Aligning Strategy, Research, and System Development, Leveraging Model-Based Systems Engineering Techniques

Photi Karagiannis[a]; Tommie Liddy[b], and Matthew Wylie[c].
Shoal Group[a], Turen[b] , Shoal Group[c]
Corresponding Author Email: photi.karagiannis@shoalgroup.com

Abstract

Research groups are challenged with ensuring that their activities are appropriately aligned to evolving strategic intent. This paper aims to address that challenge by describing an approach using Model-Based System Engineering (MBSE) techniques to bridge the gap between strategic intent and exploratory research activities such as Modelling and Simulation, and experimental prototyping.

As strategic intent evolves, so too should the research activities. However, it is often the case that as strategic intent evolves, areas of research become unaligned. Further, there exists updated strategic intent that is not supported by research or technology development activities.

To maintain alignment with strategic intent, this paper proposes an approach leveraging model-based systems engineering (MBSE) techniques. A metamodel was developed to capture and trace necessary information within the research program, such as the research program's structure, study questions, activities, prototypes, requirements and testing.

To demonstrate the approach, this paper presents a case study where a descriptive model was developed within CATIA Magic to:

- capture the structure and activities of a research group;
- link the elements of that groups research program with strategic intent; and,
- trace the strategic intent to exploratory prototyping conducted by the research group.

Population of existing data in the model found gaps in all areas of the metamodel. With an understanding of gaps, better decision making could be achieved to ensure that research remains aligned with strategic intent.

Introduction

Research is often driven from broad strategic intent. As a result, research organisations (the companies, groups, or teams that do research activities) are often driven by a strategy that is developed externally to themselves and required to align, and deliver research outcomes, to that strategy (Baker et. al 2011).

Whilst implementing and managing alignment of research to a static strategic intent may be straight forward (challenging, but straight forward), it becomes far more challenging when considering an evolving strategic intent. In fact, it can be argued that strategic alignment (as an end state) cannot be definitively achieved when the contextual environment is continually changing (Baker, J., Jones, D. 2008). To assist in maintaining alignment, this paper proposes a framework implemented in a Model-Based Systems Engineering (MBSE) environment that can be used to identify and rectify inconsistent traces.

The central element of this framework is a metamodel developed through stakeholder workshops, existing information (capture in Excel worksheets), and the Whole of System Framework (WSAF) (Robinson et. al 2010). The metamodel incorporated information elements critical to prototype system development, such as requirements engineering, system design, and verification and validation processes, formalising how data should be captured throughout the development lifecycle of a research program. The resulting metamodel was implemented in the Catia Magic tool as a SysML profile extension, enforcing structure through customised stereotypes that define elements, attributes, and relations.

With the metamodel implemented within the MBSE tool, initial data population from Excel was conducted. This process was not straightforward; it required discerning individual elements from aggregated data, interpreting relationships, and avoiding redundancies. The model's elements, such as requirements and research statements, were carefully defined and linked to facilitate analysis and communication throughout the program's lifecycle.

The research program itself was represented as a hierarchical structure within the model. At the top level, the program was divided into sub-programs focusing on distinct technology areas such as propulsion or sensing and navigation. Each sub-program encompassed specific focus areas and research activities, organised to reflect their interdependencies and relationship to requirements and strategic intent.

Prototype designs were captured in the model in terms of their physical architecture, interfaces and information flows. Prototypes were traced from Research Program Focus Areas and traced to Prototype Requirements and Verification and Validation (V&V) elements.

This paper will describe in more detail how the metamodel was used in the research program via a ficticious example system, namely the Med-evac Field Operations Rover (Me-FOR).

Sample Problem – Med-evac Field Operations Rover

The Med-evac Field Operations Rover (Me-FOR) is a fictitious system to augment and enhance the capabilities of a Combat Medic using a rover system that can act autonomously or be remotely operated. The rover follows an assigned target through a variety of terrain as an integrated part of a Combat Team. The rover will also enhance situational awareness by sharing sensor data through secure communications.

The Me-FOR will need to execute the following operational tasks:

- Be able to manoeuvre autonomously, following a designated Asset Owner
- Communicate live sensor data (including audio and video) to connected 'local' Army Personal Field Devices

- Provide power to medical equipment and operators field equipment

An exemplar mission scenario (shown in Figure 1) describes the deployment, transportation, and operation of the Me-FOR.

- The Me-FOR is packed for transport on current in-service Army land vehicles from a Forward Operations Base (FOB) to a deployment position (A).
- The Me-FOR is then switched on and set to follow a Field Medic.
- The Me-FOR travels to an Area of Interest (AoI) in an autonomous following mode over flat terrain (to point B), down an incline (to point C), and then across a small stream (to point D).
- The Me-FOR is then set to travel to various points within the AOI while securely streaming data to the Mission Commander's Personal Field Device, to aid the team search the AoI for injured personnel.
- Once the injured person is found the Field Medic loads them onto the Me-FOR and provides treatment to injuries while the Me-FOR autonomously travels back to point A for extraction.

Figure 1: Me-FOR System OV-1

Metamodel Development

The Research Program initially incorporated a light touch of systems engineering process, primarily through capturing traceability between Strategic Intent, Requirements, and technology development Activities. Notably, these traces were managed using Excel worksheets. The Excel approach resulted in the information conforming to an implied structure with implied relations. However, although the information was captured in a single place (one file) it was challenging to interrogate to gain insights into technology development and support decision making.

To build on this approach, the implied structure and set of relations were formalised into a metamodel. This was developed with the specific goal of refining the information that was already captured and used stakeholder workshops to gain a deeper understanding of what that information was being used for. From here, the metamodel was expanded to encompass critical elements related to Prototype system development, Prototype Requirements, and V&V as per the WSAF (Robinson et. al 2010). Initially focused on capturing information, the metamodel evolved to emphasise how information should be captured, ensuring consistency and efficiency throughout the development lifecycle.

The metamodel included provisions to capture elements within the model relating to Reference Data, Design Decisions, Assumptions, and Risks (Do, Q. 2012). Any of these elements can have a relation with any other element within the model. The purpose for these inclusions was to provide a means to capture rationale behind the design process at any stage in the lifecycle. This allowed for increased communication with stakeholders through simple interrogation of model data.

The metamodel is represented in Figure 2 below, simplified to show key information elements and how they are linked. The metamodel below was implemented in the Catia Magic tool as a profile extension to the Systems Modelling Language (SysML) v1.6 (Friedenthal et. al 2015). Customised stereotypes within the profile enforce the defined structure through element, attribute, and relation definition.

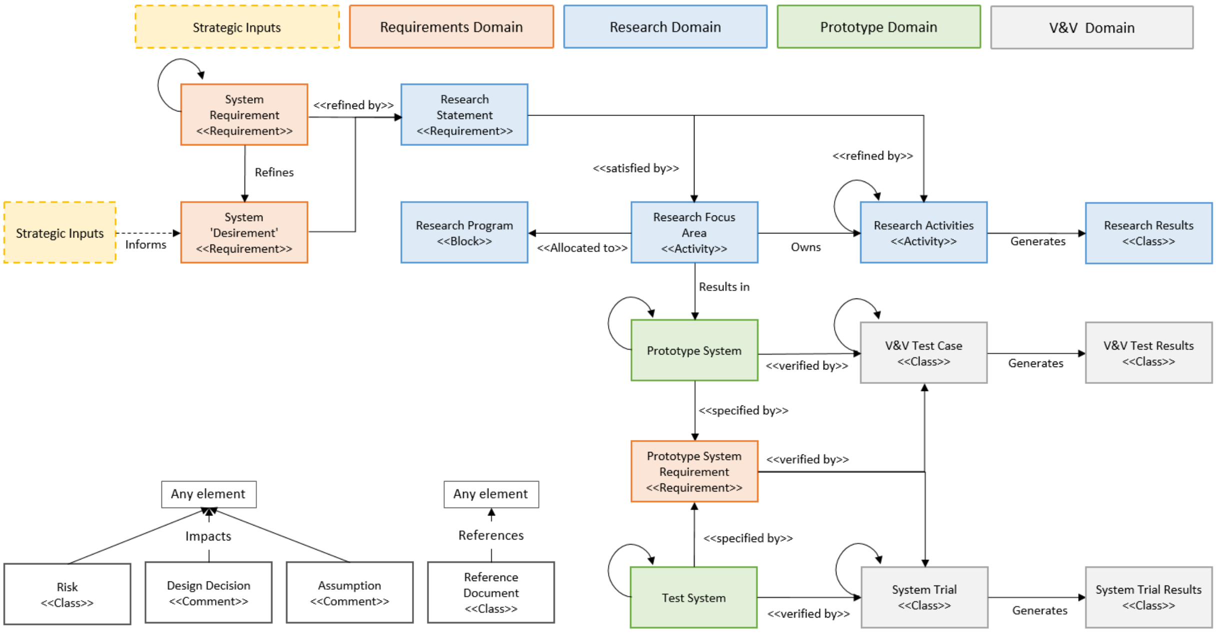

Figure 2: Metamodel

Model Population

The model was populated by capturing the existing Excel-based information in accordance with the metamodel. The process required grouping of information that may be individual attributes of an element that went beyond simple text-based representation, and the interpretation of relations to trace elements together where appropriate.

There were also elements that were represented multiple times in the originating file (through VLOOKUP and other Excel functionality). This required careful incorporation of new relations or attributes into existing model elements to prevent the model from having redundant/repeated data.

The following sections provide an overview of how the information was captured within the metamodel, using Me-FOR as the example system.

Requirement Elements

Various classes of requirements were considered by the organisation, with each having a clear definition, use, and set of attributes to be filled in. These requirements were captured as different model elements so that they could then be managed and traced within the model according to how they were used. This supported ongoing analysis, management, and communication of those requirements.

The program had two key sets of system-level requirements as inputs, namely System Requirements and System Desirements. The System Requirements were provided by external entities as requirements that the final system must meet, whereas the System Desirements were additional options the research program should investigate. System Desirements could be refined by a System Requirement or by informed by Strategic Intent, or both. The overarching aims of the Research Program were to explore technologies that could potentially meet some of these requirements, not to execute a system design and development activity that must met all of them.

The organisation employed Research Statements to group similar requirements. These Statements were written in a language and structure familiar to a research organisation. By doing so, they facilitated effective communication across the organisation and alignment with the organisation's existing practices. Subsequently, the Research Statements could then undergo review, analysis, and prioritisation. This allowed them to be purposefully assigned to specific elements within the research program (discussed in the following section). This approach was used to make best use of available specialised skills and expertise within the team while aiming to minimise management overhead.

The example in Figure 3 shows two requirement elements, System Requirement and System Desirement. The System Requirements are provided by external stakeholders relating to visible and ultraviolet wavelengths, whilst the System Desirement is related to the infrared spectrum. In this context the System Desirements exists so that the research organisation can drive their own research efforts that may be separate from the system design itself. Each requirement element is refined by one or more Research Statements, which allows the research programs to further focus their efforts. A high-level Research Statement is shown in this example, which will assist in focussing the research programs efforts in order to satisfy the requirements it is linked to. If desired by the Program, Research Statements can be written as a hierarchy of detail. For instance, the example provided could be broken down further into "can the IR camera operate in rain", or "can the IR camera operate at 5 m/s".

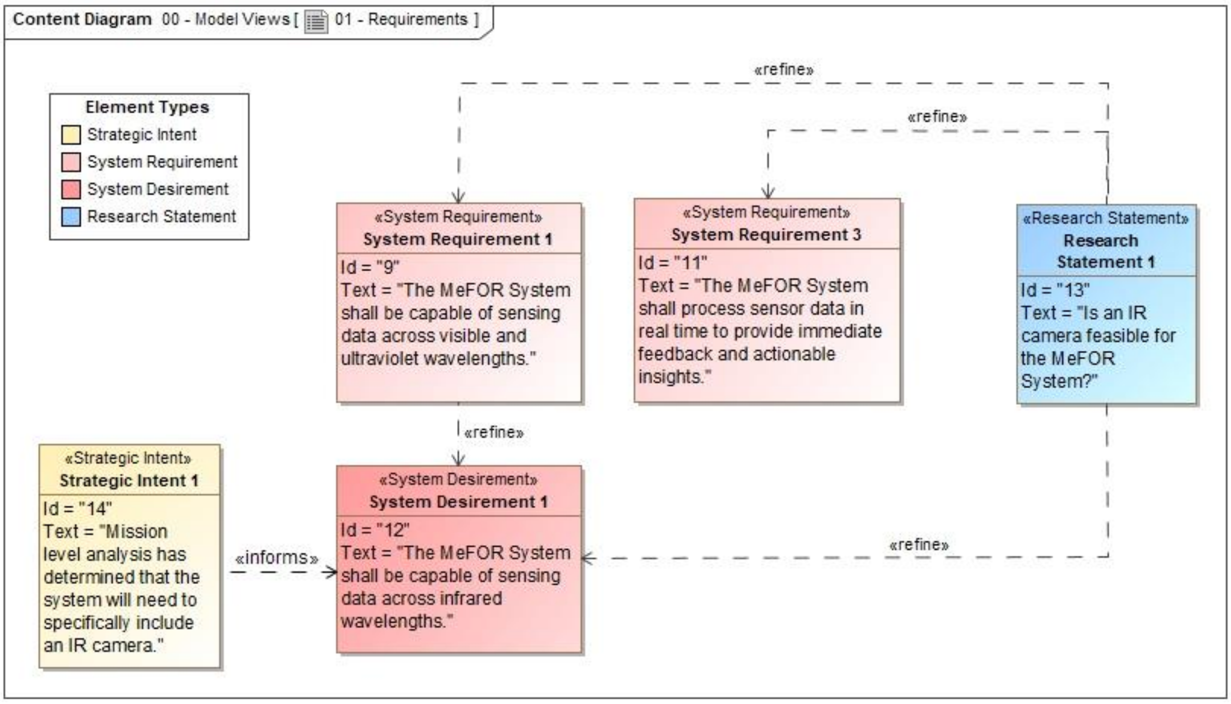

Figure 3: Linking Strategic Intent, Requirements, and Research Statements

More typical system requirements were also captured within the model. These will be discussed in the Prototype domain later in this paper.

Research Program Elements

The research being executed by the organisation was represented as a Research Program (including sub-programs), Focus Areas for that program element, and Research Activities.

Due to the size of the organisation and the research being conducted there was a single element representing the overall program, decomposed by several child research program elements based on key technology areas. This relationship was hierarchical in nature and represented the structure of the Research Program.

Within each Program, Focus Areas were developed to represent key areas of research that that Program would explore. A Focus Area could then be broken down into a set of Research Activities that it would execute to satisfy the Research Statement, and hence the requirements. This approach would ensure a comprehensive and structured progression of the organisations overarching research program.

The example shown in Figure 4 shows the Me-FOR Research Program as the top of the Research Program hierarchy. One of the sub-Research Programs, Guidance and Navigation, includes a set of three Focus Areas. As shown, the IR Focus Area, and its activities, are satisfying Research Statement 1. Figure 3 above shows the Research Statement 1 originated from two requirements, one Desirement and one Strategic Intent element.

The example also shows that the IR Focus Area are developing an IR Prototype, based on these Research Activities.

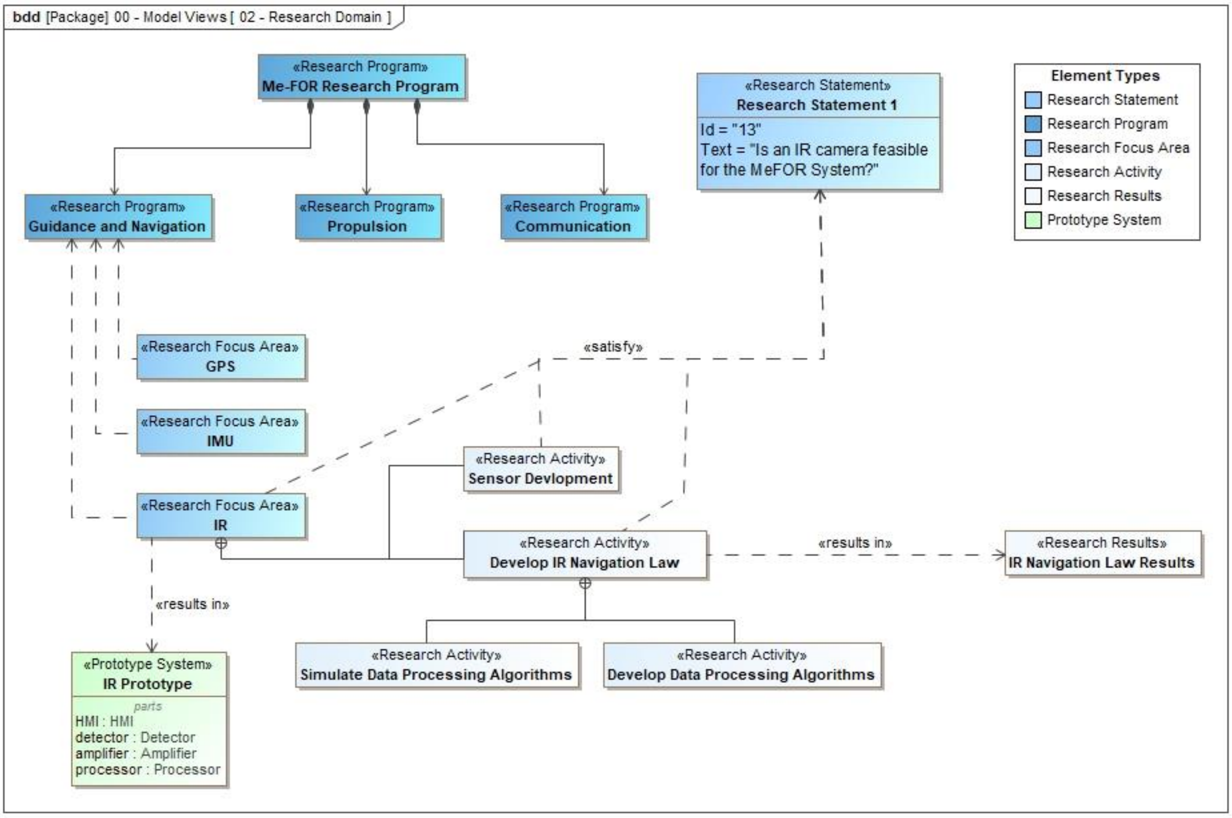

Figure 4: Linking Research Domain Elements with the Prototype Domain

Prototype Domain

The final step in the metamodel population is developing the prototype systems, their requirements, and their related Verification and Validation elements.

Prototype System Requirements are a custom requirement type to be used specifically for Prototype Systems developed by Focus Areas. These requirements are therefore separate from the System Requirements and Desirements described above. Here, they describe what the prototype needs to meet in order to be fit for trial. Then, Test Cases and Results can be developed, captured, and traced within the model.

The example in Figure 5 shows a Prototype System Requirement for the IR Camera and the Me-FOR System. The IR Camera Requirement specifies the IR Camera and is verified by a test case. Similarly, at a system level, the Me-FOR requirement specifies the Me-FOR system and is verified by the System Trial.

Note that architectural and interface diagrams were developed for all systems within the model but are not shown here.

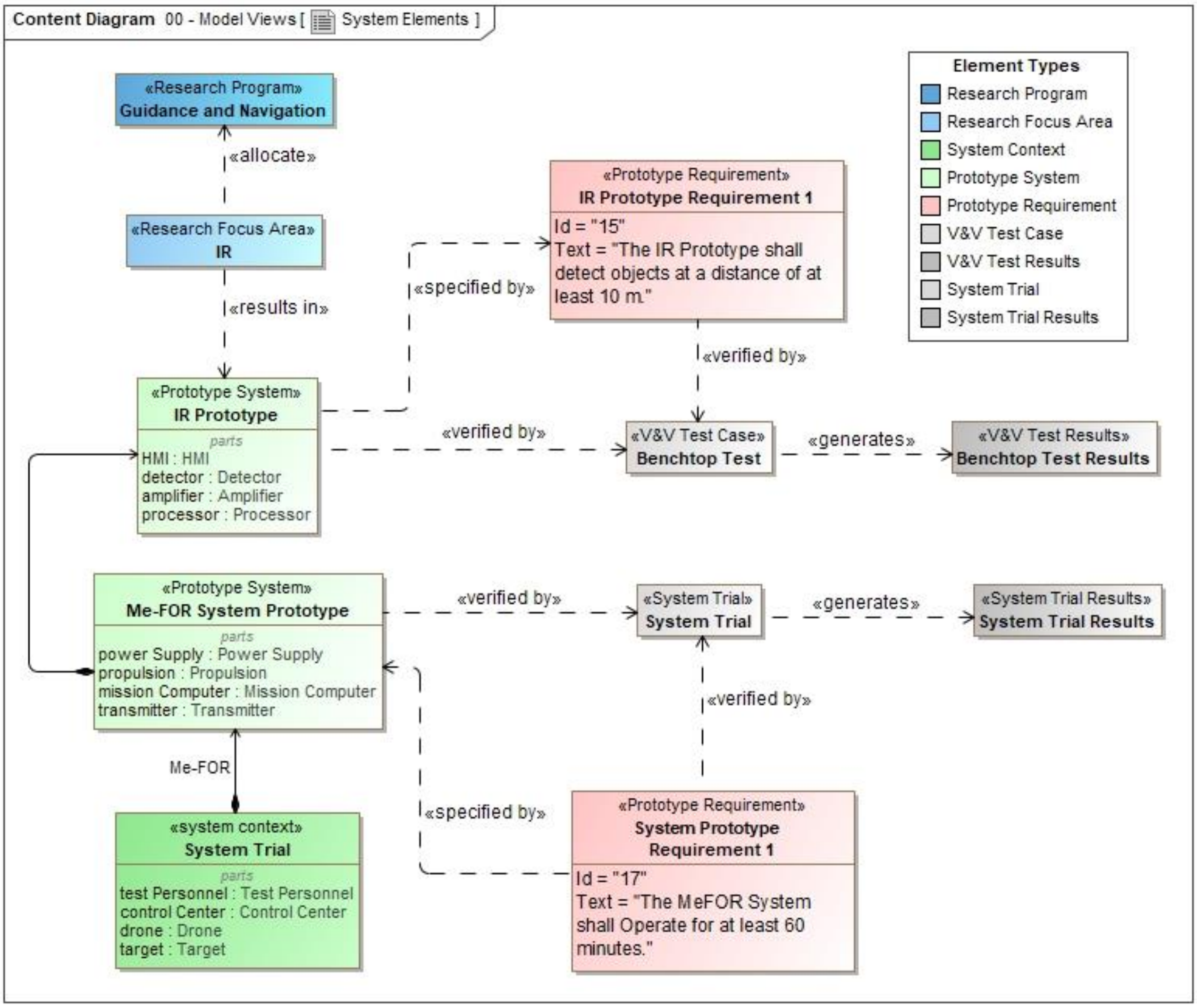

Figure 5: Linking Prototypes with Requirements and Verification and Validation Elements

Full Metamodel Thread

This paper has broken down the metamodel shown in Figure 2 into three discrete views to aid in understanding its implementation. Figure 6 brings these views together, showing the example elements across the entire metamodel. This view shows how a high-level Strategic Intent element can drive low-level prototype design. This knowledge provides the Research Program with the understanding of why certain requirements and research efforts exist, as well as understanding how evolving Strategic Intent will impact their efforts. The framework provides a more robust structure to navigating evolving Strategic Intent when compared to the Excel-based techniques originally in place.

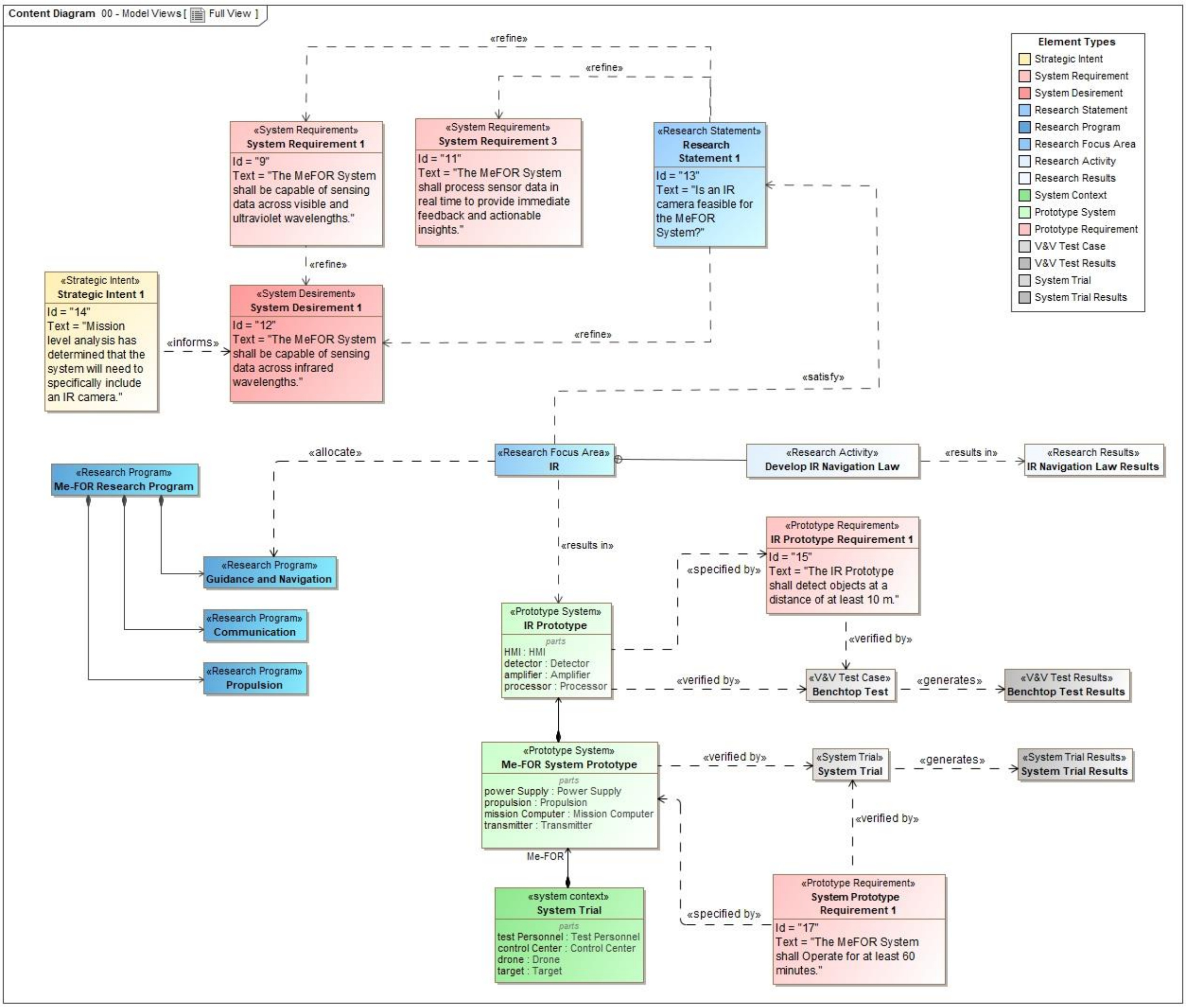

Figure 6: Full Example Thread

Insights

Traceability Gaps

This paper has provided a simplified example of how information was captured within the developed metamodel. This example assumes ideal access to information from the inception of the project; however, in practice this was not the case. The reality was that there were both knowledge and information gaps in all areas of the metamodel, leading to partial or non-existent traces.

Requirements and Research

The task of capturing Excel based data into No Magic uncovered a series of gaps surrounding the requirements and research domains. Often there were Strategic Intent elements that did not have any associated Requirements or Desirements, and hence had no associated technology development. It should be noted that there may have been specific reasoning for this, such as another research area is investigating a given Strategic Intent or simply the Strategic Intent was not relevant to the system, but this reasoning was not captured. Due to this, the data appeared to ignore sets of Strategic Intent without reasoning, undermining the abilities of the research organisation.

Additionally, there were elements in the research domain that did not link to, or had partial/poor links to, areas of the requirement domain. This implied that technology was being developed without input from stakeholders. Whether this was the case or not was unknown, as decisions were not captured against these elements.

The framework provides a means to identify these gaps and capture these traces in a more robust fashion.

Design Rationale

Design rational was not originally captured in the Excel spreadsheet against any requirement or research element. Design rationale was noted within PowerPoint presentations and briefs at ad hoc intervals throughout the design process. This led to misunderstandings of system design within the research team and stakeholders, and no centralised location of authoritative design data.

Design decision elements were captured in the framework to provide researchers with the ability to describe their design decisions against any element within the model.

Evolving Strategic Intent

Some Strategic Intent elements seemed to be agile in nature. They could be adjusted or removed depending on the overall mission of the system. Agile Strategic Intent was not captured in the Excel spreadsheet, leading to what appeared to be misaligned technology development.

The framework provides the researchers with the ability to capture change in Strategic Intent, and understand how the change impacts requirements, research, and prototype system design. This empowers researchers to conduct their prototyping with confidence they are meeting the overall strategic intent.

Conclusion

This paper has proposed a framework to support research organisations maintaining alignment with evolving Strategic Intent. The framework, when implemented in a MBSE environment, allows for Strategic Intent to be captured and linked to requirements and research areas in a more robust fashion when compared to Excel-based techniques. This allows research organisations to understand the impact that a change in strategy affects their research efforts and can adjust accordingly. Some of the key benefits, as highlighted by the example, of this framework are:

- Defining how Research efforts are driven by Strategic Intent;
- Capturing Research Activities conducted by each unique Focus Area, and their respective prototype development efforts;
- Understanding and managing the impact of evolving Strategic Intent on prototype design; and,
- Interrogating the model to uncover information gaps and present information from various perspectives.

Further work to expand the value of the proposed framework includes the addition of operational analysis modelling between Strategic Intent elements and Requirement or Desirement elements. This inclusion allows more analysis to be conducted on Strategic Intent, which would result in more robust capability needs (as opposed to simply deriving the need based on the Strategic Intent as is). These robust needs would then drive more precise requirements and research statements, resulting in a system design that is more aligned to strategy.

References

Baker, J., Jones, D. R., Cao, Q., & Song, J. (2011). Conceptualizing the dynamic strategic alignment competency. *Journal of the Association for Information Systems*, *12*(4), 299–322. https://doi.org/10.17705/1jais.00265

Baker, J., Jones, D. (2008). *A Theoretical Framework for Sustained Strategic Alignment and an Agenda for Research*, Proceedings > Proceedings of JAIS Theory Development Workshop. Sprouts: Working Papers on Information Systems, 8(16). http://sprouts.aisnet.org/8-16

Do, Q., Cook, S., & Lay, M. (2014). *An investigation of MBSE practices across the contractual boundary* [Paper presentation]. Conference on Systems Engineering Research.

Do, Q., Cook, S., Campbell, P. Scott, W. Robinson, R. Power, W. Tramoundanis, D. (2012) *Requirements for a Metamodel to Facilitate Knowledge Sharing between Project Stakeholders*, [Paper presentation]. Conference on Systems Engineering Research.

Friedenthal, S., Moore, A., & Steiner, R. (2015). *A practical guide to SysML: the systems modelling language* (Third edition.). Elsevier/Morgan Kaufmann.

Robinson, K., Tramoundanis, D., Harvey, D., Jones, M., & Wilson, S. (2010, May). *Demonstrating model-based systems engineering for specifying complex capability*. In *Systems Engineering/Test & Evaluation Conference*.