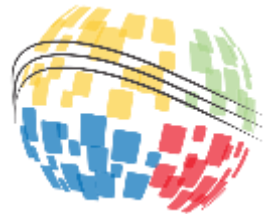




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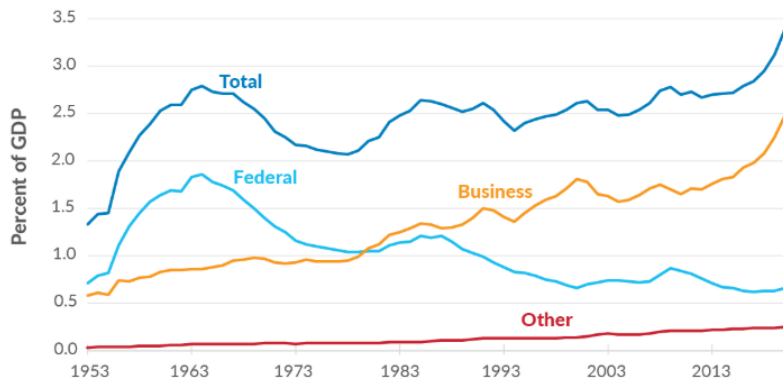
A Framework for Structuring Research Campaigns Leveraging Model Based Systems Engineering

Photi Karagiannis, **Tommie Liddy**, and Matthew Wylie

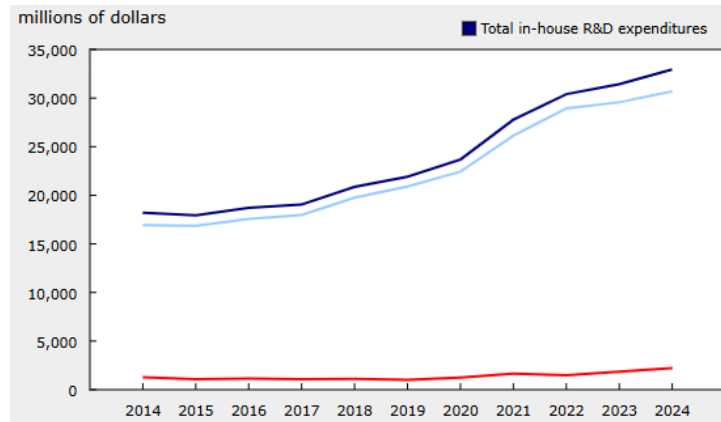


Introduction

- 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 ambitious, systems or services (and their intellectual property)

Applying Structured approaches to R&D

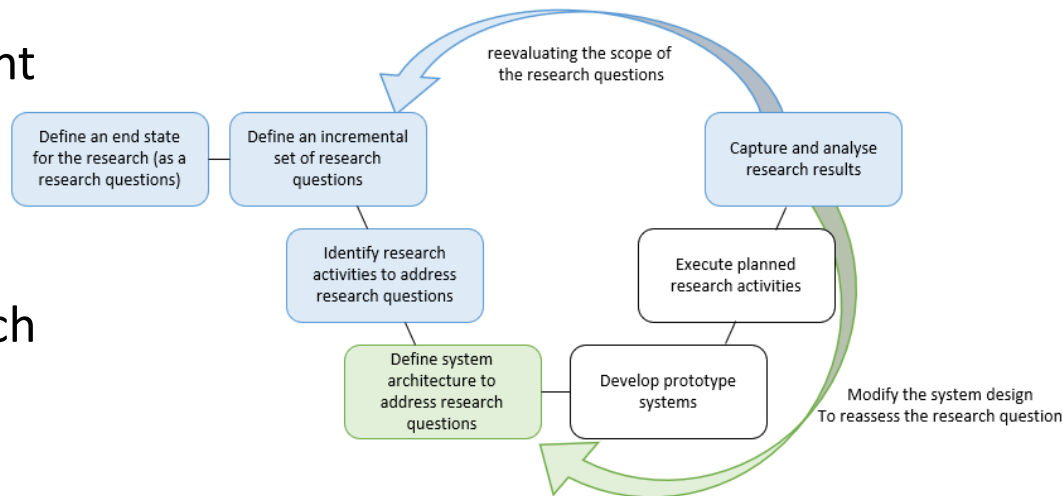
- Organisations that apply structured approaches to their research are better placed to achieve success (Brennan et al., 2020), key challenges include:
 - Accelerated innovation cycles
 - R&D projects have few accountability metrics
- There is utility in applying Systems Engineering, and more specifically 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

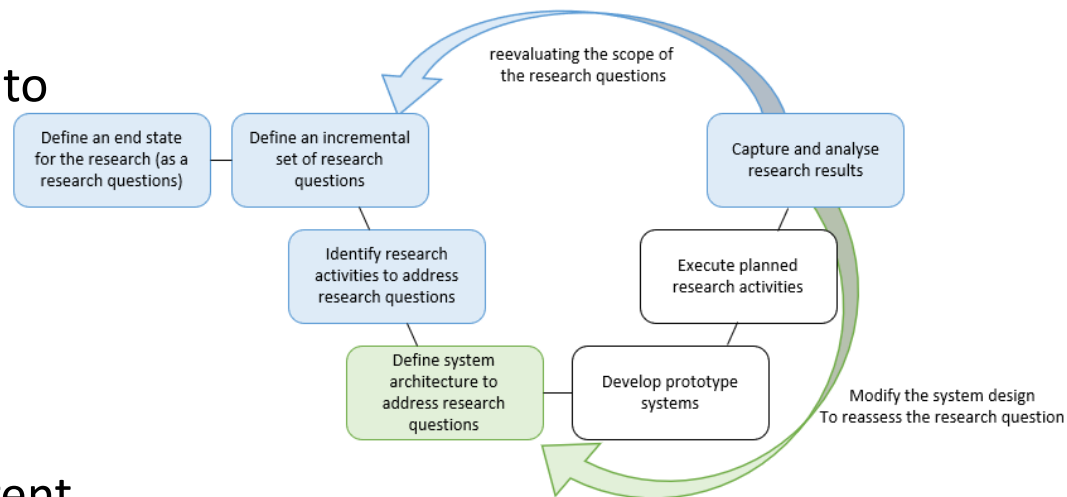
Methodology

- 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!!!



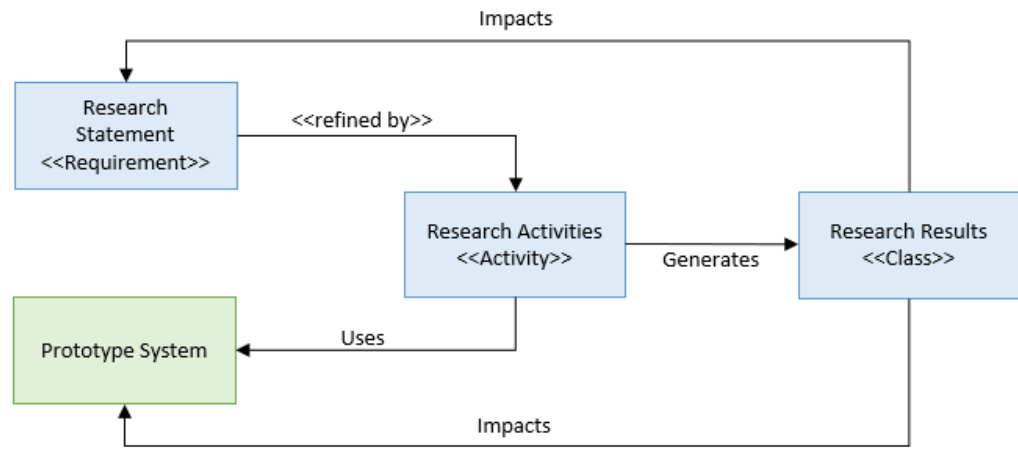
Methodology

- 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



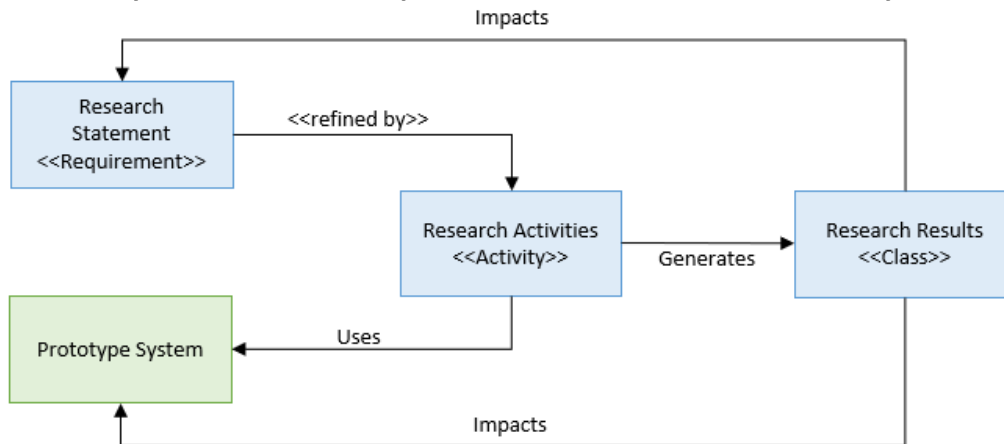
Metamodel

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



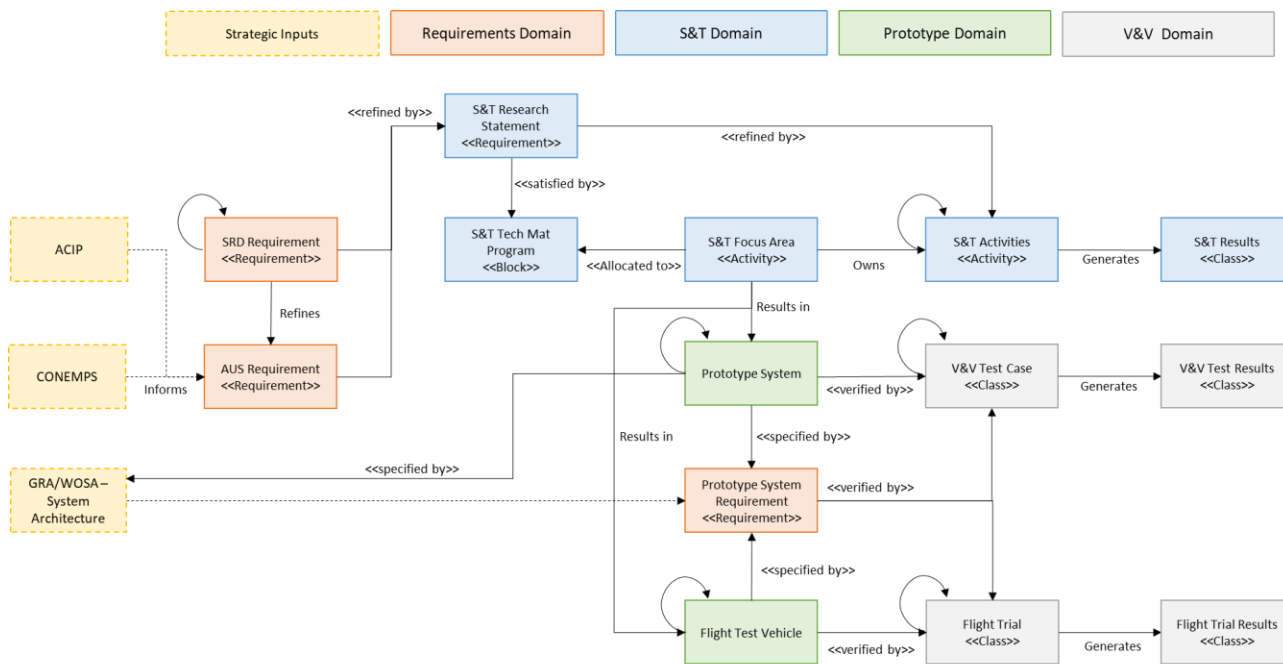
Metamodel

- 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

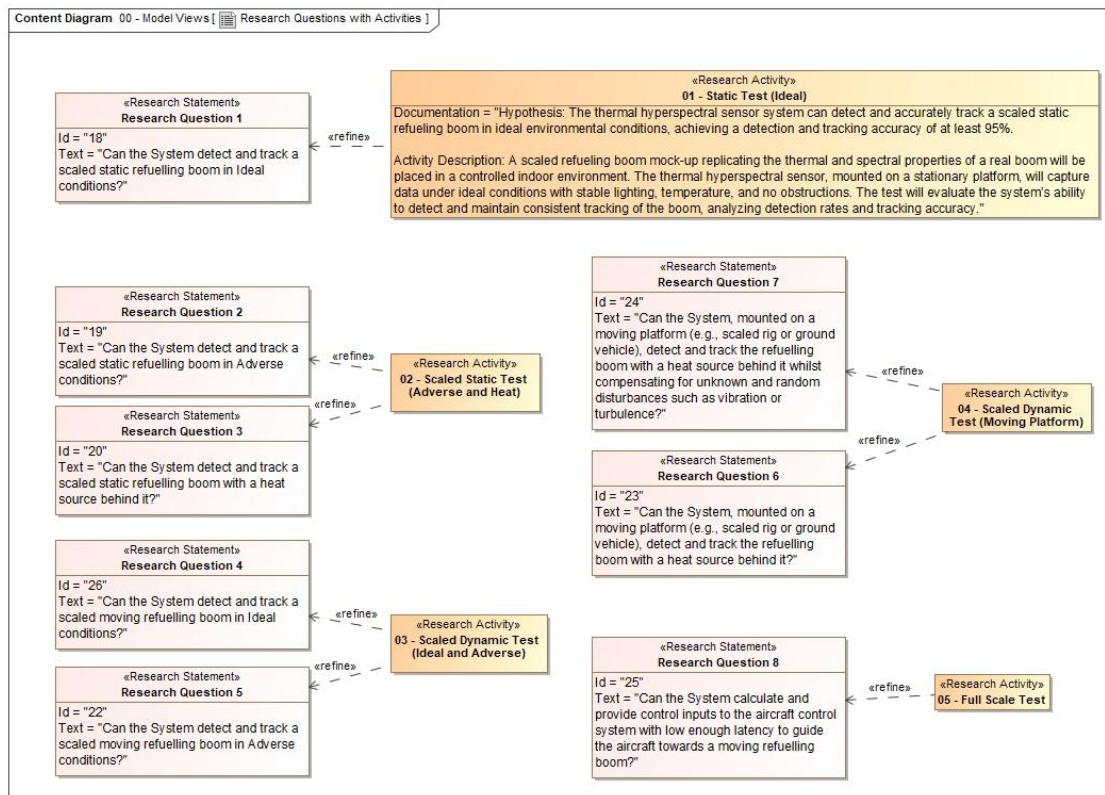
Example: Research Questions

#	△ 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 stabilisation 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

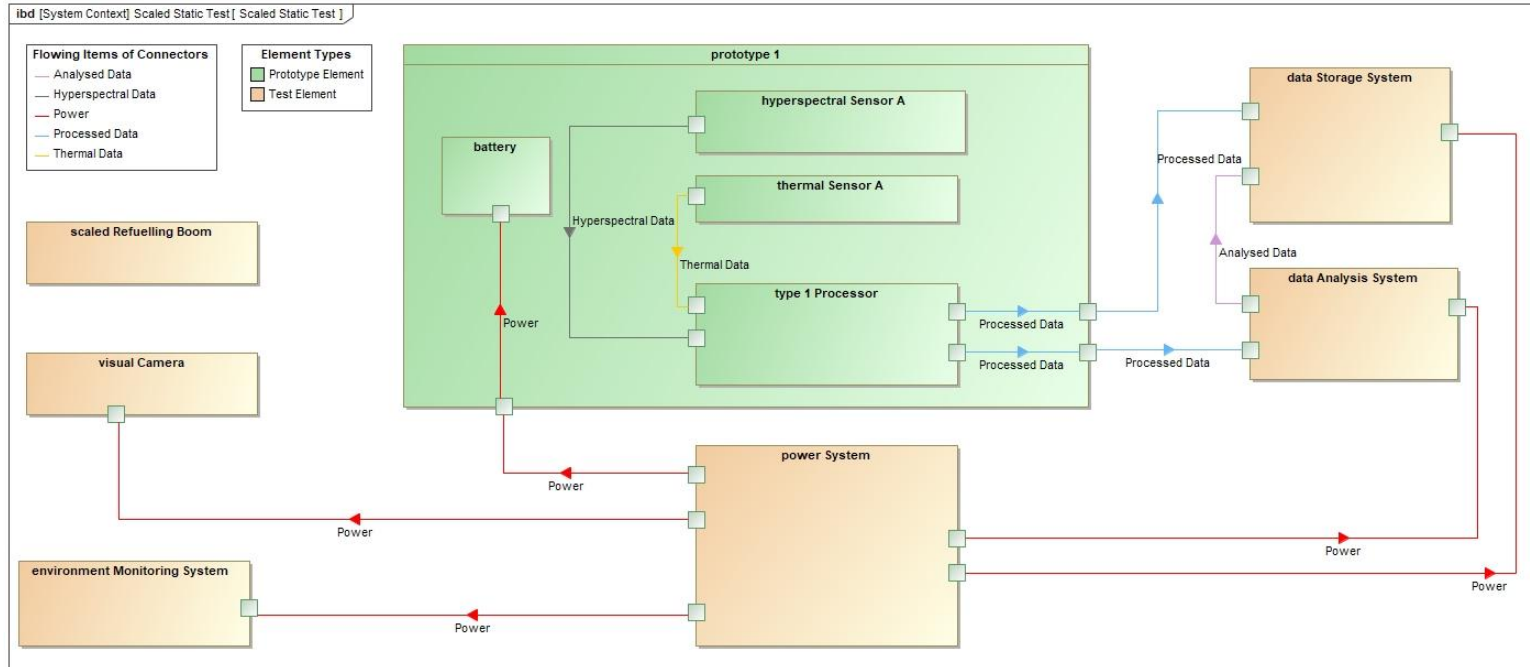
Example: Research Activities



Defining System Architecture

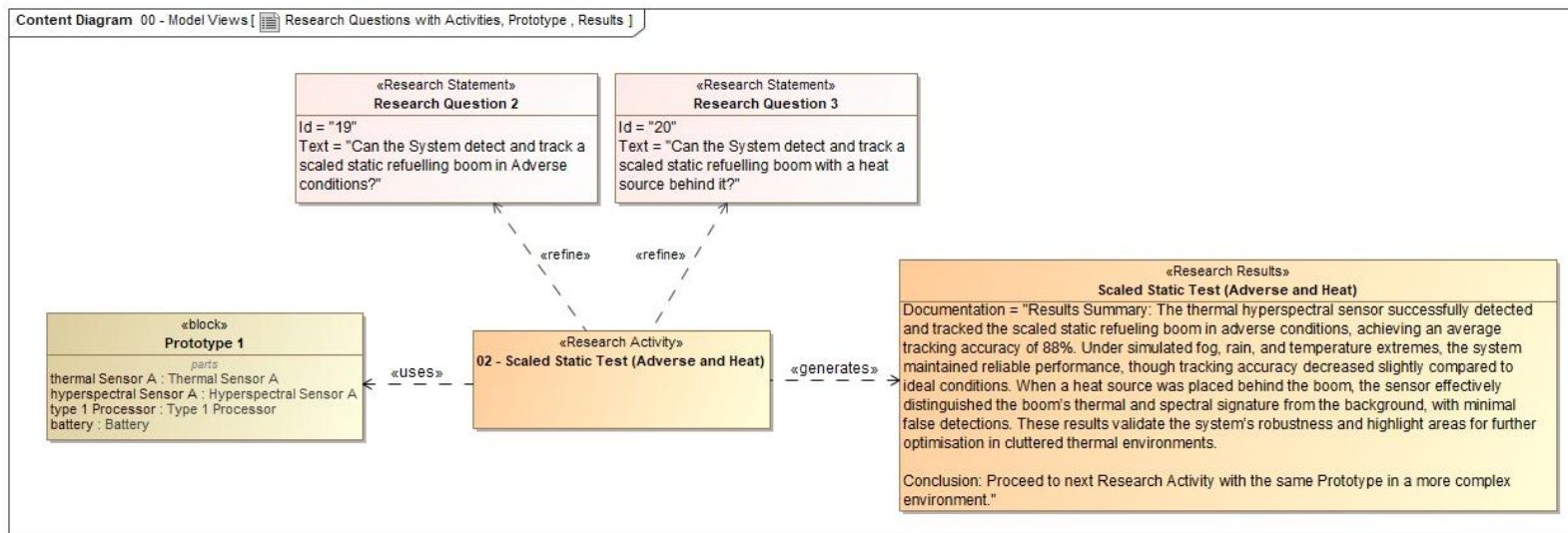
- Defining the system architecture of the prototype system returns to 'Classis Systems Engineering'
 - Understanding the context in which the system will exist which will be the **test configuration** not a deployed system in operations
 - Break the system down into subsystems to a level of definition 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:

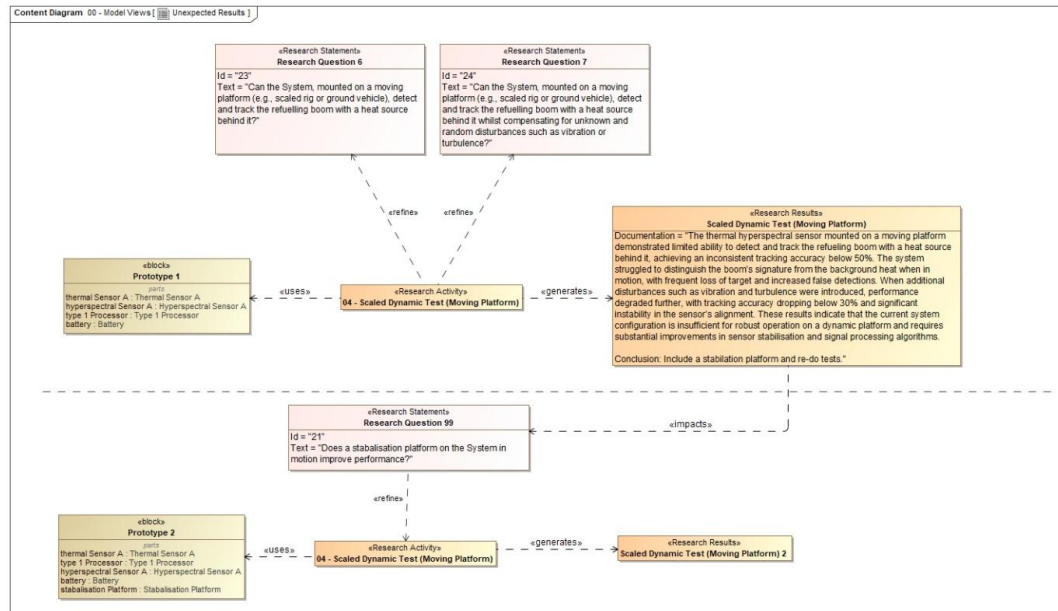


Understand results/update knowledge

- 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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