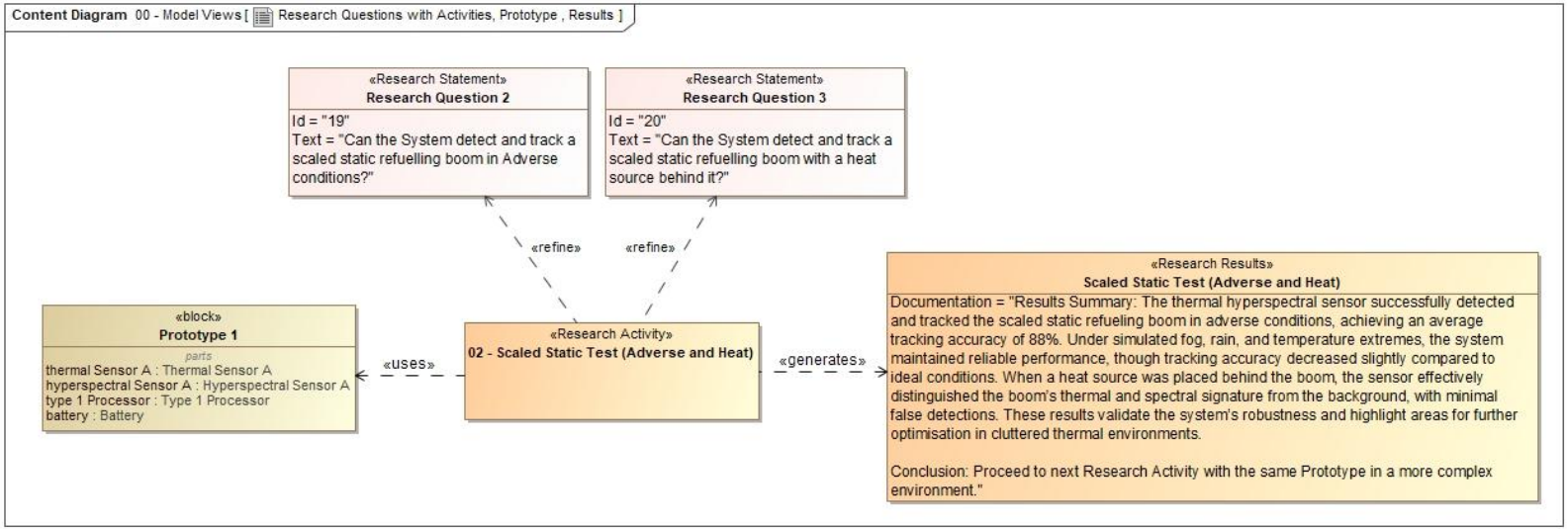
- How much architecture and design should be captured for each iteration?

Example: System Architecture



Capturing Research Results

- Summary of results captured within the model, linked to detailed data (external to the system model)
- Example:

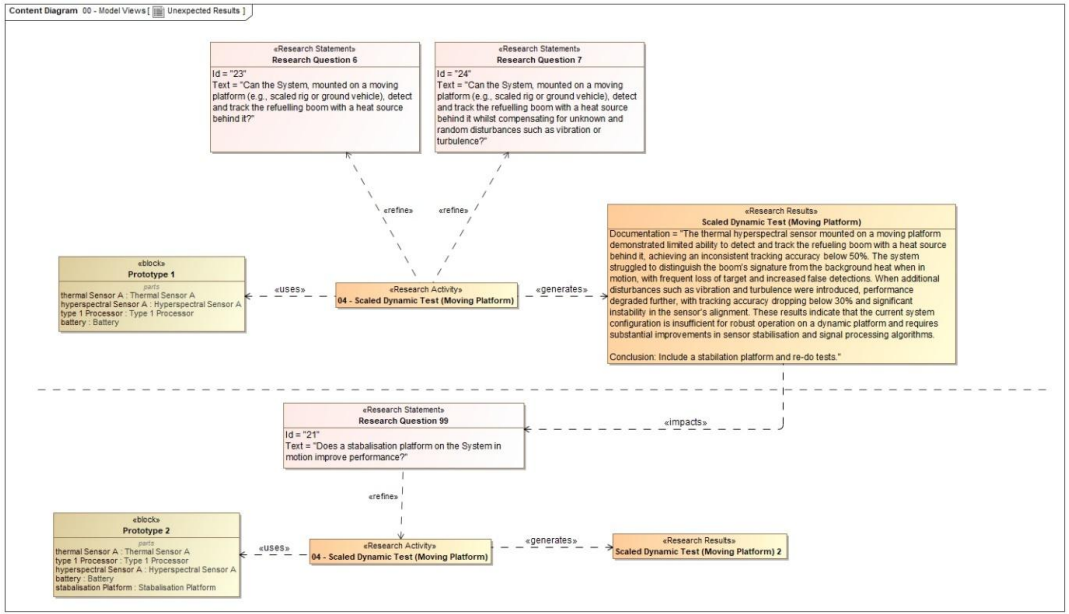


Understand results/update knowledge

- The results serve as the foundation for determining the next steps in the research campaign
- If the hypotheses is proven correct then the R&D progresses to the next defined research activity
  - Some level of re-assessment/validation of the next activity should be done
  - The lessons learnt and knowledge gained through experimentation should impact future development
- This sequential approach builds confidence in the prototype system's capabilities as it progresses toward the end goal
  - It also provides technology offramps
- Results may not always go to plan…

Handling Unexpected Results

- Further analysis **and decision-making** are required
  - Reevaluating the research question's feasibility.
  - Identifying potential flaws in the experimental design or measurement techniques.
  - Considering necessary design changes to the prototype system



Key takeaways/Recommendations

- Adopt MBSE for Traceability: Employing MBSE ensures that research questions, activities, results, and system architectures are integrated within a unified model to enables better decision-making
- Develop Well-Defined Research Questions: Establishing clear, logical research questions that scale in complexity is key
- Document Decisions Thoroughly: Maintain a detailed record of design decisions, including justifications for component choices and changes to system architecture

Summary

- We presented a framework for developing structured research campaigns that progress logically towards an ambitious end goals
  - The approach enabled flexible, yet rigorous, hypothesis testing
  - Refinement of prototype system development and/or refinement of research direction
  - Utilising MBSE providing traceability and clarity on decisions throughout the research campaign

- Applying this framework gives R&D programs the tools to be more effective

Questions?

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