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**DEVELOPING A MODEL-BASED APPROACH TO FORECAST A
COMPETITOR'S SYSTEM**

THESIS

Mr. Christopher A. Del Vecchio

AFIT-ENP-MS-22-J-020

DEPARTMENT OF THE AIR FORCE

AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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AFIT-ENP-MS-22-J-020

DEVELOPING A MODEL-BASED APPROACH TO FORECAST A COMPETITOR'S
SYSTEM

THESIS

Presented to the Faculty

Department of Systems Engineering and Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Scientific and Technical Intelligence

Christopher A. Del Vecchio, BS

May 2022

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DEVELOPING A MODEL-BASED APPROACH TO FORECAST A COMPETITOR'S
SYSTEM

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Abstract

The purpose of this research is to develop a model-based approach to competitive technical intelligence to forecast a competitor's system. This analysis is currently driven by the writing of long narrative reports that are laborious to maintain and update, while also providing little clarity on how the forecast was developed. To do this, a framework of antithesis processes, or Anti-Processes, were derived from the systems engineering technical processes. This was then combined with analytical tradecraft from the field of competitive technical intelligence to build a SysML reference model, which was then applied to a small case study to enhance and refine the model. The Anti-Processes provided a solid foundation to frame and conduct analysis of a competitor's system in the specific stages explored. The layered approach to the SysML reference model provided traceability and a means of deconstructing the analytical process of each Anti-Process. Finally, the parametric model of a Bayesian Inference technique, Subjective Logic, enabled a dynamically updateable model to calculate likelihood and uncertainty of forecasts within each Anti-Process. Ultimately, the Anti-Process framework and SysML reference model provide a rigorous, model-based approach to intelligence forecasts of competitor's systems.

Acknowledgments

I would like to express my sincere appreciation to my faculty advisor, Dr. Thomas Ford, for his guidance and support throughout the course of this thesis effort. The insight and experience was greatly appreciated—the work captured herein could not have been done to this level without it. I would, also, like to thank my sponsor for both the support and latitude provided to me in this endeavor.

Christopher A. Del Vecchio

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DEVELOPING A MODEL-BASED APPROACH TO FORECAST A COMPETITOR'S SYSTEM

I. Introduction

General Issue

Address the lack of structured and digital-driven techniques to aid in the forecast of characteristics and capabilities of competitors' systems for which there is little knowledge and capture the analytical process from which the forecast is developed.

Terminology

Many of the terms in this section are used in the general public with varied meanings. For the purposes of this research, the following terms provide a baseline.

Intelligence: the provision of information about targets of concern for the use of decision makers

Competitive Intelligence: a subset of intelligence. A discipline that enables organizations to reduce strategic risk and increase revenue opportunities by having a deep understanding of what has happened, what is happening, and what may happen in their operating environment

Competitive Technical Intelligence: a subset of competitive intelligence. A systematic process focused on monitoring the competitive and technical environment for the purpose of better decision making in the areas of technology innovation, technology forecasting, product design, research and development

Intelligence Analysis: a generalized term within the intelligence cycle referring to the work of an intelligence professional to make sense of collected information

Intelligence Assessment: the result of intelligence analysis. An estimate to be delivered to decision makers

Intelligence Forecast: the use of abductive reasoning to synthesize an assessment of a target of concern under uncertainty

Uncertainty: a varying level to describe the lack of complete knowledge on a topic. Total uncertainty is the lack of any relevant knowledge on a topic

Confidence: the negation of uncertainty. Total confidence is having complete knowledge on a topic

Problem Statement

Current State:

Currently, the methods to analyze competitors' systems are document-based approaches which lack transparency and require significant resources to maintain. The main methodology ingest and store this information is to retrieve source documents and store them in unstructured shared folders and OneNote files. The information in these documents is then analyzed informally by individual analysts to develop an assessment of the capabilities and performance (C&P) of a competitor's system and this information is disseminated by means of lengthy narrative reports on these systems.

As new information is consumed by the analyst, it requires significant rework to the document-based approach demonstrated above. Further, much of the knowledge of specific information taken into consideration, the degree to which this information is

trusted and leveraged, and the relevance of the information is largely omitted from these reports.

When additional information is needed or misunderstanding from the reports or presentations arises, requests for information (RFIs) are sent to the subject matter expert (SME) to elaborate or correct misunderstandings. To complicate the matter further, most of the community knowledge lies within the minds of a few experienced individuals. These individuals typically lack a systematic process of knowledge capture for new analysts to leverage in their own analysis.

Key Contributors:

- Lengthy narratives are often too long and complex for readers to digest when looking for specific information.
- Document-based approach restricts reusability and interoperability with digital practices both upstream and downstream.
- Capture of specific information used to make assessments is not recorded and is difficult to replicate.
- Final narrative reports are semi-structured constructs that require additional processing prior to extended exploitation.

Future State:

System models derived from model-based systems engineering would provide a structured, digital-driven approach to capture the knowledge of a competitor's system and the structure of the analysis. The end result would be a system model that captures large amounts of component level data on a system, what type of uses that system would have, its functionality, interfaces, and innerworkings. The model would also identify

assessments of analytical judgement vs sourced assessments which is referred to as traceability. Primarily, a systematic process for conducting analysis would be useful in more efficient development and more dynamically updatable analysis.

Ultimately, narrative reports would still be necessary particularly in exploratory situations. However, these reports could likely be smaller in nature because significant portions of the structured data could be found in the system model saving both customer and analyst time. Further, like many digital-driven approaches, the documentation could be a semi-automated output, not the key driver behind the analysis.

Research Objectives

Objective 1: Develop a robust model-based approach that captures the analytical process with an open structure so that information can be added or refined.

Objective 2: Identify processes (systems engineering anti-processes) that support the generation of a system reference model for threat assessments.

Objective 3: Identify methodologies within MBSE to support unique uses within the IC

Objective 3a: Assign likelihood and confidence level to assessments

Objective 3b: Distinguish attributes if associated with judgement derived assessments or source derived assessments

Objective 3c: Identify gaps in knowledge base and generate list of unknowns

Objective 3d: Identify impacted higher-order assessments and reports if attribute assessments are changed

Methodology: Model-Based Competitive Technical Intelligence

The methodology establishes a framework leveraging well established processes from mature fields of study including model-based systems engineering (MBSE), Competitive Intelligence, and Subjective Logic. A case study was used to demonstrate the use of the methodology in building a reference model for a competitor's system.

The framework above will later be referred to as the Anti-Process Machine. As will be shown, the Anti-Process Machine represents the digital thread of the competitor's system. As knowledge of the competitor's system are introduced into the Anti-Process Machine, the representation of the system's end-to-end lifecycle will be represented.

In the case study, elements of the Anti-Process Machine are used to forecast aspects of a competitor's system. Forecasting is not limited to the prediction of a future state of a system, but also encompasses the estimate of current or past states which are not understood. These forecasts demonstrate the ability to exercise the method, Model-Based Competitive Technical Intelligence (MBCTI), on a real problem.

Assumptions/Limitations

System analysis in the context of this research is limited to the analysis of a singular system and has not addressed the upstream and downstream influences of the analysis of complex systems of systems. Further, not all analytical tradecraft methodologies are captured within the reference model. This is due in large part to the lack of compatibility between analytical tradecraft and systems modeling. This and similar topics will be identified as beneficial areas of continued research to develop a more robust, integrated, end-to-end process.

Implications or Expected Contributions

The approach developed in this research provides the beginning of a path toward a digital-driven approach of the analysis of a competitor's system and capturing that knowledge in a more expressive manor than the current document-based approach.

Summary and Thesis Structure

The structure of this thesis follows a scholarly article format. Thesis chapters include papers that have been submitted to the INCOSE International Symposium (INCOSE IS), the Conference on Systems Engineering Research (CSER), and a chapter that focuses on the application of the MBCTI methodology developed in the two conference papers to a case study that will be submitted as another conference paper or journal article. The INCOSE IS and CSER papers are included verbatim to what was submitted to the conferences with updates requested by reviewers. The following is the structure of the remaining chapters of the thesis:

- II. INCOSE Symposium Paper—II. Systems Engineering Anti-Processes:
Assessing a Competitor's System
- III. CSER Paper—III. SysML Reference Model for Assessing a Competitor's
System
- IV. Exemplar--IV. Applying SysML Reference Model to Ford Bronco Case
Study
- V. Conclusion & Future Research

II. Systems Engineering Anti-Processes: Assessing a Competitor's System

Chapter Overview

The purpose of this chapter is to establish a framework to break down the intelligence problem of the analysis of a competitor's system using established Systems Engineering (SE) processes for the purposes to forecast a competitor's system. It seeks to define a set of Antithesis processes and establish useful intelligence techniques to be leveraged throughout this research.

Abstract

This paper investigates the combination of systems engineering and the domain of competitive intelligence to develop a holistic and predictive approach to assess a competitor's system. To do this, systems engineering is leveraged as a framework to analyze a competitor's full life-cycle approach to the development of a system which is done by deriving Anti-Processes from the Systems Engineering Technical Processes. Further, contextual information is derived to assist in the assessment of each Anti-Process. Lastly, by means of developing the Anti-Processes, a technology roadmap technique is utilized to inform a projection capability to analyze a competitor's future system. The well-established discipline of systems engineering provided an ideal framework to assess the full life-cycle of a competitor's system and project associated risk which will provide decision makers with critical information to develop competitive business strategies.

Introduction

Systems Engineering processes are well-documented in the INCOSE SE Handbook, ISO 15288, the NASA Systems Engineering Handbook, among others, and are commonly used to efficiently develop a new system or modify an existing system. Unfortunately, the SE processes are not designed to support the forecast of an existing or future system. This capability is needed to enable competitive intelligence. We postulate that SE "Anti-Processes" can be described which provide this essential capability – these Anti-Processes providing a digital thread of the competitor's system. The SE Anti-Processes are derived from the existing SE technical processes using methodical techniques such as decomposition analysis (Pherson & Heuer 2021) and concept mapping (Zhang et al. 2016).

To investigate the possibilities of identifying and capturing a competitor's system development and its capabilities, this paper explores techniques applied to the systems engineering (SE) process. In particular, the SE processes are well-established and have been in practice for decades (NASA 2016; ISO, IEC & IEEE 2017; DoD 2013; INCOSE 2015). The categorization of the steps in the SE process, it is possible to determine what observations may be available to capture during each phase of the process. This provides insight into the progress of a developmental system. This SE antithesis is referred to as an Anti-Process throughout the paper. By further understanding the potential observable information and the results of each phase of the Anti-Process, we can capture a snapshot of potential capabilities of a developmental system. At each phase of the SE process, there are typical deliverables which can provide context to a system's potential capabilities and potential risks in not achieving those desired capabilities.

This process is similar to what Richards and Heuer refer to as “System 2” thinking for intelligence which is categorized by 4 quadrants as depicted in Table 1. Due to the predictive nature of this proposed construct, Richards and Heuer suggest that this type of analysis lies in foresight analysis which is a subset of structured analysis – Quadrant II (Pherson & Heuer 2021). Structured analysis lies at the intersection of qualitative analysis and a combination of unknowns and knowns. The goal in the application of intelligence analytical techniques, competitive intelligence categorical sources, and technology roadmapping is to assist in the development of a path forward to move from quadrant II to quadrant III where the analysis becomes more rigorous and less abstract. A more structured reference frame to describe the state of the competitor’s system development provide a less ambiguous description and definition which is more aptly digested for decision making purposes as emphasized by Arend (Arend 2020).

Table 1: 4 Quadrants of System 2 Thinking for Intelligence Analysis

	Known Attributes	Known and Unknown Attributes
Qualitative	I. Critical Thinking	II. Structured Analysis
Quantitative	IV. Empirical Analysis	III. Quasi-Quantitative Analysis

Related Works

Current Analytic Techniques.

A critique from Gartin points out that analytical techniques in intelligence have largely used antiquated practices until very recently. Some future techniques rely on data science practices and structured analytic techniques (Gartin 2001). Many structured analytic techniques provide general tools that the analyst can use to assist in developing

assessments (Heuer 2008). These techniques can be useful in certain situations, but don't always provide a full context to topic areas such as the analysis of technical systems. Technical competitive intelligence, a sub-set of competitive intelligence, offers a promising insight to maintain competitive advantage according to Muller (Muller 2006). This intelligence type is focused on deriving the technological trend from various sources to understand the technological direction of a competitor for decision makers to develop competitive strategies. Further, philosophical approaches have been leveraged to approach requirements needed for competitive intelligence, but even these approaches fail to show how a system is developed and how those requirements are fulfilled (De Rozario 2009). As mentioned by Gartin, data science techniques such as machine learning may be needed, but these techniques rely heavily on highly prepared data with well labeled information for maximum impact (Heinrich & Frye n.d.). Machine learning techniques may have future use, but first a structured framework is needed to assist in these future models.

The Anti-Processes provide a rigorous method to predict the capabilities of a system in development, its current stage in development, risks associated with its continued development, and the likelihood that each capability will be realized. In some cases, it is useful to break down a system into its various capability requirements when applying these Anti-Processes to provide insight into the modular capabilities of the system. Ultimately, many of the capabilities will have interdependencies to other capabilities and technologies which are taken into account at the system level.

Analysis of Various Systems Engineering Processes

A quick analysis of the various established SE practices from NASA, the Defense Acquisition Guide, ISO 15288, and the INCOSE SE handbook demonstrate a very similar structure between the processes. Each has technical processes that are specifically related to the development of the system across its lifecycle. Each also contains supporting processes; however, the arguments of this paper will primarily focus on the technical processes defined in the INCOSE SE handbook; however, these arguments can be applied to any of the SE practices noted above. Each SE process in the technical process category will be broken down and its Anti-Process will be derived.

Results

Richards and Hueur suggest a decomposition approach when analyzing a problem set which they define as breaking down the problem or issue into its component parts so that each part can be considered separately (Pherson & Heuer 2021). Leveraging this technique, the basic methodology is to analyze each technical process presented by the INCOSE SE Handbook and synthesize an Anti-Process. Each technical process has an Anti-Process counterpart. Each Anti-Process will identify areas that are crucial for observations related to that process. For each technical process, an Input-Process-Output (IPO) transformation model is applied as shown in Figure 1 (Manenti et al. 2019).

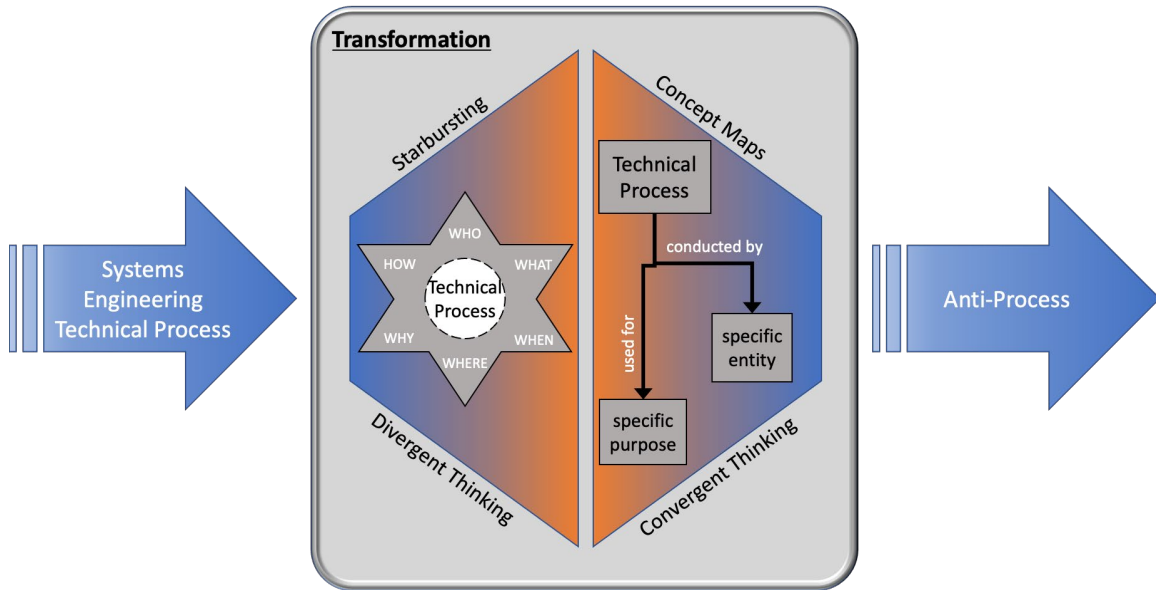


Figure 1: Input-Process-Output Transformation Model for SE Technical Process to Anti-Process

In some cases, the SE technical process has a simple logical transform. However, many transformations are not as obvious and leverage techniques from intelligence analysis in the IPO model in Figure 1. For each SE technical process, an empirical analytical technique referred to as starbursting was used as the main enabler to the Analytic Process in the IPO model. Starbursting is a very simple brainstorming technique with a central problem or issue at the center of the star and interrogative questions are asked: who, what, when, where, why, how. This is typical of Descriptive and Explanatory Analysis which are the initial phases of intelligence analysis according to Grunt (Grunt 2017). Starbursting provided an essential divergent generation of related thoughts to the SE Technical Process, but a convergent process was needed to constrain the variation between posed interrogatives (Glory E. Aviña, Christian D. Schunn et al. 2018). The

structured technique used here was concept mapping informed by the specific SE Technical Process and its intended purpose. Concept mapping provides a relationship map with the SE Technical Process at the top of the concept map demonstrating the known relationships which provide a method to down select the interrogatives (Davies 2011).

This IPO model provided a suitable means of transforming the SE Technical Process to an Anti-Process (see Table 2).

Table 2: SE Technical Processes with Derived Anti-Processes

SE Technical Process	Posed Interrogatives	Anti-Process	Brief Purpose Description
Business or Mission Analysis	What is the mission objective of the force/technology? What are possible gaps in the current force? Why are they seen as gaps? What capabilities are currently in place?	Business or Mission Analysis and Definition	To analyze competitor's current capabilities and market coverage to anticipate potential needs.
Stakeholder needs and Requirements Definition	What needs were identified in the mission analysis? Have any capabilities been identified to fill this need? Who are the stakeholders? What are their needs? Have any mission requirements been announced?	Stakeholder Needs and Requirements Identification	To identify stakeholders, their roles, and define what needs have been portrayed.
System Requirements Definition	How do the stakeholder/mission requirements break down into system level requirements? What parameters/properties are associated with the requirements? How will the characteristics be measured?	System Requirements Identification	To identify derived system requirements and how they support mission success.
Architecture Definition	Is there an existing architecture? How will the new system be incorporated into the existing	As-Is, To-Be Architecture Analysis	To analyze the current and near-term architecture

	<p>architecture? What technology is needed to make the transition? What technology is available? When can the architecture be ready?</p>		<p>and identify how a new system would integrate into the current architecture and identify needs to be addressed.</p>
Design Definition	<p>What is the design? What could the design be? What are the potential alternatives? What are typical design practices for this technology? What are the design capabilities of the developer?</p>	Design Exploration Analysis and System Definition	<p>To develop an understanding of the potential designs that could be explored that fulfill basic design criteria.</p>
System Analysis	<p>What disciplinary modeling needs to be conducted? What inputs will these models need? What outputs will downstream models need? What outputs will the stakeholder need? What are satisfactory results?</p>	Disciplinary System Analysis	<p>To provide rigorous analysis of expected system performance in order to assist in further analysis of verification, validation, and operational capabilities.</p>
Implementation	<p>What are the processes to develop the system? Who are the developers? What production capacity do they have? What contracts have been developed? How will the system be produced? Why were those developers selected?</p>	Development Plan and Supply Chain Analysis	<p>To provide detailed understanding of the development process which provides insight into capacity, production rates, production gaps, etc.</p>
Verification	<p>Does the assessed design meet initial requirements? What deltas can be identified? What are the risks? What prototypes exist? Do they match assessed design?</p>	Assessment Verification	<p>To evaluate the assessed design(s) against initial design specifications and identify mismatches. Also to identify any potential prototypes and compare to assessed design.</p>
Transition	<p>What is the plan to get the system fielded?</p>	Integration Plan	<p>To provide insight into the plan to</p>

	<p>What testing is anticipated? What testing capabilities exist? Does any technology or facilities need to be developed to conduct testing? When will testing occur? How will testing be conducted? What data is needed? Who is conducting the testing?</p>		<p>develop assessed system from initial design to operational system.</p>
Validation	<p>What were the test results? Did the test results satisfy intended uses? Who is the approval authority? What is status of testing? How long did testing take? What is the likelihood that the system is approved for operations? What has changed?</p>	<p>Validate and Re-assess</p>	<p>To validate current system model (abstract or digital) against intended use, provide insight into validation results, and re-assess if needed.</p>
Operation	<p>How is the system being used? What is the training regimen? When will the system reach IOC? When will the system reach FOC? Where is training conducted? Who conducts training? Have any issues been identified? What facilities are needed for operations?</p>	<p>Operational Evaluation</p>	<p>To provide insight into the operational capacity, usage, limitations, and fielded issues.</p>
Maintenance	<p>What are the initial maintenance plans? Are there any routine maintenance cycles? When is maintenance conducted? Where is maintenance conducted? How is maintenance training conducted? Are there any certifications? How long does that take? What is the mean-time-between-overhaul?</p>	<p>Maintenance Evaluation</p>	<p>To assist in understanding needed maintenance practices, cycles, and maintainability</p>
Disposal	<p>When is the system expected to</p>	<p>End of Life</p>	<p>To ensure an</p>

	go offline? What can be salvaged? Are there any service life extension plans? What metric constitutes end of life?	Evaluation	accurate depiction of the end of the life cycle of the system being analyzed.
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Discussion

With the Anti-Processes established, it is imperative to create a methodology to inform this framework. Based on research from Bartes, the typical intelligence cycle consists of 5 phases: planning, collection, processing, analysis, and dissemination (Bartes 2013). Rouach et al. provide further insight into the potential sources of information that could fulfil the initial collection phase. The author describes Competitive Intelligence (CI) as containing the following characteristics: it is an art of collecting, processing and storing information to be made available to people at all levels of the firm to help shape its future and protect it against current competitive threat – it involves a transfer of knowledge from the environment to the organization within established rules (Rouach & Santi 2001). Further, the authors note that CI is not simply data, but that the data must be analyzed in order to create consumable information in the form of intelligence and break down competitive intelligence into four interconnected categories: market intelligence, competitor's intelligence, technological intelligence, and strategic/social intelligence.

- Market: information referring to market support including suppliers and contractors as well as products, services, and innovation
- Technological: research, patents, publications

- Strategic: Human resources, economic, political, and legal impacts
- Competitor's: the intelligence derived from the information in the other categories that provides an insight into a competitor's position to produce a system

These aspects of competitive intelligence are applied to the technical processes to introduce potential sources of collection which inform each Anti-Process. Further, this information provides the context of the data that is collected. By categorizing the observations and collected data into Anti-Processes, it provides a structured framework to the analysis of a systems' development. This was done with the comparison of the competitive intelligence aspects of the underlying contextual sources in Figure 2 to the reduced set of interrogatives posed in Table 2. One exception was System Analysis. This Anti-Process uses traditional discipline engineering techniques to evaluate the assessed system's performance.

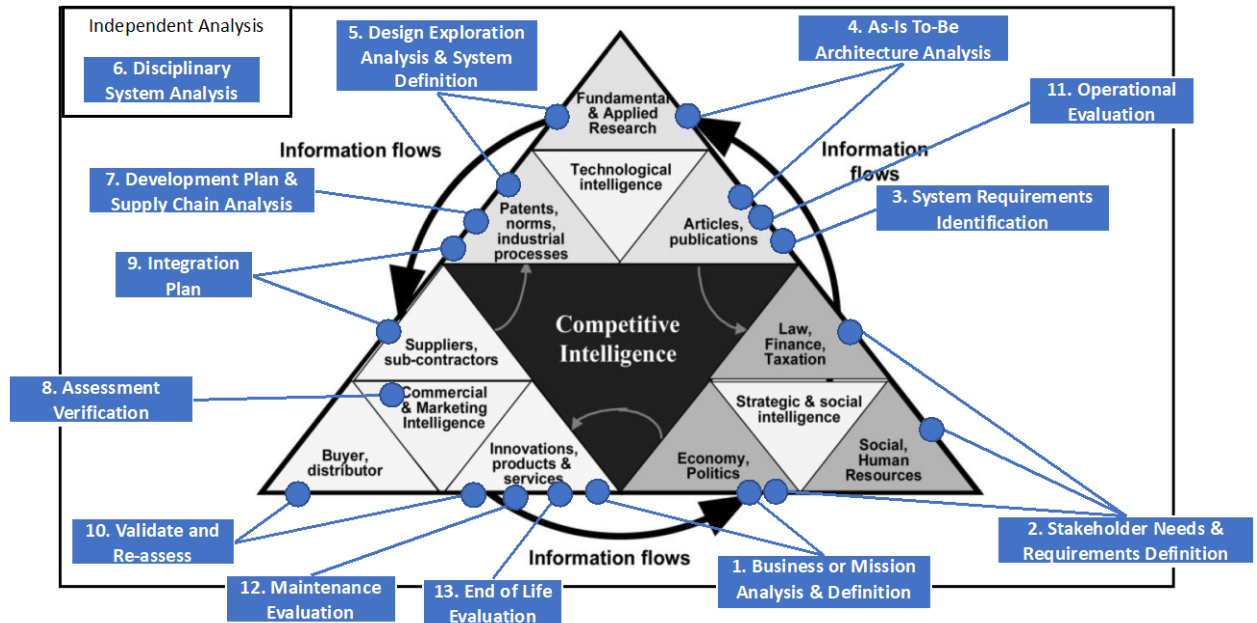


Figure 2: Anti-Processes Mapped to Informational Sources, Extended from Rouach and Santi's Competitive Intelligence Pyramid (Rouach & Santi 2001)

Ultimately, the combination of the Anti-Processes, the intelligence cycle, and information from the potential sources create a framework illustrated in Figure 3. This machine operates in an iterative process and is important to note, that it is not linear. While the events of a competitor's system's development may transpire in a linear timeline, the added utility in the Anti-Process framework is the ability to forecast a competitor's system irrespective of the stage of development. Put another way, each Anti-Process represents a corollary process in the competitor's development of a system; however, the Anti-Process machine can be used asynchronously by the analyst to analyze and make assessments of that representative Anti-Process prior to or after the competitor has reached that stage in development. The input of each of the Anti-Processes is the collection phase of the intelligence cycle which is built from the categories shown in

Figure 2. Hotie et al. developed a value process model that helps describe how value is passed between entities (Hotie & Gordijn 2019). This is also represented within the Anti-Process framework where an intelligence need originates from a stakeholder internal to the organization and the Anti-Processes assist in the analysis of the competitor to fulfill that intelligence need focusing on the external competitor. The meta-value process travels from internal stakeholder through the competitive intelligence cycle back to the stakeholder in the form of an assessment of the competitor. In terms of the value process, the value is exchanging between the stakeholder and the analyst or suborganization responsible for the individual Anti-Process, that value then transitions to any other segment of the Anti-Process framework, and then back to the stakeholder. Previously, it was mentioned that each Anti-Process contains its own iterative cycle, this also allows for the value process model to travel into the Anti-Process framework at any individual Anti-Process rather than relying on a waterfall effect from beginning to end of the thread.

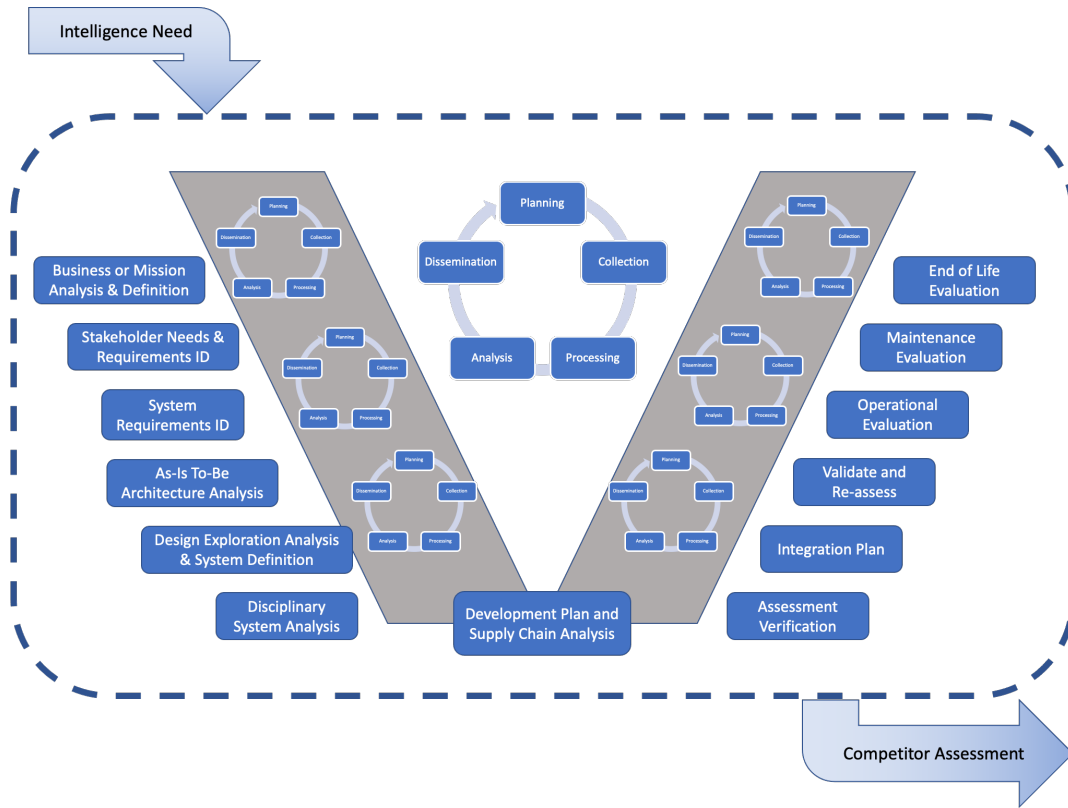


Figure 3: Anti-Process Framework

Competitive intelligence also opens the doorway to a comparative use of SE practices with the introduction of a methodology called technology roadmapping to provide a projection or forecast of the object of interest. Zhang et al. conducted extensive research into technology roadmapping and how it supports competitive intelligence. Technology roadmapping is used to evaluate data related to a technological field and using various techniques, it can be used to develop a trend of technology and technology needs. It is possible to obtain a detailed understanding of the direction an industry or specific organization is headed by analyzing sources such as patents, research papers, and articles. Further, it is possible to predict the next steps and direction of these same entities

by developing a technology roadmap (Zhang et al. 2016). While technology roadmapping provides a significant insight, Zhang et al. also emphasize the fact that this process, especially for foresight or predictive uses, requires expert input. Thus, while the Anti-Process can provide a framework for a system's capability and development analysis, it will likely never fully escape the need for expert insight. The technology roadmap is further explained by Martin and Daim as a linear project timeline. And in this timeline, each line item represents a technology unlike a traditional project timeline which consists of tasks. Each technology incorporated into a system must be finished for the intended system to be realized. If one technology is behind the schedule of the system for which it is being developed, this technology will affect the overall timeline or technology of the system (Martin & Daim 2012).

Martin et al. demonstrate two useful technology roadmap techniques to help predict the risk in the development. First, the authors use a breakdown of the diverse needs (i.e., required technologies) to develop a new system and demonstrate if there is a misalignment between any of the realized support structures. This adds an ability to use each Anti-Processes to assess risk to the development. Second, they introduce the concept that the analysis of only the current point of development provides a view of the potential uncertainty moving forward (Martin & Daim 2012). When applied to the Anti-Processes, a roadmap of the development can be created and assist in capturing the amount of uncertainty in the assessment (see Figure 4). It is important to note that uncertainty will always be present when not apprised of all details (Lowenthal 2021), thus even as the assessment intersects with the current point in development, there is still uncertainty. To

further demonstrate this concept, a simplified, hypothetical scenario was constructed below.

Hypothetical Forecasting Scenario

The output of the System Analysis Anti-Process of a new portable computer system has provided the assessment that the system will require a battery with a power capacity of A. With the parallel development of the Anti-Processes of the competitor as opposed to one Anti-Process at a time, the user of this model could use the Operational Evaluation Anti-Process to determine that the current technology on the market can provide a maximum power capacity of B. If B is less than A, this indicates an incongruity between system needs and current capability. This then provides an opportunity to explore potential explanations or alternative explanations as described by Heuer (Pherson & Heuer 2021). To capture the potential alternatives, the list of hypotheses need to be exclusive and exhaustive (Pope & Jøsang n.d.). For this hypothetical scenario, the following alternatives would be considered:

- h1: the portable computer system will not have the necessary power supply within the proposed schedule;
- h2: the portable computer system will have the necessary power supply and additional collection is needed (this is considered a collection gap);
- h3: the portable computer system will have the necessary power supply and the system analysis was incorrect (this is considered an analytical gap).

The alternatives, in this context, indicate a need to evaluate the sources and methodologies of the analysis. If the sources and methodologies can be confidently evaluated and tested, then h1 becomes the most likely hypothesis, thus the analyst would provide the decision maker with the assessment that the portable computer system will likely not be ready for deployment within the current assessment of the defined system and developmental timeline.

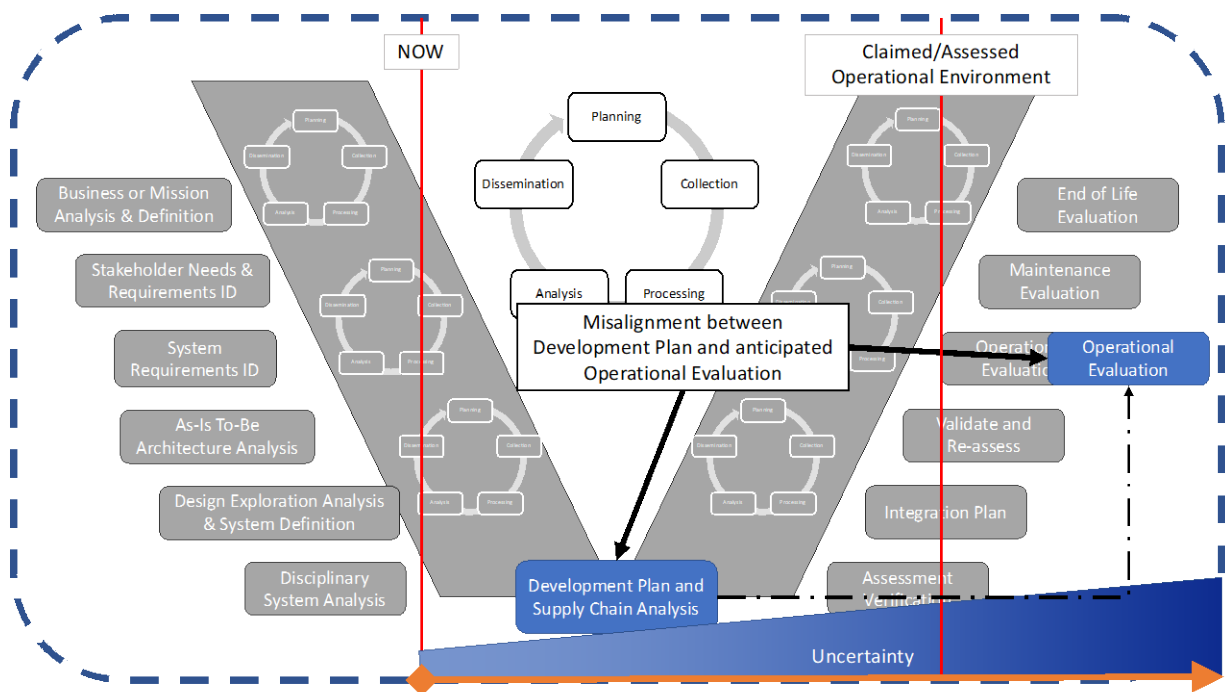


Figure 4: Hypothetical Scenario to Demonstrate Roadmap Techniques for Prediction
Uses

Conclusion

In conclusion, Systems Engineering Anti-Processes applied to a system provide an opportunity to improve awareness and understanding of the market space and the

competitor's abilities within that market space – a thread of the competitor's system development. Varying approaches exist in assessing the current market space and for assessing competitors within that market space. However, many of these practices do not focus on the development of a system. Further, the few approaches that provide assessments of systems or technology demonstrate limited ability to assess the capability of the system and typically focus on a few elements of the system or technology. Systems engineering is a systematic approach, but is used to develop a system, not assess a system or market space.

The combination of elements from systems engineering, competitive intelligence, and technology roadmaps, this research demonstrated that the SE technical processes can be used as a basis for a framework to structurally analyze a competitor's development of a product, technology, or capability. The Anti-Process demonstrates the ability to take an intelligence need, decompose it into manageable portions, and iteratively provide systematic assessments of a competitor's system development. This provides a holistic approach to the assessment of a developmental system, technology, or capability. Additionally, the Anti-Processes reveal the full life-cycle of the development and expose the needs a competitor will have across the life cycle of a system. With this, the overall process assists in informing the current capability the competitor must perform in the market space. And, the application of a technology roadmap to the Anti-Processes, the framework provides an ability to project potential outcomes that can assess needs that will require attention if the system moves forward to realization. This provides further depth to the analysis with a risk assessment from the competitor's perspective to achieve the anticipated system.

These techniques provide a systematic approach to the assessment of a competitors' current and future system capabilities and their ability to achieve these systems. This complex framework would further benefit from research and development to determine a white-box problem for each Anti-Process and the relationships between them. Due to the complexity of these multivariate relationships, systems modeling would be an ideal tool to more rigorously capture this information. Ultimately, the framework of the Systems Engineering Anti-Process demonstrates a high utility to provide decision makers with critical information to make decisions based on competitors' systems development with past, current, and future context.

III. SysML Reference Model for Assessing a Competitor's System

Chapter Overview

The purpose of this chapter is to investigate the use of SysML to develop a model-based approach to the analysis of a competitor's system. This paper was initially published without the terminology, digital thread, and was not altered to incorporate this terminology; however, the term is fitting for two reasons. 1) it develops the thread of the Anti-Process Machine developed in Chapter II into a digital model, and 2) develops a digital thread of the intelligence analysis including the uncertainty in that analysis as demonstrated by Singh and Willcox (Singh & Willcox n.d.).

Abstract

The Systems Engineering Anti-Process Machine – a set of systems engineering antithesis processes – was derived from the aggregation of techniques within the Systems Engineering Technical Processes and various components of competitive intelligence. The Anti-Process Machine is used to predict a competitor's future system (or an existing system whose character is unknown) to assist in the decision-making process for strategic business decisions. The research in this area is nascent and requires further investigation. In particular, the method of processing the information within the Anti-Process Machine and the method of capturing this information are largely unresearched. This paper investigates a transdisciplinary approach to address these problems, leveraging the fields of model-based systems engineering, knowledge modeling, and subjective logic. Primarily, this paper focuses on developing a SysML reference model for a single Anti-Process. The result is the basis for an analytic method to predict a competitor's system as

well as a digitally-enabled method of capturing this knowledge. Additional comprehensive research in this area is required to realize the entire Anti-Process Machine.

Introduction

In Chapter II , the Systems Engineering Technical Processes were applied to the generalized scenario of forecasting a competitor’s system – resulting in the Systems Engineering Anti-Process Machine. A quick description of this terminology: Anti-Process refers to a set of antithesis processes that focus on the method of determining what a competitor will accomplish, is accomplishing, or has accomplished during the associated Systems Engineering Technical Process from which the Anti-Processes were derived. Additionally, the term “machine” is similar to a function machine or a black box system – the machine has inputs, outputs, and a rule or process is encapsulated within, which results in a transformation from the input to the output. Later in the paper, an automobile example has been constructed to step through the SysML reference model. In this example, a single Anti-Process, Design Exploration, is explored which is the counterpart to the SE Technical Process, Design Definition. In comparison, the Anti-Process Machine refers to the meta process of predicting or assessing a competitor's system.

The Anti-Process Machine leverages the methodical and rigorous approach of Systems Engineering and integrates it with proven competitive intelligence techniques.

The machine takes an intelligence need as an input, analysis is conducted within the machine, informed by data collection, and finally a prediction (or assessment) is delivered. As the amount of knowledge increases, the need to transform a mental model into a digital representation becomes crucial to the decision making process (Zoppelletto et al. 2020) (Nilsson 1999). A mental model of the Anti-Process Machine is a complex problem with multiple interdependent relationships including a functional representation of the competitor's system. Simply, it becomes too much for the individual to keep track of and communicate effectively. A SysML model readily allows the complexity of the information and its relationships to be captured, queried, visualized, or otherwise analyzed.

The output of the Anti-Process Machine is the prediction (or assessment) of the competitor. The output would generally be thought of as the delivered assessment to the stakeholder. However, the customer or stakeholder typically does not need to understand the full depth of the underlying model and analysis. Thus, it is important to consider what information is transferred from Anti-Process to Anti-Process in the larger machine. Nilsson encourages modelers to understand the information value that should be represented to decision makers (Nilsson 1999). The solution utilized in the research of this paper is to use abstraction layers or conceptual layers as described by Tolk (Tolk, Diallo & Turnitsa 2007). These layers allow the underlying details of the process and analysis to be captured, but provide the ability control the flow of information. This flow of information allows the user to access different layers of the Anti-Process based on their needs. This paper explores the uses of these conceptual layers within SysML to capture the reference model of the Design Exploration Anti-Process.

Systems Engineering Anti-Process Machine

To further describe the Systems Engineering Anti-Process Machine, the approach to developing a problem domain by Mazeika et al. is used by first considering the black box problem, then the white box, and finally a solution (Mazeika, Morkevicius & Aleksandraviciene 2016). The Anti-Process Machine will serve as the black box problem, then stepping into one of the Anti-Processes, demonstrate a white box problem where the reference model for the individual Anti-Process is developed. And finally, a solution for a simplified automobile example is constructed.

The Anti-Process Machine is composed of individual Anti-Processes. This machine interacts with a collection apparatus as well as an organization. This organization can be viewed as any stakeholder actor – it can be an external stakeholder, customer, or colleague working on a different part of the Anti-Process. Additionally, the organization originates an intelligence need and receives an assessment of the competitor of interest once analysis is concluded. The collection apparatus provides evidence to be analyzed within the Anti-Process Machine. A diagram representing this high-level description is depicted in the block definition diagram (BDD) below, see Figure 1.

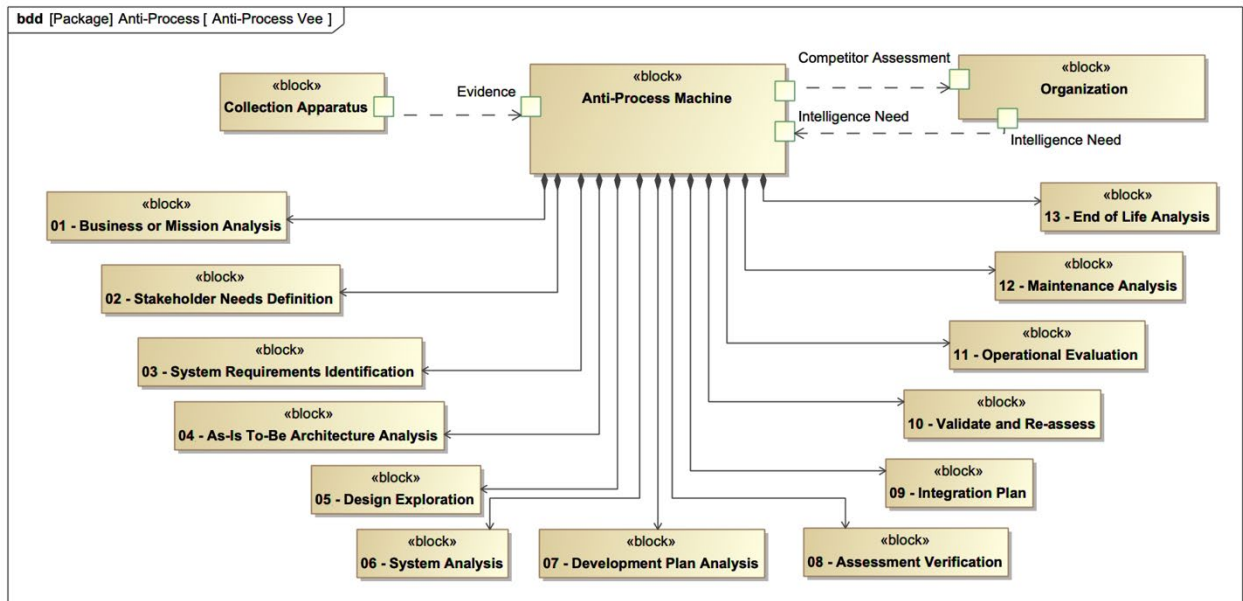


Figure 5: Anti-Process Machine SysML Block Definition Diagram

The internal block diagram of the Anti-Process Machine block shows the flow of information between each of the individual Anti-Processes, see Figure 2. This demonstrates that evidence flows into each step of the Anti-Process Machine and likewise for intelligence needs, meanwhile the competitor assessment can flow out from each Anti-Process. Each of the Anti-Processes can be conducted independently, but it requires assumptions to be made of the information that is flowing into the individual Anti-Process. Ideally, each Anti-Process would be constructed independently and allow information to flow between the Anti-Processes to form an interconnected model of federated Anti-Process models.

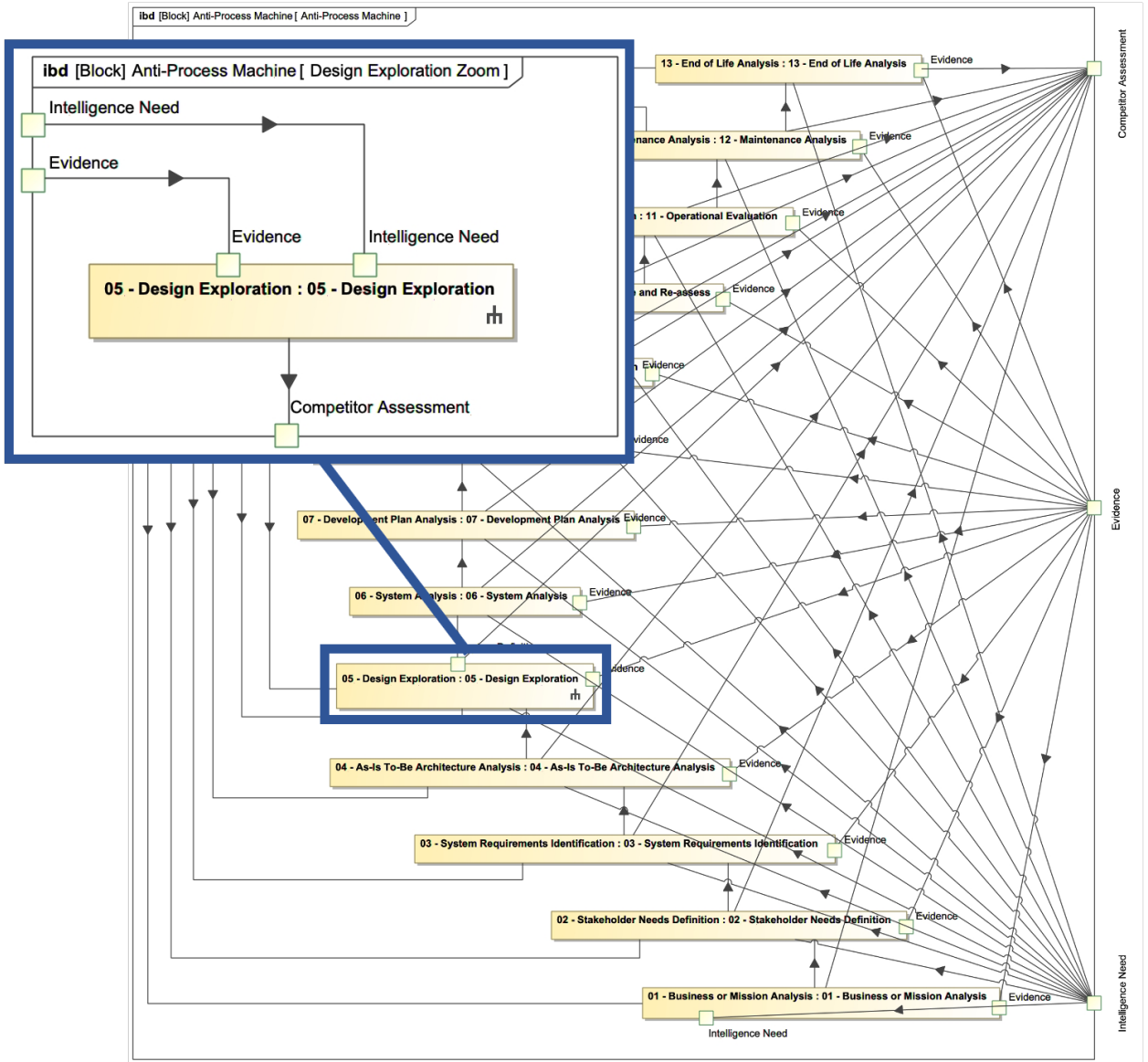


Figure 6: Anti-Process Machine SysML Internal Block Diagram with Zoom-In of Design Exploration Anti-Process

Results

Conceptual Layers

For the purposes of this paper, most of the Anti-Process Machine is left as a black box problem and focuses on Design Exploration Analysis and System Definition to continue the process of establishing a white box problem and reference model, then establishes a solution for the automobile example. In Chapter II, an input-process-output (IPO) transformation model was used to determine relevant interrogatives for each Anti-Process (Grunt 2017). These interrogatives are the following for Design Exploration: What is the design? What could the design be? What are the alternatives? To address these interrogatives, sources of evidence are used to derive an assessment. Then, the most likely assessment is used as the system definition. These then compose the three layers of the reference model: Source Layer, Assessment Layer, and Definition Layer. In this case, the final layer would be the System Definition Layer which would then be used as the system as the analytic process moves through the Anti-Process Machine. Conceptual layers are especially prominent in system modeling as demonstrated by Tolk et al. (Tolk, Diallo & Turnitsa 2007; Mazeika, Morkevicius & Aleksandraviciene 2016; Tolk & Muguira 2003). The conceptual layers allow for high level layers to be integrated with lower-level layers. This is done so that information from the lowest level layers can be accessed by higher level layers without necessarily needing to access the lower level. Thus, this methodology is ideal for the Anti-Process Machine.

Within each layer lies a set of elements necessary to derive the realized system for further analysis. The Source Layer is comprised of evidence, the Assessment Layer is

comprised of alternatives, and the System Definition Layer is comprised of the hierarchal structure of the system being defined.

Each lowest level of the system structure contains several value properties pertinent to defining the system for the future work as defined by the relevant stakeholders. For instance, to define a system for a mechanical engineer to conduct power transference analysis of the drive train of an automobile, will require the drive type of the automobile. Thus, the lowest level component for that example would be a “Drive” block which would inherit a value property of “driveType” from the Assessment Layer which is discussed further below.

In the Assessment Layer, analysis of competing hypotheses (ACH) is implemented. ACH is a common methodology within competitive intelligence used to evaluate available evidence and limit bias which compares several options relevant to the evidence and analyze the alternatives to determine the most likely (Heuer 2008). This is because the system definition is unknown and the consideration of feasible options, reduces bias (Pope & Jøsang n.d.)(Pherson & Heuer 2021). Since the evidence potentially supports multiple hypotheses, an appropriately exhaustive list of alternative hypotheses are developed (Pope & Jøsang n.d.). The alternatives could be quite literal as in the example where the alternative hypotheses are all related to a different drive type and relate directly to evidence. However, the alternative hypotheses could be more indirect in other Anti-Processes such as the hypotheses that would follow the intelligence need, “will a competitor accelerate their time-to-market when a new product is announced?” A possible list of exhaustive hypotheses includes: h_1 : The competitor will not accelerate, h_2 : the competitor will accelerate, but does not have the means to meet

accelerated timeline, h_3 : the competitor will accelerate and meet the revised schedule. The evidence is likely to be more abductive in these scenarios, meaning that few pieces of evidence will directly indicate the supported hypothesis. In some cases, the list of alternatives can be quite extensive and benefits from expertise to narrow the list of alternative hypotheses (Rouach & Santi 2001).

Finally, the Source Layer captures the information from the relevant sources or pieces of evidence as informed by the collection process. The 5 steps of the collection process (i.e., the competitive intelligence cycle) are Planning, Collection, Processing, Analysis/Exploitation, Dissemination (Bartes 2013). The evidence is planned by capturing the requirements of the intelligence need. In the example, “What is the drive type of a competitor’s automobile being introduced next year?” Then, collection begins with the observation of evidence in appropriate mediums. The first step to the reference model in its current state is to process the source information where the extracted information is assigned to block elements in the Source Layer with the appropriate value properties for items of interest for downstream analysis or stakeholder needs. Initially, this layered model would be similar to the reference model in Figure 3.

The relationship between the layers were needed to later communicate information across the layers. In this paper, the layers are demonstrated within the same diagram. However, as the model increases in size and complexity, these layers will likely be contained in separate diagrams. At the time of this research, a method has not been constructed to address this issue. Thus, a notation of the rationale for the relationships serves as springboard for future research.

First, within the Definition Layer, the lowest level elements of the system inherit from the Assessment Layer using a specialization relationship. Since the lowest level element should have the same features as the final assessment—which will vary over time based on the supporting evidence—it allows the component definition to inherit directly each time the final simulation is run. This relationship also allows for alternatives to be simulated. Additionally, the lowest level element in the Definition Layer can inherit from multiple assessment blocks in the Assessment layer which enables the ability to assign several values to the component without additional model construction.

Lastly, the relationship between the Assessment Layer and the Source Layer is comprised of composition relationships. Each hypothesis is composed of every relevant piece of information and it either supports the hypothesis or does not support the hypothesis. This becomes relevant in the determination of the most likely hypothesis. In future research, it would be prudent to develop a new relationship element that allows for the determination of support to the hypothesis or its complement, does not support. This would allow for a more convenient method of applying binomial probability distribution which are further described within this paper. As of the writing of this paper, the value properties for belief mass are assigned manually at the hypothesis level. The composition of the source layer is intended for knowledge capture, traceability, and communication purposes.

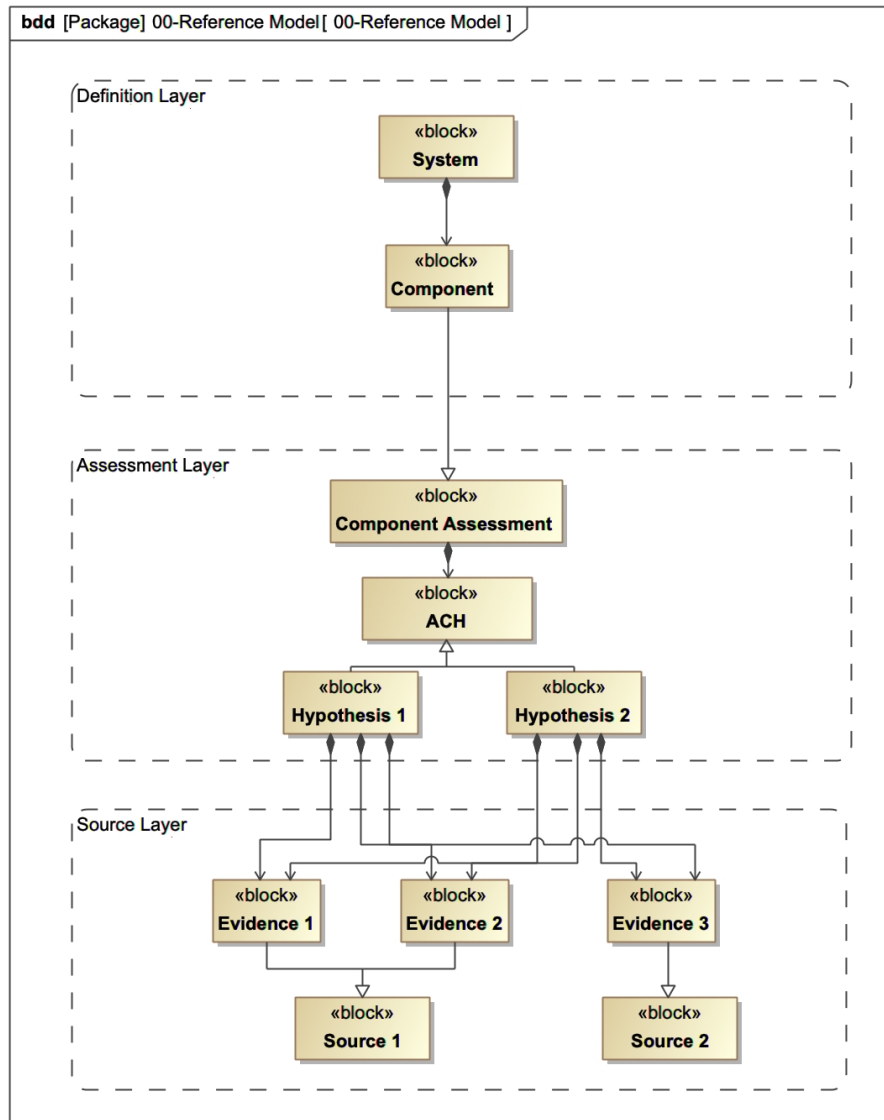


Figure 7: SysML Reference Model

Opinion Development

Due to the nature of predictive analysis, there will always be uncertainty in the prediction (Martin & Daim 2012). Because of this, it is important to capture the probability and the uncertainty of that probable outcome. This provides a high degree of

transparency to the stakeholder that may need to make decisions based on your assessment of the competitor. According to several works, subjective logic and belief functions hold a particular utility in determining probability while demonstrating uncertainty simultaneously (Škorić, de Hoogh & Zannone 2015)(Denoeux 2017)(Singh Sidhu 2014). Subjective logic uses the term “opinion” to express a belief function. This belief function is primarily used to demonstrate the trust between entities. The opinion is expressed as follows in the set of equations in Equation 1.

$$\omega_X^A = (b_X^A, d_X^A, u_X^A, a), \text{ where}$$

$$\{b, d, u, a\} \in (0,1) \text{ and } (b + d + u) = 1$$

$$b = \textit{belief}$$

$$d = \textit{disbelief}$$

$$u = \textit{uncertainty}$$

$$a = \textit{atomicity}$$

(1)

$$E(x) = \textit{expected value}, \text{ where}$$

$$E(x) = b + a \cdot u$$

(2)

The opinion is denoted by ω and represents the belief function from one entity to another and is stated as noted in Equation 1 as “A’s opinion on X.” The opinion is defined as a triple of belief, disbelief, and uncertainty in the source. The atomicity is included with the triple for calculation of the expected value further discussed below. The

atomicity is a Bayesian prior term. In most cases, the problem set is binomial and will use an uninformative prior of $a = 0.5$ in most situations (Pope & Jøsang n.d.). This prior could be affected by experience or other observable information. For instance, if a subject matter expert insists that one outcome is more likely than the other or history shows that the outcome is Hypothesis A 60% of the time, then that atomicity can be adjusted to $a = 0.6$ to account for that prior knowledge. The expected value of the opinion is the probability that the element in question can be trusted such as a sensor or individual in a social network. In the automobile example, the expected value provides the probability of the assessed system within the Definition Layer or the assessment in the Assessment Layer. The expected value is expressed as shown in Equation 2 (Arend 2020).

The probability of the system is computed with an opinion rollup pattern applied to the system and its alternative hypotheses. There are two main operators in subjective logic when introduced to a network—particularly a hierarchal structure—consensus and discounting operators. The consensus operator is used to determine the aggregation of multiple sources' opinions of the same topic. The discounting operator is used to determine the resulting opinion from a chain of opinions down to the base topic. For the purposes of the rollup pattern discussed later, the consensus operator is the only operator used. This is because the current model does not contain opinions of any other entity. The scope of the opinion rollup pattern could be broadened to include the discounting operator if the need for an opinion of another entity is required – for instance, the opinion of the validity of a source may be a potential application of the discounting operator. See Equation 2 to demonstrate the use of a consensus operator.

The rollup pattern was developed with a generalized formula for the consensus operator of two or more opinions, see Equation 3. The generalization in Equation 2 enables the creation of a new rollup pattern which was modified from the existing cost rollup pattern. The Jython constraint expression in the rollup pattern was modified to a specification resembling Equation 4 and the the necessary parts, value properties, and constraint parameters (MBSE Execution 2021c)(Dassault Systèmes n.d.). Note that if $b, d, \text{ or } u = 0$, the rollup pattern is constrained to fail because it does not meet the initial requirements. This will require each lowest level element in the rollup to have a non-zero term for every element of the opinion.

- Two opinions

$$\omega_X^A = (b_X^A, d_X^A, u_X^A); \omega_X^B = (b_X^B, d_X^B, u_X^B)$$

- Consensus Operator

$$\omega_X^A \oplus \omega_X^B = \left(\frac{b_X^A \cdot u_X^B + b_X^B \cdot u_X^A}{u_X^A + u_X^B - u_X^A \cdot u_X^B}, \frac{d_X^A \cdot u_X^B + d_X^B \cdot u_X^A}{u_X^A + u_X^B - u_X^A \cdot u_X^B}, \frac{u_X^A \cdot u_X^B}{u_X^A + u_X^B - u_X^A \cdot u_X^B} \right) \quad (3)$$

- Generalization of the Consensus Operator

$$\bigoplus_0^n \omega_X^i = \left(\frac{\sum_0^n \frac{b_X^i}{u_X^i}}{\left(\sum_0^n \frac{1}{u_X^i}\right) - n}, \frac{\sum_0^n \frac{d_X^i}{u_X^i}}{\left(\sum_0^n \frac{1}{u_X^i}\right) - n}, \frac{1}{\left(\sum_0^n \frac{1}{u_X^i}\right) - n} \right); \text{ where } n \geq 1, u > 0 \quad (4)$$

ACH Trade Study

An automobile example was developed to demonstrate the application of the opinion rollup pattern above and further elements of the discussion in this section. The example is the reference model applied to assessing an automobile. In this example, the Automobile is only composed of a Drive and a Radio for simplicity of demonstration. For these same reasons, a singular attribute of the Drive is being assessed, Drive Type, of which there are only 3 alternatives. The opinion rollup pattern was applied to the system Definition Layer and the Assessment Layer demonstrated in the example in Figure 4 and opinion values assigned where appropriate.

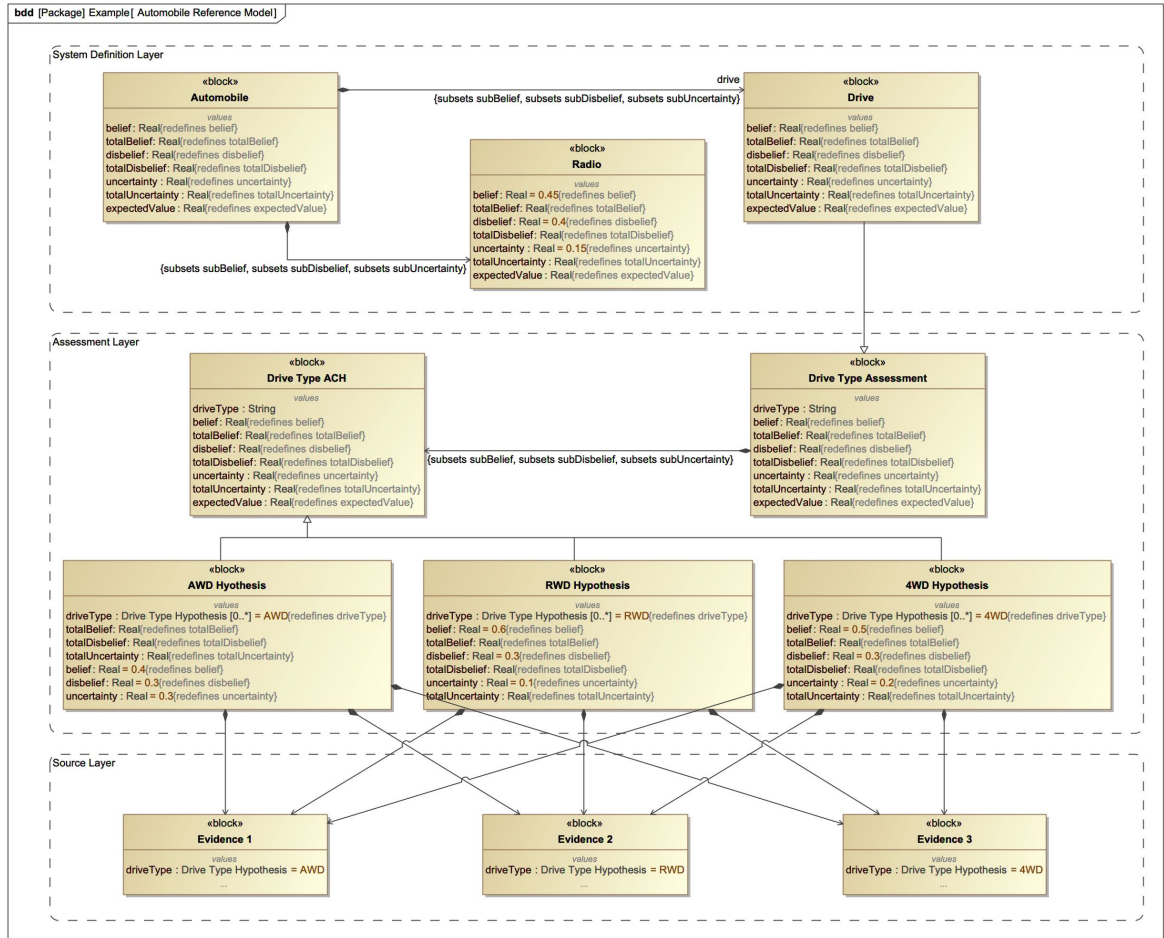


Figure 8: Reference Model Applied to Automobile Example

In the assessment layer, analysis of competing hypotheses (ACH) was implemented to express the alternative explanations of the evidence gathered. In this layer, hypotheses are alternatives to the ACH block and can be included in the opinion rollup pattern by adjusting the inherited values in the specialization to redefine the values in the generalization (Pope & Jøsang 2005). With the opinion rollup pattern applied, the likelihood of each alternative can be displayed in an instance table after running a

simulation of the Final Assessment block and defining the alternative – in the case of Figure 4, the Drive Type Assessment block within the Assessment Layer.

To determine the most likely alternative based on the expected value, a trade study is constructed similar to how system alternatives can be scored to determine the optimal configuration using an assigned objective function. In this case, the expected value serves as the objective function. The trade study is designed to evaluate all alternatives of the targeted element. When a trade study is applied to the Drive Type Assessment block in Figure 4, the trade study calculates the expected value for each alternative of the Drive ACH block and return the alternative with the highest expected value—the most likely hypothesis.

A trade study is applied to every ACH block in the assessment layer but is also applied to the system in the Definition Layer. The trade study in the Definition Layer is applied to the overall system which will select the most likely configuration based on all the alternative hypotheses in the Assessment Layer, show the winning configuration, probability, and uncertainty. To further the discussion, it can be shown that an automobile is more than just a drive train as currently shown in the example in Figure 4. If more components are added and ideally more assessments and evidence, then many alternative configurations will need to be evaluated. An automated trade study analysis is an ideal method for evaluating these alternatives. The automation enables the modeler to focus on the development of the analysis behind each forecast rather than determining the most likely configuration.

The methodology demonstrated in this paper uses SysML as the medium and is conducted irrespective of chosen tool with the exception of the following discussion

surrounding a specific use in Cameo Systems Modeler with the Cameo Simulation Toolkit—the simulation configuration tools. By defining the simulation using a simulation configuration, the user can easily run (and re-run) the simulation to obtain the most likely system configuration. This is done by applying the System Trade Study block as the executionTarget in the simulation configuration, see Figure 6 (a). The result of all the configurations are exported to a CSV (comma separated value) file to record all configurations. This can be crucial to communicate, particularly when the configurations have similar likelihood or large uncertainty (Ford 2021)(MBSE Execution 2021a)(MBSE Execution 2021b). The automated trade study simulation would ideally be run any time new sources and evidence is introduced or a new understanding of the evidence can be modelled. If the resulting configuration is unchanged, then no additional action would need to be taken. If the configuration did change, it would need to trigger downstream actions as well.

When new evidence is introduced to the model, the probability of the alternatives will change as well which could result in the need for a new simulation of the System trade study. The trade studies applied to the Component Assessment blocks in the Assessment Layer provide a “scope” into the assessments for further analysis. By having a trade study to evaluate the assessment within the ACH, it enables the modeler to understand the impact to the system configuration in a smaller workspace than the full system trade study. This saves significant time as the system models become more complex and number of alternative hypotheses increase drastically. Figure 5 illustrates the use of multiple trade studies within separate layers of the automobile example.

The automobile example in Figure 4 was simulated using the following configuration, see Figure 6 (a), to demonstrate the result of the trade study analysis. The results of this example provide the following instance table, see Figure 6 (b). The resulting opinion of the automobile is expressed as $\omega_{auto} = (0.5745, 0.3617, 0.0638)$ with an expected value of $E(x) = 0.6064$ and shows the most likely configuration with Rear Wheel Drive (RWD). Said differently, the assessed automobile configuration has a 60.6% probability of being comprised of the defined system composition including the RWD alternative with approximately 6.4% uncertainty.

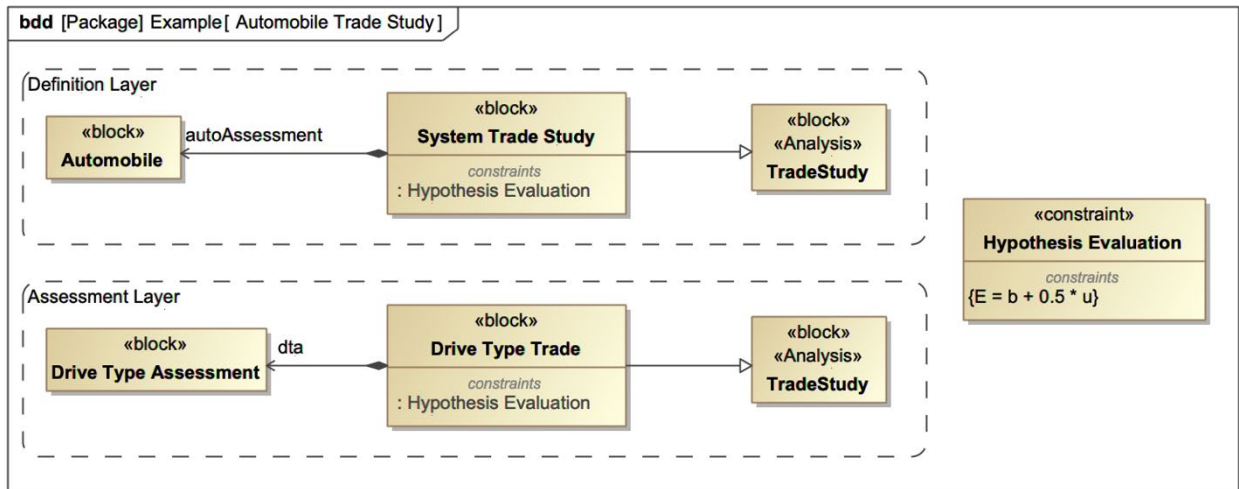
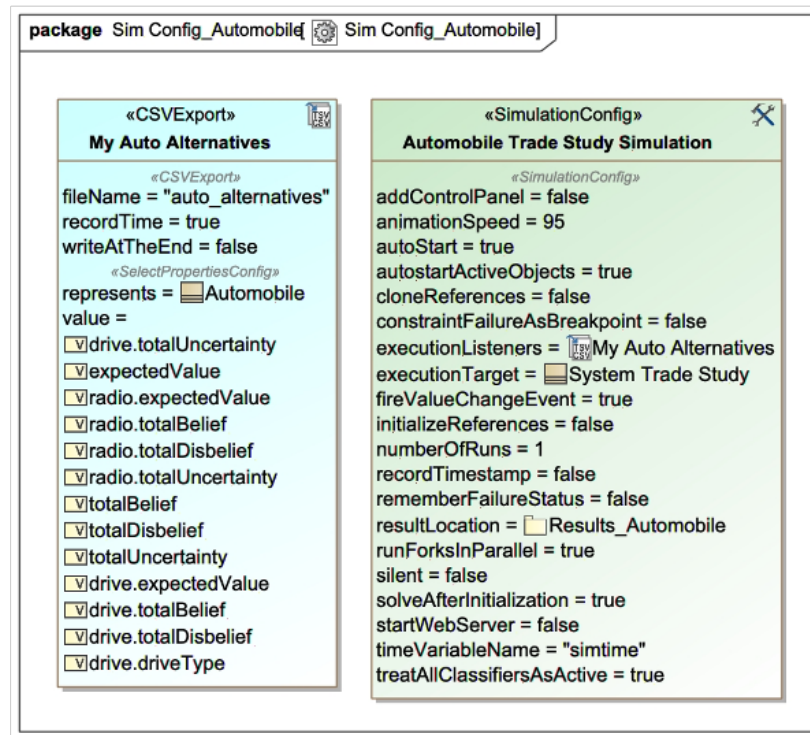


Figure 9: Trade Studies within the Assessment and Definition Layers

(a)



(b)

#	Name	N : Integer	score : Real	winner : String	autoAssessment.expectedValue : Real	autoAssessment.totalBelief : Real	autoAssessment.totalDisbelief : Real	autoAssessment.totalUncertainty : Real
1	system Trade Study	3	0.6064	hf_automobile : RWD Hypothesis	0.6064	0.5745	0.3617	0.0638

Figure 10: (a) Simulation Configuration, (b) Results from Automobile Example

Conclusion

The need to rigorously capture the assessment of a competitor's system was aided by the application of digital modeling techniques to the Systems Engineering Anti-Process Machine. In the past, capturing this knowledge was relegated to mental models and documentation-based approaches. Capturing knowledge in traditional methods resulted in interdependent knowledge that remains disconnected. This paper

demonstrated the utility of SysML to create a method of capturing this knowledge in an interconnected model by developing a model of the Anti-Process Machine that will in later studies allow communication of defined attributes between the Anti-Processes.

A conceptual layered approach provided a means of decomposing the problem set into layers associated with the problem: sources, assessments, and definition. The Source Layer provided a storage space and processing environment for sources and the associated items of evidence within those sources. The Assessment Layer provided an environment to conduct analysis – analysis of competing hypotheses was the tradecraft approach conveyed in this paper but it is not limited to this sole technique. And finally, the Definition Layer provided an environment to develop the generalized system which inherits from the lower levels of abstraction. This provided a framework that when applied to a specific example with assigned value properties was successfully able to communicate the information from the lowest layer of abstraction, Sources Layer, to the highest layer of abstraction, Definition Layer.

Once these layers are developed, subjective logic provided a means to form opinions and assign probability of an individual element. Currently, this is conducted by assigning opinion values directly to each hypothesis in the Assessment Layer and simulating the opinion rollup pattern that executed probability based on those assigned trust values and the associated constraint expression as shown in the previous section. Alternative hypotheses could then be evaluated based on supporting evidence by conducting a trade study in the Assessment Layer. The trade study determined the most likely hypothesis and assigned the associated values to the component being analyzed. A

trade study in this layer provided a means to observe lower level effects of the opinion – particularly, as new evidence was introduced.

Ultimately, the system definition and its associated composition is the output from the Design Exploration Anti-Process which is produced by simulating the system in the System Definition Layer. The associated trade study determines the most likely system while also capturing all potential alternatives and associated likelihoods. The most likely system and components then become the defined system to be used in other segments of the Anti-Process Machine.

The final result is the ability to not only define a system, likelihood, and uncertainty which are the typical properties associated with analytical assessments. But, the reference model also provides a means to capture the analytical process and trace the definition of the system to its associated hypotheses and sources of information that were used to develop those hypotheses. Further, this study demonstrated that it is possible to do all of these functions within a SysML tool to provide a digital model of this complex knowledge.

In the current state of the Anti-Process reference model, the information flow between the boundaries of each Anti-Process has not been established. In particular, the interfaces are used to demonstrate the flow of information, but have not been utilized to flow objects between Anti-Processes or the Anti-Process Machine and its external actors such as the collection apparatus and the organization blocks shown in Figure 1. Additionally, the method of assigning opinion values currently resides in the assessment layer. Ideally, the assignment of trust values would be transitioned to an automated evidence-based approach where the opinion values are automatically assigned to the

hypotheses in the assessment layer dependent on whether the evidence supports or does not support the hypothesis. Lastly, while the configuration derived in the simulation provides the most likely system, the definition of important attributes (e.g., mass) was not investigated. This is a critical feature so that the system definition being distributed to other segments of the Anti-Process Machine will have access to those value properties.

IV. Applying SysML Reference Model to Ford Bronco Case Study

Chapter Overview

The purpose of this chapter is to expand on the definition of technical competitive intelligence and develop an instance of the Systems Engineering Anti-Process Machine developed in Chapter II & III. The instance of the Anti-Process Machine is intended to demonstrate a small-scale use of the method using data collected surrounding a specific, real-world, scenario below. This will only explore a few of the individual Anti-Processes but explains the fundamental principles of the developed Model-Based Competitive Technical Intelligence (MBCTI) methodology. This chapter does not focus on developing the scope of assessments expressed in the definition layer of each Anti-Process needed for the appropriate forecast of the competitor, but only to demonstrate the application of the MBCTI method.

Scenario

In 2017, Ford announced it would return the Ford Bronco to production. The method for forecasting a future system described in this thesis will be used to retroactively “predict” the character of the Ford Bronco. A retroactive prediction case study was adopted so that the accuracy of the method could be determined based upon what the Ford Bronco eventually became. Specific care was taken to avoid researching the final configuration of the Ford Bronco so as not to contaminate the results of the method. This case study will explore the following Anti-Processes:

- Stakeholder Needs and Requirements Definition
- Business or Mission Analysis and Definition

- Operational Evaluation

The organization has been asked to develop an assessment related to the following Intelligence Needs:

- Has Ford Motor Company established a need for a 4x4 Midsize SUV?
- Does Ford Motor Company have a gap in market coverage for a 4x4 Midsize SUV?

The Anti-Processes were explored individually following the SysML reference model developed in Chapter III with the exception of Operational Evaluation – information in this Anti-Process was used as an input to Business Analysis.

Introduction

This paper is intended to formalize an investigation method to understand a competitor's system. While formalizing a method to investigate a competitor's system, it is also important to keep in mind the age of digital transformation. Many methods exist to predict an outcome and to analyze a problem, but making sure that this information can be consumed by individuals as well as serve a higher function to connect to other environments that need this information.

To address these two major concerns, we have chosen to investigate the use of the combination of competitive technical intelligence techniques, systems engineering, and SysML using Catia Magic System of Systems Architect with System Modeler Analysis plugin. Competitive technical intelligence provides a formalized methodology to address the development of an assessment while systems engineering provides a formalized

process of the development of the system. Lastly, the use of the intersection of SysML and Catia Magic provides a digital tool to address the continuous drive to replace document based processes, with digital driven processes.

The combination of aspects of competitive intelligence and systems engineering, we were able to derive a formalized system that provides a solid framework for the forecast of the thread of a competitor's system which we are calling the Systems Engineering Anti-Process (or Anti-Process for short). SysML provided a suitable framework for modeling a system as this is its intended purpose and is the de facto language for modeling a system. However, SysML did pose several challenges to capturing competitive intelligence. This required converting competitive intelligence, which is typically a human-driven process with largely analog methodologies, to elements that can be consumed by a computer. To address this, the SysML model was divided into three major categories: the Definition Layer, the Assessment Layer, and the Sources Layer. The definition layer is where typical systems engineering modeling would take place to include system definition, behaviors, viewpoints, etc. The Assessment and Sources Layers capture significant portions of the competitive intelligence problem set. Even here, it required leveraging further fields of research to develop the elements needed to construct a model of competitive intelligence.

Chapters II and III investigate the information above and worked towards isolated sections of the Anti-Process Machine – a term representing the larger process of interaction between the collection apparatus and the stakeholders requesting the information. This product broadens this research and investigates more fully the following Anti-Processes: Business/Mission Analysis, and Stakeholder Needs Definition.

We do this by devising a retrospective case study of the announcement of the Ford Bronco and constructing these sections of the Anti-Process machine to provide a preliminary assessment of the competitive market that the Ford Bronco would likely reside.

Background and Previous Works

Current Analytic Techniques.

This paper will explore many of the factors related to competitive intelligence. Competitive intelligence, sometimes referred to as corporate intelligence, refers to the ability to gather, analyze, and use information collected on competitors, customers, and other market factors that contribute to a business's competitive advantage. (Bloomenthal 2021) Rouach and Santi describe Competitive Intelligence (CI) as containing the following characteristics: it is an art of collecting, processing and storing information to be made available to people at all levels of the firm to help shape its future and protect it against current competitive threat – it involves a transfer of knowledge from the environment to the organization within established rules. (Rouach & Santi 2001) Further, the authors note that CI is not simply data, but that the data must be analyzed in order to create consumable information in the form of intelligence.

Based on research from Bartes, the typical intelligence cycle consists of 4 phases: collection, processing, analysis, and dissemination. The author further explains that combined with the larger scope of intelligence, it becomes apparent that there is a fifth very important phase: planning. (Bartes 2013) It is important to understand this because

as we iterate through the intelligence cycle, these are the nuances that explain why when one conclusion is reached, seemingly the process is started anew. This is because each time an intelligence question has reached a momentary conclusion, it results in new questions and additional need to further investigate. Said differently, the prior credence is affected by new evidence.

A critique from Gartin points out that analytical techniques in intelligence have largely used antiquated practices until very recently. Some future techniques rely on data science practices and structured analytic techniques. (Gartin 2001) Many structured analytic techniques provide general tools that the analyst can use to assist in developing assessments. (Heuer 2008) These techniques can be useful in certain situations, but don't always provide a full context to topic areas such as technical systems analysis. Technical competitive intelligence, a sub-set of competitive intelligence, offers a promising insight to maintain competitive advantage according to Muller. (Muller 2006) This intelligence type is focused on deriving the technological trend from various sources to understand the technological direction of a competitor for decision makers to develop competitive strategies. Further, philosophical approaches have been leveraged to approach requirements needed for competitive intelligence, but even these approaches fail to show how a system is developed and how those requirements are fulfilled. (De Rozario 2009) As mentioned by Gartin, data science techniques such as machine learning may be needed, but these techniques rely heavily on having highly prepared data with well labeled information for maximum impact. (Heinrich & Frye n.d.) Machine learning techniques may have future use, but first a structured framework is needed to assist in these future models.

In the case study of the Ford Bronco and transforming the problem set into a SysML model, one issue comes up almost immediately – how to decompose the information and capture the knowledge. With the use of SysML, a knowledge model of the system, assessments, as well as the sources used to build those assessments is being developed. According to Heuer, an additional iterative cycle exists within the analysis phase of the intelligence cycle (see Figure 1) (Heuer 2008). For instance, from an intelligence question, there is relevant information available. The intelligence cycle then suggests that a plan is developed, the information is collected, processed, analyzed, and finally disseminated. It is during the analysis phase that a set of alternative hypotheses are developed that could possibly explain the observations. (Mangio & Wilkinson 2008) This embedded cycle begins with an evaluation of the problem, then generate hypotheses, collect data, decide if a hypothesis can be selected, and then monitor (see Figure 11). The existing body of research does not expand on when it is appropriate to decide if a hypothesis can be selected or when enough information has been incorporated to move to the monitor stage of the cycle. For this research, this is treated as an ongoing cycle and new information can be introduced on any iteration.

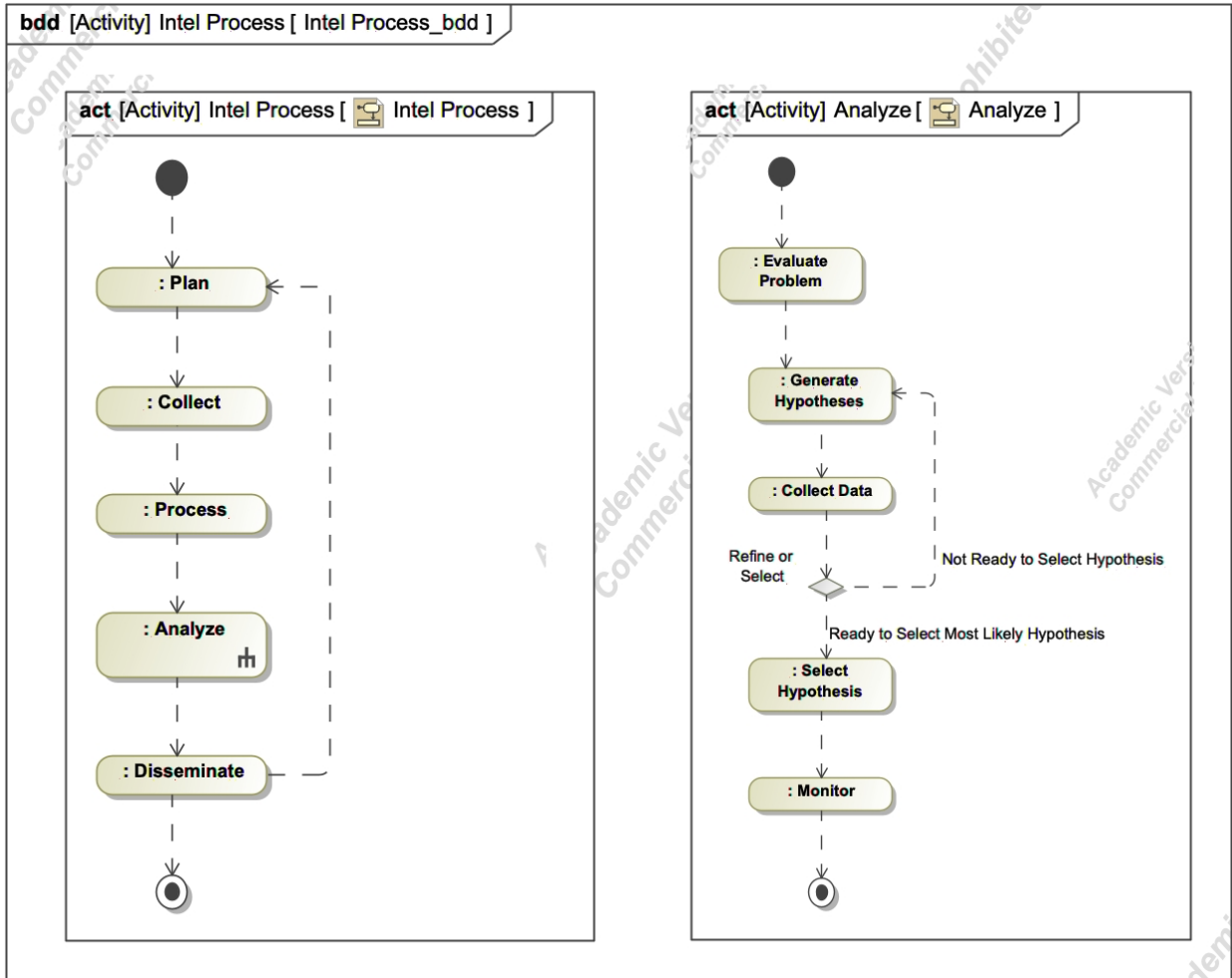


Figure 11: Analysis Process Imbedded in Intelligence Cycle

One additional expansion of the previous work in Chapter III is the addition of assigning a credibility opinion to the source and a reliability opinion to each item of evidence extracted from the source. This will come in the form of an opinion as before, $\omega = (belief, disbelief, uncertainty)$. This research does not explore the process of evaluating evidence or sources and is left for future research. Instead credibility opinions were assigned based on perceived closeness to the information. Josang et al. indicate that subjectively assigning an opinion to the reliability is a preferred method. This may seem

counter intuitive, but it provides an opportunity to express and capture the individual analysts subjective interpretation of the evidence. Further, subjective logic – the method used to update the assessment based on evidence – uses a discounting operator between these two opinions. Using the discounting operator in this way has been shown to lessen the impact of inadvertently introducing bias (Pope, Josang & McAnally 2006). This is partly because the source itself can be more objectively evaluated as compared to the evidence or information contained within that source. *(Note: If there is a widely agreed upon or otherwise acceptable means of assigning credibility or reliability from a particular category of intelligence, this should be used instead of subjective assignment).* See below for an example of the discounting operator being used to establish the likelihood.

$$CREDIBILITY = \omega_{SOURCE} = \omega_S = (0.8, 0.2, 0.0)$$

$$RELIABILITY = \omega_{EVIDENCE} = \omega_E = (0.6, 0.4, 0.0)$$

$$\omega^{S \circ E} = (b_S \cdot b_E, b_S \cdot d_E, d_S + u_S + b_S \cdot u_E)$$

$$b_{S \circ E} = 0.8 \cdot 0.6 = 0.48$$

$$d_{S \circ E} = 0.8 \cdot 0.4 = 0.32$$

$$u_{S \circ E} = 0.2 + 0 + 0.8 \cdot 0 = 0.2$$

$$\omega^{S \circ E} = (0.48, 0.32, 0.2)$$

To accommodate the updates, a new reference model had to be constructed (see Figure 12). The updates in the reference model demonstrated in Chapter III are noted in the case study which steps through an example of these uses.

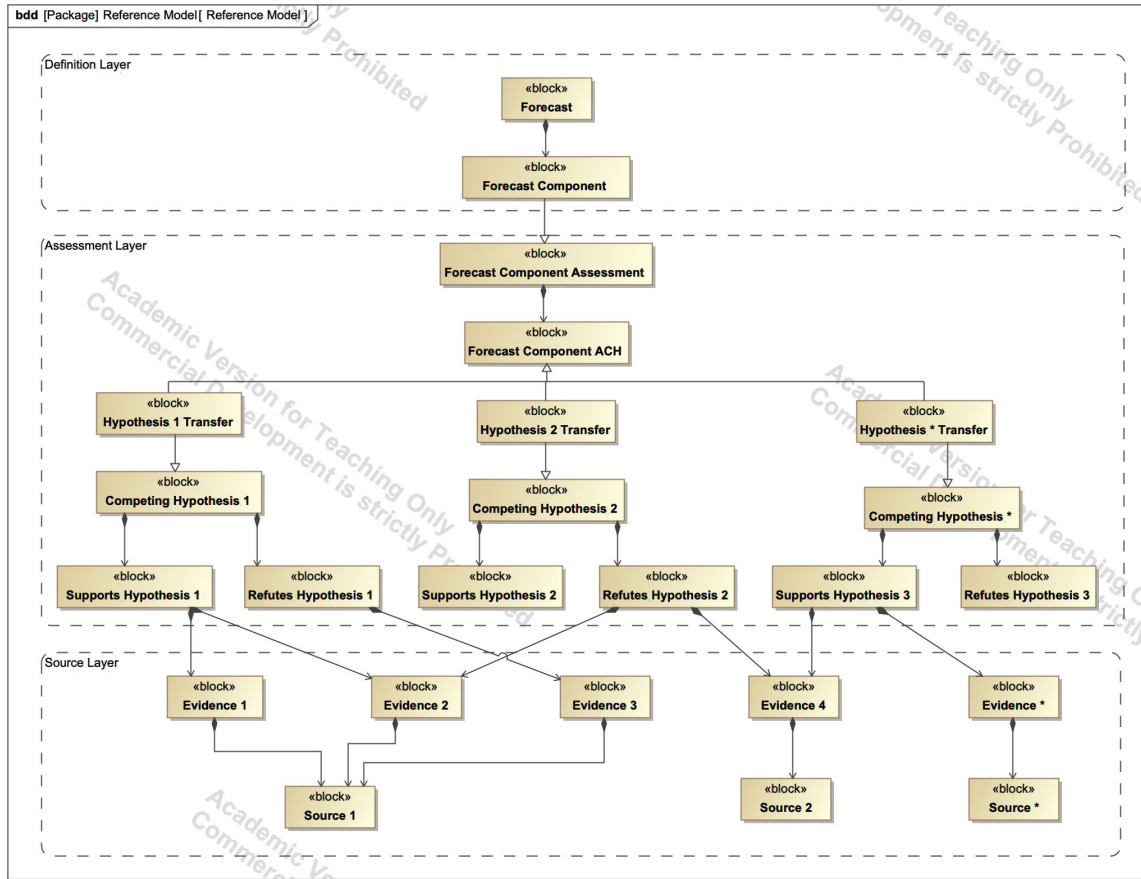


Figure 12: Refined Reference Model

Case Study

Stakeholder Needs Step-Through Example

The beginning of the intelligence cycle is planning, but the beginning of the Anti-Process Machine can be at any individual Anti-Process. For this case study, the intelligence need is a question: Has Ford Motor Company established a need for a 4x4 Midsize SUV? It is understood that the Ford Motor Company would likely establish this need based on the feedback and understanding of the consumer, but isn't relevant to distinguish to demonstrate the MBCTI method.

Logically then, the intelligence need is coming directly into the Anti-Process, Stakeholder Needs and Requirements Definition and is the starting point of this intelligence cycle (see Figure 13). The first step is to account for the evidence related to this need.

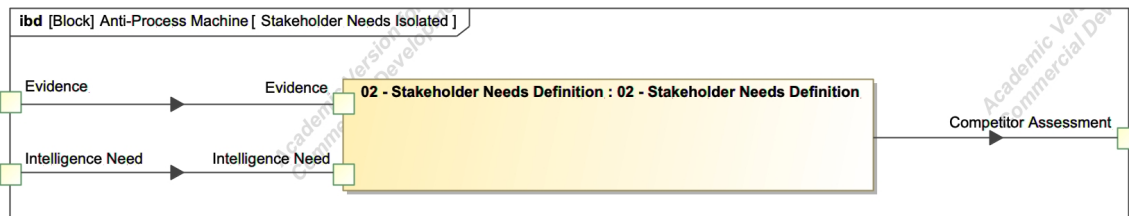


Figure 13: Flow Going To and From the Starting Point of This Analysis, Stakeholder Needs Anti-Process

Source Layer

Using the refined reference model (see Figure 12) as the guide to developing the model for this situation, the evidence is transitioned into the Source Layer of the model. At this stage there are several items of evidence to consider from one source for this intelligence need. The source is the announcement of the Ford Bronco. A Ford Motor Company President of the Americas announced that the Bronco would return and be a 4x4 midsize SUV for the adventurer outside the city. There were four items of evidence extracted from this statement to assist in determining the assessment.

- Source 1. The Ford President of the Americas
 - Evidence 1. The Bronco will be a 4x4 SUV
 - Evidence 2. The Bronco will be a Midsize SUV
 - Evidence 3. The Bronco will be a for a thrill seeker

Evidence 4. The Bronco will be for outside the City

$$\omega_S = (0.8,0.1,0.1)$$

$$\omega_{E1} = (0.5,0.3,0.2)$$

$$\omega_{E2} = (0.6,0.2,0.2)$$

$$\omega_{E3} = (0.4,0.5,0.1)$$

$$\omega_{E4} = (0.4,0.3,0.3)$$

This is the first of the notes demonstrating the differences from the original to the updated reference model. The relationship has changed between the evidence stereotyped blocks and the source stereotyped blocks from an inheritance relationship to a composition relationship (see Figure 14). This is due to the added opinions at this level. To reduce complexity and increase re-use, the same constraint used to apply the OpinionRollupPattern in the reference model example was modified to incorporate the discounting operator. The OpinionRollupPattern details are contained in Appendix A for reference. If each item of evidence was simulated at this point, it would have its own reconciled opinion (see Table 3).

Table 3: Reconciled Opinions for Evidence

Evidence	Source Credibility	Evidence Reliability	Reconciled Opinion
4x4 SUV	(0.8,0.1,0.1)	(0.5,0.3,0.2)	(0.4,0.24,0.36)
Midsize SUV	(0.8,0.1,0.1)	(0.6,0.2,0.2)	(0.48,0.16,0.36)
Thrill Seeker	(0.8,0.1,0.1)	(0.4,0.5,0.1)	(0.32,0.4,0.28)
Outside City	(0.8,0.1,0.1)	(0.4,0.3,0.3)	(0.32,0.24,0.3)

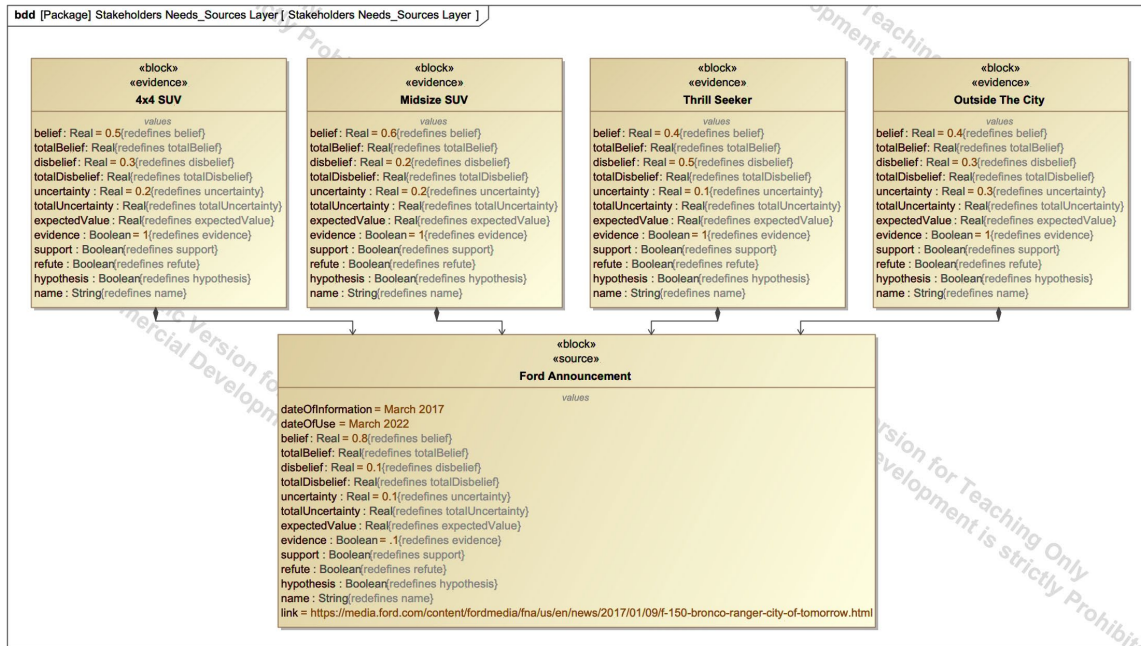


Figure 14: Source Layer Example

Assessment Layer

From there, the assessment layer was developed. One assessment is being made: Ford’s need of a 4x4 midsize SUV. This has been broadened based on the tradecraft described earlier not to satisfy or bias the continued collection. The assessment being considered here is the Bronco Vehicle Type Need. This allows the analyst to consider possible options other than 4x4 Midsize SUV. In fact, three hypotheses have been considered: Standard Midsize SUV, 4x4 Midsize SUV, and No Vehicle. The last is the consideration that Ford doesn’t actually have a need in this area and the announcement is some type of misinformation.

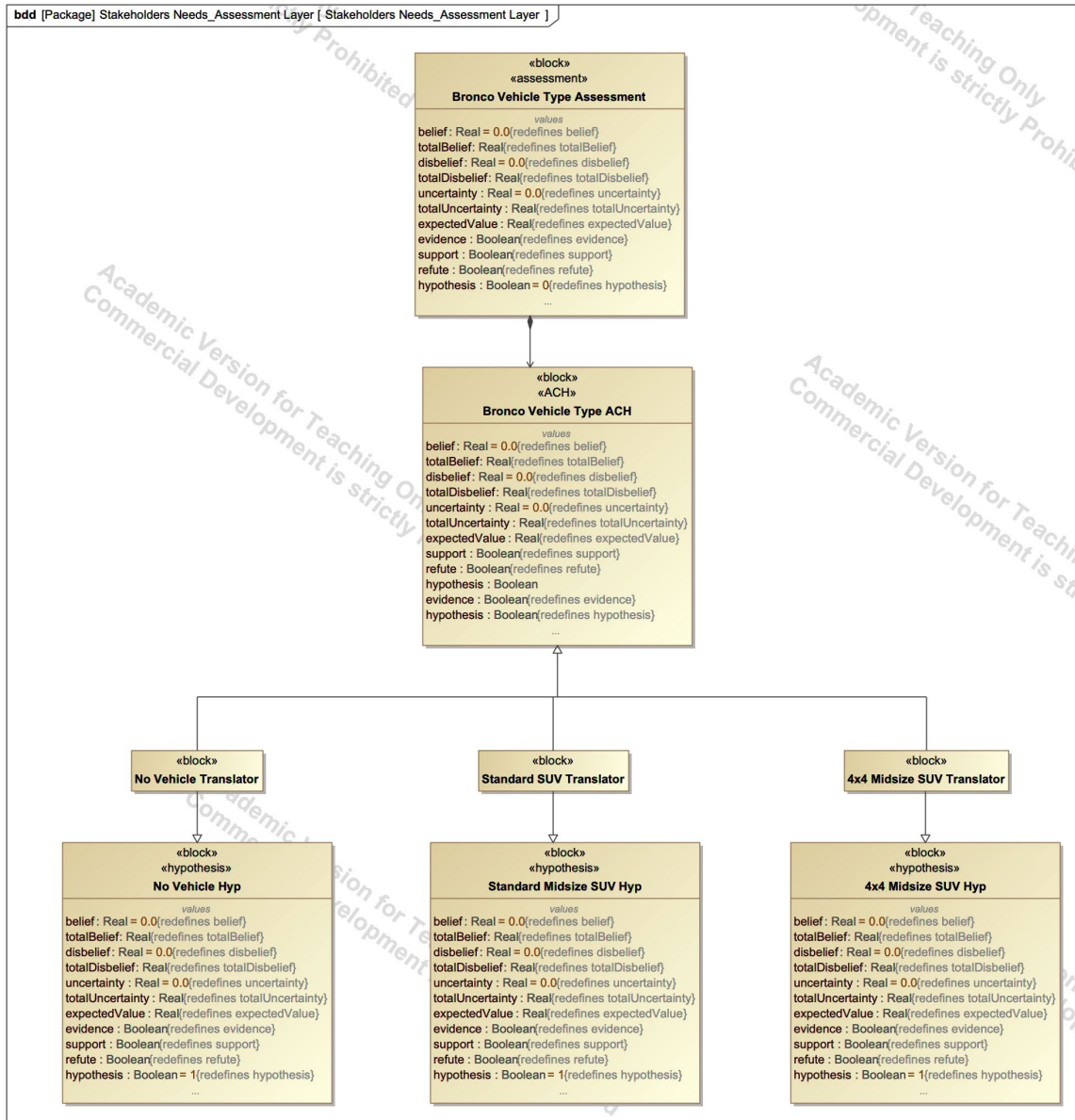


Figure 15: Assessment Layer Example

Again, there is a slight difference from the previous reference model described in Chapter III. First is the relationship between the hypotheses and the items of evidence. To calculate the opinion of each hypothesis, the evidence is first categorized into supporting or refuting evidence, this is shown below for the Standard Midsize SUV Hypothesis (see

Figure 16). This is calculated by transforming the opinion into a support and refute function and then back to an opinion for the hypothesis as shown in the series of equations below (Pope & Jøsang n.d.).

$$r \equiv \text{Supporting Evidence}, s \equiv \text{Refuting Evidence}$$

$$r = 2 \cdot \sum_{i=1}^n \frac{b_{\text{Supporting Evidence}_i}}{u_{\text{Supporting Evidence}_i}}, s = 2 \cdot \sum_{i=1}^n \frac{d_{\text{Refuting Evidence}_i}}{u_{\text{Refuting Evidence}_i}}$$

$$b_{HYP} = \frac{r}{r + s + 2}, d_{HYP} = \frac{s}{r + s + 2}, u_{HYP} = \frac{2}{r + s + 2}$$

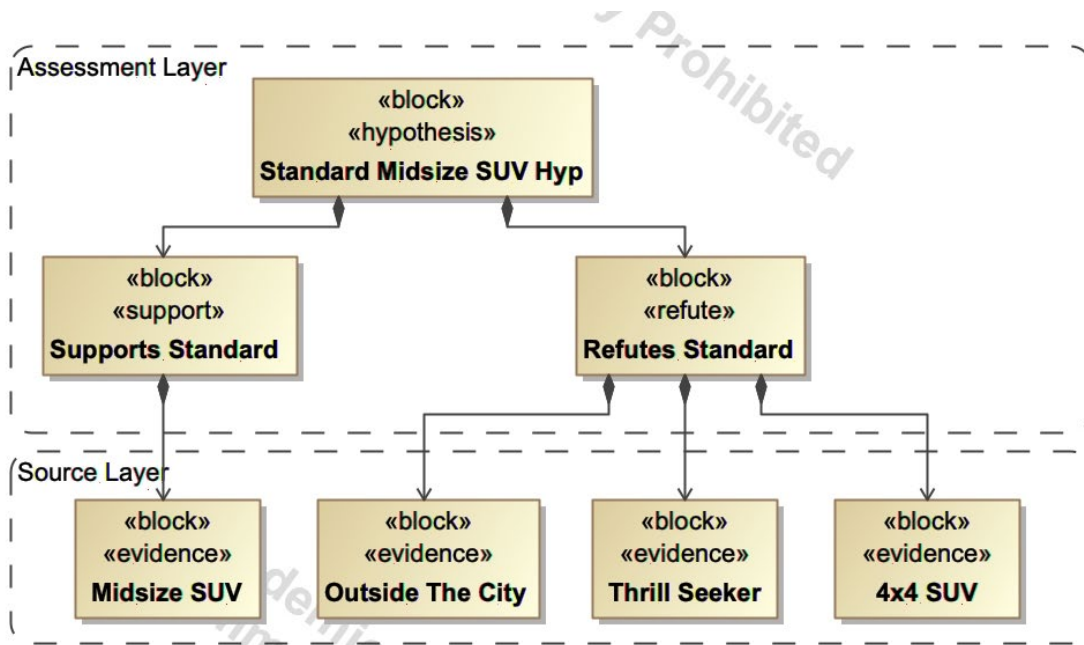


Figure 16: Relationship Between Hypothesis and Evidence

The other change in the assessment layer is the addition of a “translator” block between the «ACH» stereotyped blocks and the «hypothesis» stereotyped blocks. This was done because of the way in which a simulation is conducted that evaluates the

alternatives at this level. With the addition of conditional statements in the jython script in the constraint expressions that control the calculation in the OpinionRollupPattern, the simulation needed a degree of separation between the «hypotheses» and the «ACH» stereotyped blocks. This largely represents the same intention as before, but simply allows the simulation to run.

At this point, it is there are many calculations being conducted as the simulation is being conducted. Some of them have been discussed so far. To visualize the effect, a series of graphs have been included to show how the statistical representation of each hypothesis is changed with the addition of evidence. In particular, the change in the resulting belief function represented by a Beta distribution curve is shown for the Standard SUV Hypothesis (see Figure 17). The left column represents the evidence applied sequentially and the right column represents the statistical representation in the belief of that hypothesis. From top to bottom, the resulting is slowly transformed. Two particular observations are of particular importance.

1. The likelihood of the hypothesis is reduced when refuting evidence is introduced and increased when supporting evidence is introduced.
2. The uncertainty is reduced each time evidence is introduced regardless of whether the information supports or refutes the hypothesis.

Both of these behaviors match expectations both mathematically and intuitively. Intuitively, the result can be explained as follows. When considering a position on a topic, as information is introduced that agrees with a particular position, that position is reinforced. The corollary to this is when information is introduced that disagree with a

position, the position is suppressed. In contrast, the more iterations of reinforcement or suppression, the more strongly the position is held.

Effects of Evidence on Hypothesis (Standard SUV)

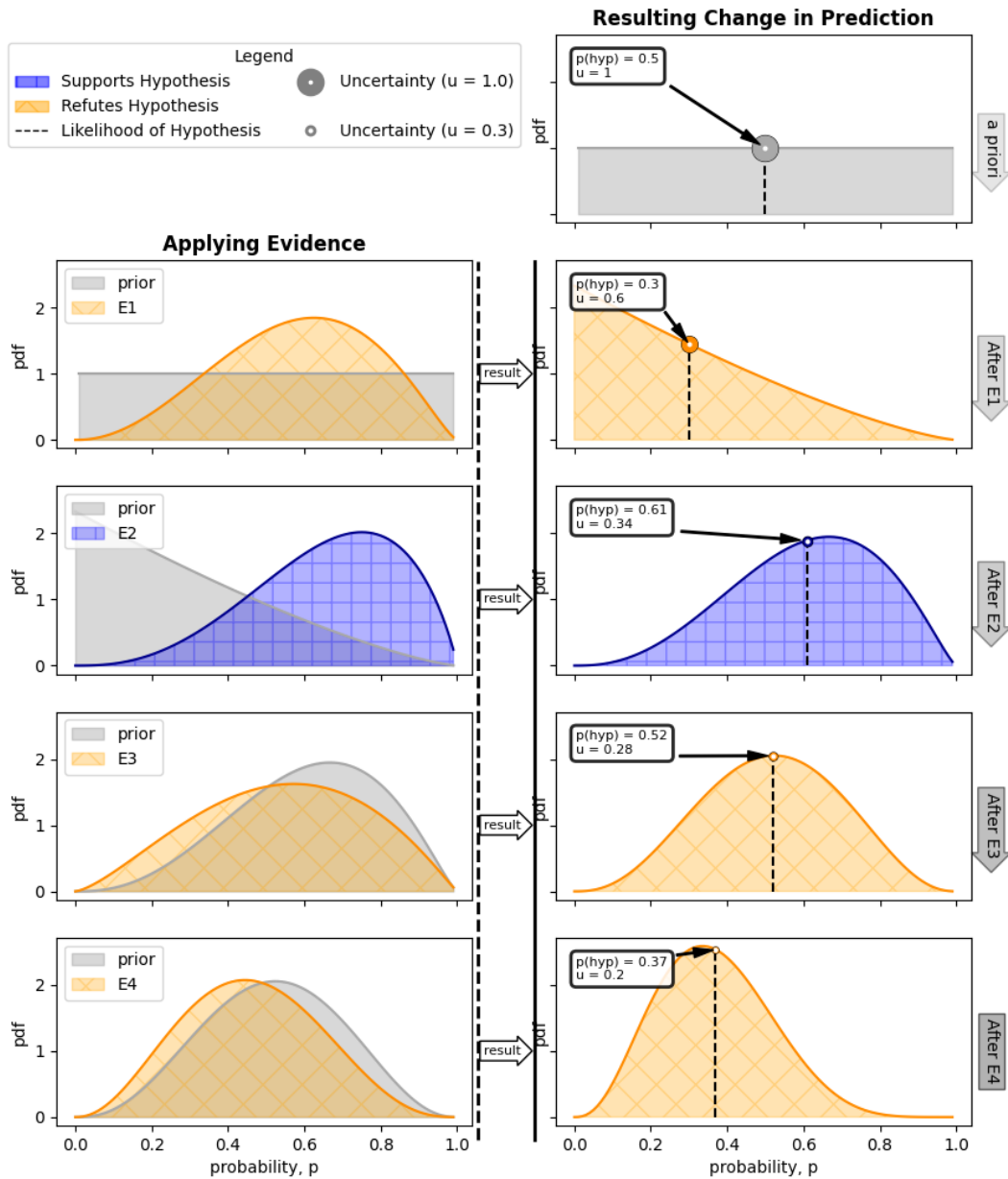


Figure 17: The Effects of Evidence on the Standard SUV Hypothesis

The results of all the ACH are shown in the tables below and a visual representation has been provided as well.

Table 4: Results of ACH of Vehicle Type for the Ford Bronco

Bronco Vehicle Type ACH			
Hypothesis	4x4 Midsize	Standard Midsize	No Vehicle
Likelihood	0.91	0.37	0.12
Uncertainty	0.19	0.20	0.24
Opinion	(0.81,0.0,0.19)	(0.27,0.53,0.20)	(0.0,0.76,0.24)

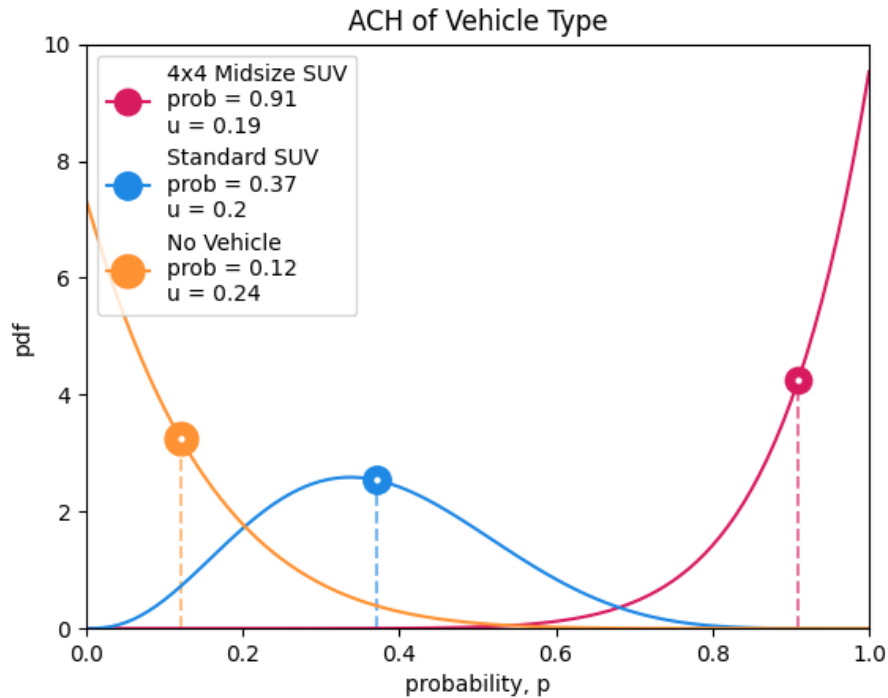


Figure 18: Results of ACH for the Vehicle Type of the Ford Bronco

Definition Layer

In this case study, the resulting definition layer is not particularly interesting. However, it is essential to how the analysis and model is constructed. In the definition layer, the composition of the analysis is constructed. For the Ford Bronco stakeholder needs, the definition layer contains the business need which is currently composed of the need of a 4x4 midsize SUV (see Figure 20). The «forecasted component» hosts the selected hypothesis. Said differently, the most likely hypothesis is reflected in the definition layer as the forecast of that component. In the case of this «forecasted component», Need of a 4x4 Midsize SUV takes on the opinion of the 4x4 Midsize SUV «hypothesis»: $\omega_{NEED} = (0.81, 0.0, 0.19)$

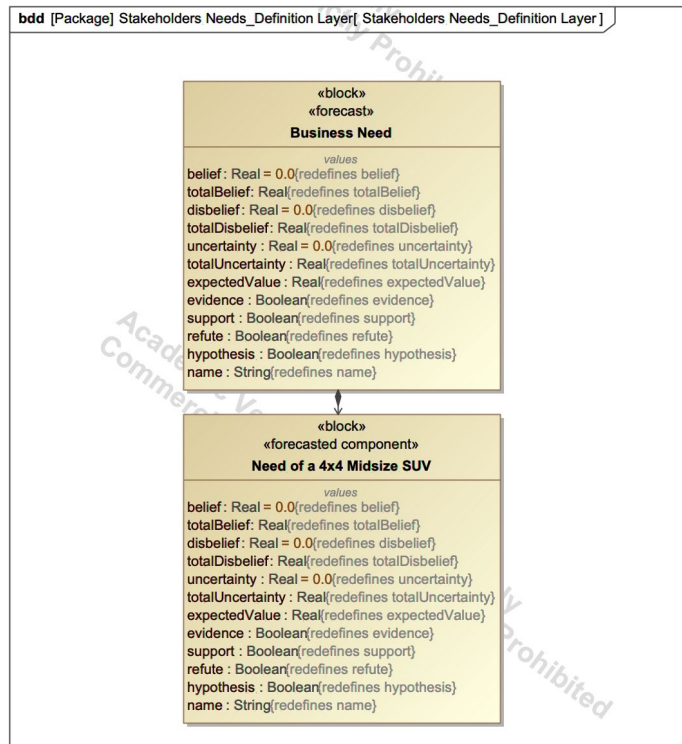


Figure 19: Definition Layer Example

Forecast Results

As shown in Chapter II and III, this analysis is done in support of the organization or stakeholders. The results of the analysis, typically what would reside in the Definition Layer of the Anti-Process model, is the output to the organization. Two intelligence needs were identified and two results were created. To automate this calculation as demonstrated in Chapter III, a trade study is developed at the applicable level. Similarly, this was developed for both «forecasts» in the case study (see Figure 20). The objective function – or more generically, the scoring function – is the expectation value based on the «forecast» opinion: $E(x) = b_{forecast} + 0.5 \cdot u_{forecast}$. For this trade study to run, the

appropriate configuration of the internal structure is constructed so that a simulation can execute and compare all of the relevant alternatives (see Figure 21 and Figure 22). The simulation configuration, as mentioned in Chapter III, is a specific feature of the tool—Catia Magic System of Systems Architect with System Modeler Analysis plugin (see).

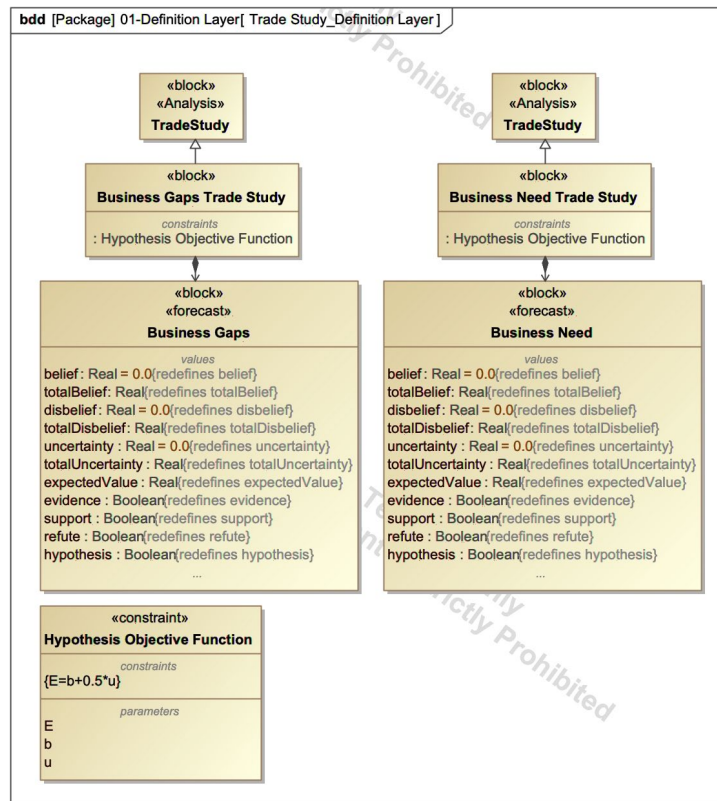


Figure 20: Trade Studies Used for Automated Forecasting

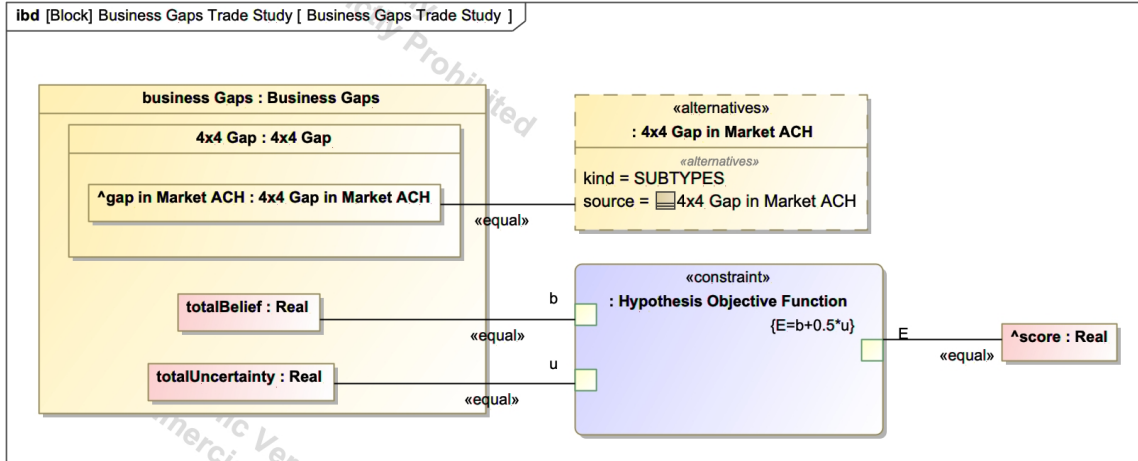


Figure 21: Internal Block Diagram of Gaps Trade Study

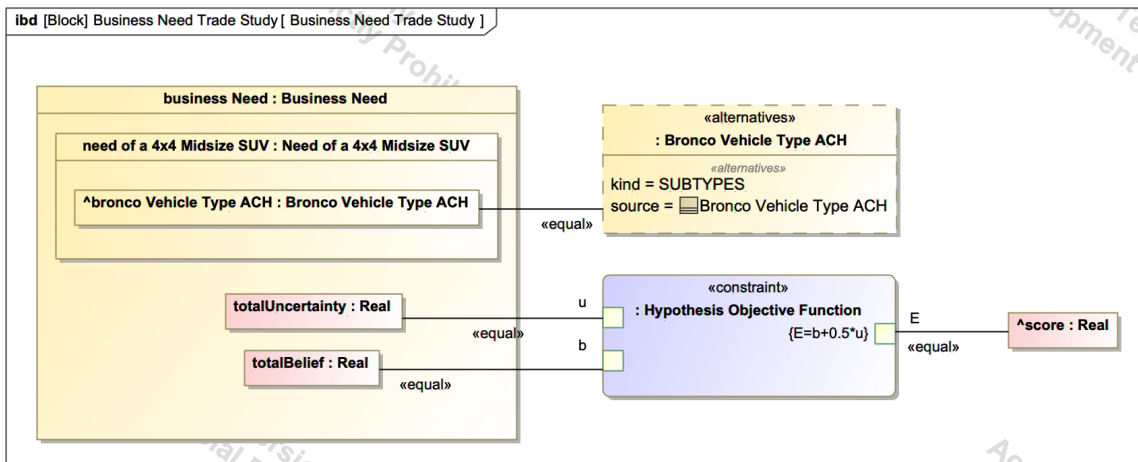


Figure 22: Internal Block Diagram of Needs Trade Study

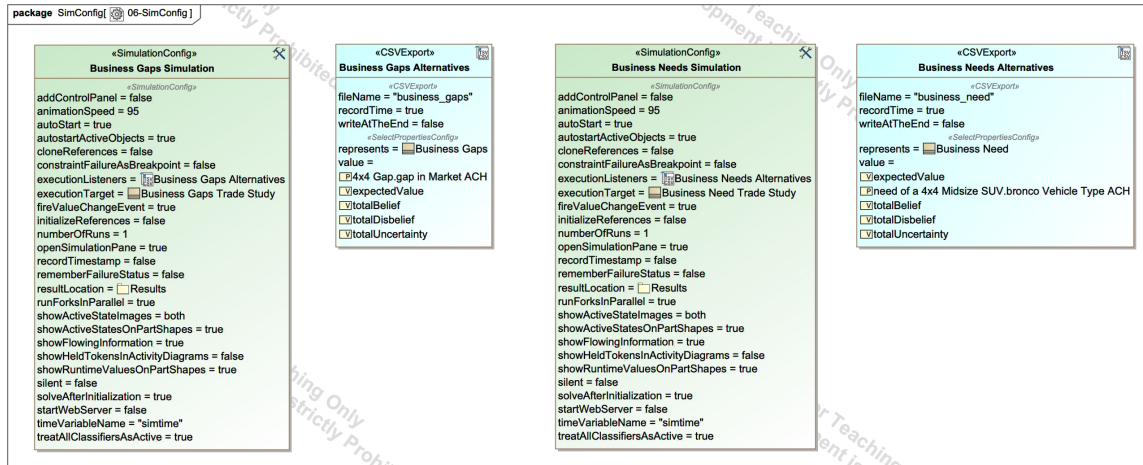


Figure 23: Simulation Configuration Diagram for Gaps and Needs Trade Study

The results of those simulation configurations are captured below (see Table 4, Table 5, Figure 24, & Figure 25). The tables below highlight the most likely hypothesis with a bold box. With this, the forecast provided to the organization is this:

- Ford has very likely (0.91) expressed a need to develop a 4x4 midsize SUV with low confidence (0.19).
- Analysis of the market of midsize SUVs and 4x4 midsize SUVs indicates that Ford very likely (0.85) has a gap in market coverage for 4x4 midsize SUVs with low confidence (0.29).

Table 5: Results of ACH of Vehicle Type for the Ford Bronco

	Bronco Vehicle Type ACH		
Hypothesis	4x4 Midsize	Standard Midsize	No Vehicle
Likelihood	0.91	0.37	0.12
Uncertainty	0.19	0.20	0.24
Opinion	(0.81,0.0,0.19)	(0.27,0.53,0.20)	(0.0,0.76,0.24)

Table 6: Results of ACH of Market Gap for Vehicle Type for Midsize SUVs

Gap in 4x4 Market ACH			
Hypothesis	Gap in 4x4	Gap in Standard	Gap in Both
Likelihood	0.85	0.39	0.34
Uncertainty	0.29	0.77	0.67
Opinion	(0.71,0.0,0.29)	(0.23,0.0,0.77)	(0.0,0.33,0.67)

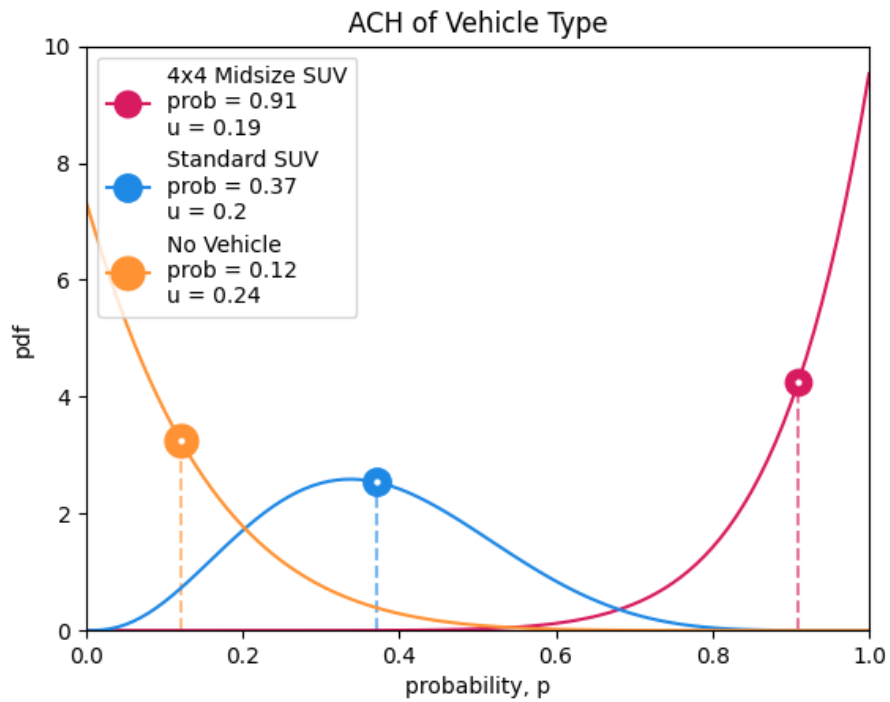


Figure 24: Results of ACH for the Vehicle Type of the Ford Bronco

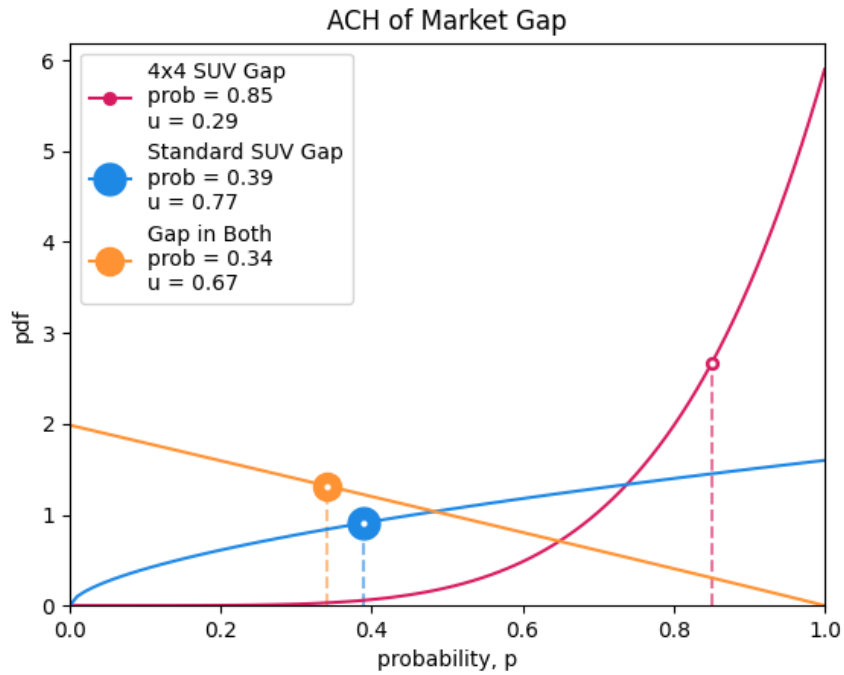


Figure 25: Results of ACH of the Gaps in Market for Midsize SUV Types

Updating the Model

One of the key utilities of this model-based approach is the ability to dynamically update the model. This can be done in three major categories:

1. Changing or updating the opinion of the reliability of evidence or the credibility of the source,

For instance, if a source of information is followed over time and the credibility is tracked, updates to the credibility will change the resulting forecast. To demonstrate, imagine if the President of the Americas for Ford Motor Company, who made the announcement about the Ford Bronco, was tracked over time to determine how often his statements accurate. And after some amount of time, the following change in opinion was

developed. This would result in a change in the reconciled opinion between the evidence and the source. Introducing much less belief and increased uncertainty in the case below.

$$\omega_{S0} = (0.8,0.1,0.1); \omega_{S1} = (0.6,0.2,0.2)$$

Table 7: Effects of Updated Credibility

Evidence	Source Credibility $\left(\frac{\omega_{S0}}{\omega_{S1}}\right)$	Evidence Reliability	Reconciled Opinion $\left(\frac{\omega_0}{\omega_1}\right)$
4x4 SUV	(0.8,0.1,0.1)	(0.5,0.3,0.2)	(0.4,0.24,0.36)
	(0.6,0.2,0.2)		(0.3,0.18,0.52)
Midsize SUV	(0.8,0.1,0.1)	(0.6,0.2,0.2)	(0.48,0.16,0.36)
	(0.6,0.2,0.2)		(0.36,0.12,0.52)
Thrill Seeker	(0.8,0.1,0.1)	(0.4,0.5,0.1)	(0.32,0.4,0.28)
	(0.6,0.2,0.2)		(0.24,0.3,0.46)
Outside City	(0.8,0.1,0.1)	(0.4,0.3,0.3)	(0.32,0.24,0.3)
	(0.6,0.2,0.2)		(0.24,0.18,0.58)

2. Changing the underlying atomicity or base rate of the prior within the alternative hypotheses.

This is a much more subtle change and one that is not recommended. This change effects the likelihood by addressing the atomicity of the uninformed prior. Said differently, this affects the likelihood of a hypothesis before any evidence is introduced. This is only recommended in a situation where an expert opinion needs to be included that cannot be treated as a source. To demonstrate, the atomicity of the hypotheses in the Standard Midsize SUV Hypothesis was changed from 0.5 (even chances) to 0.8 (very likely).

$$\omega_{HYP1} = (b, d, u, a) = (0.27,0.53,0.2,0.5)$$

$$\omega_{HYP2} = (0.27,0.53,0.2,0.8)$$

While the opinion of the hypothesis is unchanged the expectation value is considerably different. $E(x_{HYP1}) = 0.27 + 0.5 \cdot 0.2 = 0.37$; $E(x_{HYP2}) = 0.27 + 0.5 \cdot 0.8 = 0.67$. While this doesn't change the winning hypothesis in this particular situation, it is not recommended because it introduces a bias. This bias could inappropriately effect the forecast if not carefully monitored.

3. Adding elements to the model.

Finally, adding elements to the model is the most rational method to updating the model. This was done to construct the case study itself. But, beyond adding new evidence or sources, creating new ACH, or developing a new forecast, there is a means to interconnect the results of one ACH to other hypotheses. For instance, if the result of an ACH from one Anti-Process supports or refutes the hypothesis in another Anti-Process, this can be included in the "evidence" supporting that hypothesis. A demonstration from the case study is below. Within the Business Analysis Anti-Process, the result of the Gaps In Market «ACH» forecasted that Ford had a gap in 4x4 Midsize SUVs. The Gap in 4x4 «hypothesis», then supports the 4x4 Midsize SUV «hypothesis» in the Stakeholder Needs Anti-Process. As expected, the likelihood of this hypothesis increased by this added information.

$$\omega_{HYP1} = (0.81, 0.0, 0.19); E(x_1) = 0.91$$

$$\omega_{HYP2} = (0.87, 0.0, 0.13); E(x_2) = 0.94$$

Discussion

The Systems Engineering Anti-Process Machine provides a rigorous approach to intelligence analysis. As shown in the case study, the modeling structure is a convenient method to break the analytic problem into its fundamental pieces. By following the SysML reference model and applying subjective logic to the analysis of competing hypotheses analytic technique, the analysis transitions from largely qualitative to quantitative analysis. This model-based approach provides a more dynamically updated knowledge capture. As new information is discovered, it can be introduced to the model and the results can quickly be updated. While not explored in the case study, the system model developed in the system exploration Anti-Process would provide a rich environment to explore the competitor's system and define it using typical system modeling methodologies. In addition to the preferred quantitative analytic results and the increase in dynamic update, there is one emergent property that is of significant importance to technical competitive intelligence analysis: traceability.

Traceability

It is important that the analysis of technical systems be highly traceable. This is important because it allows the analyst to express how they developed the forecast. The information in the definition layer allows those interested in the high level forecast to see what «forecast components» built up the forecast and what assessments those components are inheriting from. The inheritance from the assessment layer indicates to the viewer that there has been analysis conducted against this forecast. This is valuable because occasionally, a parametric model of the forecast may need a component that has not been analyzed. In such a case, a placeholder can be constructed and express that

sentiment to the consumer. The assessment layer expresses all the assessments being made and all alternatives that have been considered. Further, this layer maps to the evidence in the source layer that either supports or refutes each hypothesis. Lastly the evidence demonstrates the information that was extracted from each source and that what sources were included in the analysis. The combination of the model structure, conceptual layers, and the graphical language of SysML provide an expressive means to communicate and capture the knowledge of the analyst.

MBCTI as a Digital Thread

Further, MBCTI was shown to demonstrate several of the aspects of the digital thread for intelligence analysis of a competitor's system. The model of the Anti-Processes demonstrate analysis of the various stages of the lifecycle of the competitor's system. This provided an insight to the entire lifecycle, both across the breadth of the lifecycle and into the depths of it as well. Additionally, MBCTI provided a digital thread of the competitive technical intelligence analysis itself. This aspect demonstrated the process of intelligence analysis and captured it in a digital model for use and re-use as new information came in. Further, it introduced uncertainty as an integral segment of the analysis demonstrating the uncertainty of each Anti-Process within the thread.

V. Conclusions and Recommendations

Introduction

The goals of this research were to develop a system model for a competitor's system and a model-based approach for the prediction and analysis of a competitor's system. More specifically, the primary goal was to develop a model-based approach for analysis with the development of a competitor's system as the underlying framework from which the analysis is built.

Summary

Objective 1: Develop a robust model-based approach that captures the analytical process with an open structure so that information can be added or refined.

This objective was ultimately achieved by the combination of the Anti-Process Machine and the SysML reference model developed for each Anti-Process. The MBCTI method demonstrated the ability to update the model and autonomously shift the outcomes of the analysis of competing hypotheses.

Objective 2: Identify processes (systems engineering anti-processes) that support the generation of a system reference model for threat assessments.

This area was explored in Chapter II where the Anti-Processes were derived from the Systems Engineering Technical Processes and aspects of technical competitive intelligence were introduced to integrate the world of systems development with

intelligence analysis of technical systems. This objective was ultimately used to build the MBCTI in Objective 1.

Objective 3: Identify methodologies within MBSE to support unique uses within the IC

This objective was investigated thoroughly in the initial development of a SysML reference model in Chapter III and then expanded on in Chapter IV when applied to a case study of the Ford Bronco. This is one of the most promising outcomes of this research as it allows a systematic, model-based process to analyze a competitor while also integrating the necessary attributes of intelligence analysis including traceability, forecasting, likelihood statements, and uncertainty statements. Further, the reference model developed is a structure that is more dynamic than a document-based practice.

Objective 3a: Assign likelihood and confidence level to assessments

The use of subjective logic enabled a quantitative approach to express the likelihood and uncertainty of an assessment or forecast.

Objective 3b: Distinguish attributes if associated with judgement derived assessments or source derived assessments

As shown in the traceability section of Chapter IV, the traceability is expressed through the graphical representation of SysML. This would provide downstream analysts and other stakeholder with a means to determine where analytical gaps lie.

Objective 3c: Identify gaps in knowledge base and generate list of unknowns

Much like Objective 3b, this was a part of the emergent property of traceability. While a list isn't generated from the model, it does serve to capture what information is being

considered in the model so that any analyst or stakeholder can determine if more information is needed.

Objective 3d: Identify impacted higher-order assessments and reports if attribute assessments are changed

This objective was achieved largely through the use of the tools trade study capabilities. By establishing a simulation through the simulation configurations, the analyst can run (and re-run) the simulation to determine confidence level. When the trade study simulations are run, the resulting information is stored in an instance table that will show each run which will allow the analyst to determine if there has been a significant change.

Recommendations for Future Research

Expand the MBCTI to Include a Digital Twin: Interoperability with a System Model and Other Domain Models. This research explores the use of SysML as a modeling paradigm for assessing and forecasting a system and its associated development, maintenance, operation, and sunset. In the age of digital transformation, it would be useful to understand how those forecasts could be used to inform other modeling platforms such as physics based models (e.g., STK), mathematical models (e.g., MATLAB), 3D CAD models (e.g., SolidWorks), or other simulation models (e.g., Modelica). This would be a the exploration of a Digital Twin intertwined with a Digital Thread. The MBCTI method demonstrated in this paper could be used as the model-based approach to intelligence analysis, maintain the thread of the competitor, and develop a system model in the System Design Exploration and System Definition Anti-Process. The system model could then be integrated with the domain models noted above

as the analysis in the Disciplinary System Analysis Anti-Process. These two Anti-Processes combined would represent the Digital Twin of the competitor's system.

Murphy proofing. There are many aspects of the model that currently require a decent understanding of SysML and the tool that was used, Catia Magic System of Systems Architect with the Magic Model Analyst plugin. Finding methods to limit the error of use could significantly improve the useability of the reference model.

Automation of Ingesting Evidence. Evidence is a significant portion of the information used to develop a forecast of the competitor's system. A means to automate this practice could be extremely useful. A possible solution could be the research and development of opaque actions that scrub known resources for information and use machine learning algorithms to categorize them into the appropriate Anti-Process for an analyst to determine how to build into the analysis.

Source Credibility. Assigning source credibility has significant effects on the parametric model of belief and likelihood. A rigorously defined approach to assigning this opinion is a needed element to reduce the bias of subjectively assigning credibility scores.

Source Diversification. Diversity of source types is seen as a desirable quality in analysis as it indicates less dependency on a single source or source type which may be falsified. The current model does not necessarily take this into account. A study into the correctness of this perception and how to apply it to the subjective logic belief function would extend the capabilities.

Effects of Time on Likelihood. One of the topics covered in Chapter II is that the uncertainty of a forecast is time dependent. Meaning that the further away the forecasted

system is from being realized, the more uncertainty in the forecast because it is likely that the competitor will have opportunities to make different decisions about the system. Similarly, evidence may also have a time dependence. For example, if evidence is discovered long after it was originally captured, its relevance may be in question because many decisions about the system have likely been made since that evidence transpired to the time that it was collected and captured. Additional investigation of both the time from the forecasted state and the decay of reliability of evidence over time should be conducted to study the effects to likelihood and uncertainty of the forecast.

Explicit Traceability and Gap Identification. While traceability is inherent in the expressive, graphics-based language of SysML, and explicit reporting of this information would be very useful. A method to determine the information in the Definition layer is traced to the assessment layer and to the source layer. This could be a part of the feedback to a collection system for future collection.

Hypothesis Types and Definition Layer Inheritance. There seems to be different categories of hypotheses. Possibly qualitative and quantitative. Possibly research into what these categories are and what information gets passed into the definition layer would be extremely beneficial. For instance, the range of an aircraft seems quantitative, but how does the analyst develop a discretized set of hypotheses to analyze this? In this instance a distribution of the possibilities seems more appropriate. Further research in this area would be needed to determine the abilities to express this in a SysML model. (note: research from property based requirements could possibly be leveraged to support this)

Increased Interoperability within Anti-Processes. The current method of introducing information from one Anti-Process to another is by manually placing the

winning hypothesis into the other Anti-Process. A method to do this more seamlessly (i.e., automatically) would improve the capabilities of this method.

Improve Parametric Model. The current model has one large constraint built into the rollup pattern that controls the calculations in the belief function. It would be useful to break this into different sections. Research into the modularity of the constraints that control the rollup pattern could make the parametric model of the Anti-Process more flexible to individual needs.

Feedback Loop. The functionality of interoperability is an important aspect of research, but a detailed study of which Anti-Processes should pass information and what information should be passed would improve the connectivity of interrelated analyses to be co-developed rather than entirely isolated. This may come in the form of interface management between the Anti-Processes.

Automated Report Generation. The need for reports will likely still be a part of the intelligence enterprise. Research surrounding report generation using the SysML reference model would be of added benefit to reduce burdens of the analyst's time for report writing and would allow them to maintain focus on analysis and forecasting the competitor's system.

Explore Other Tradecraft Methodologies. The SysML reference model developed herein leverages the use of analysis of competing hypotheses as the main analytic tradecraft used for conducting analysis. While this was the most compatible approach to a scientific and rigorous method, it is not the only method of developing an intelligence forecast. Research of incorporating additional methodologies would expand the applicability of this model-based approach.

Significance of Research

This research plays an important role in Digital Transformation and lays the groundwork for a dynamic, model-based approach to the analysis and forecast of competitor's systems. Analysis of competitor's systems is a crucial role in supporting the decision makers in a wide variety of fields such as business, strategic, and policy decisions. The more accurately, transparently, and rapidly this intelligence can be delivered, the more successful those decisions are enabled to be. This research is a fundamental step in that direction.

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Appendix A: Opinion Rollup Pattern Details

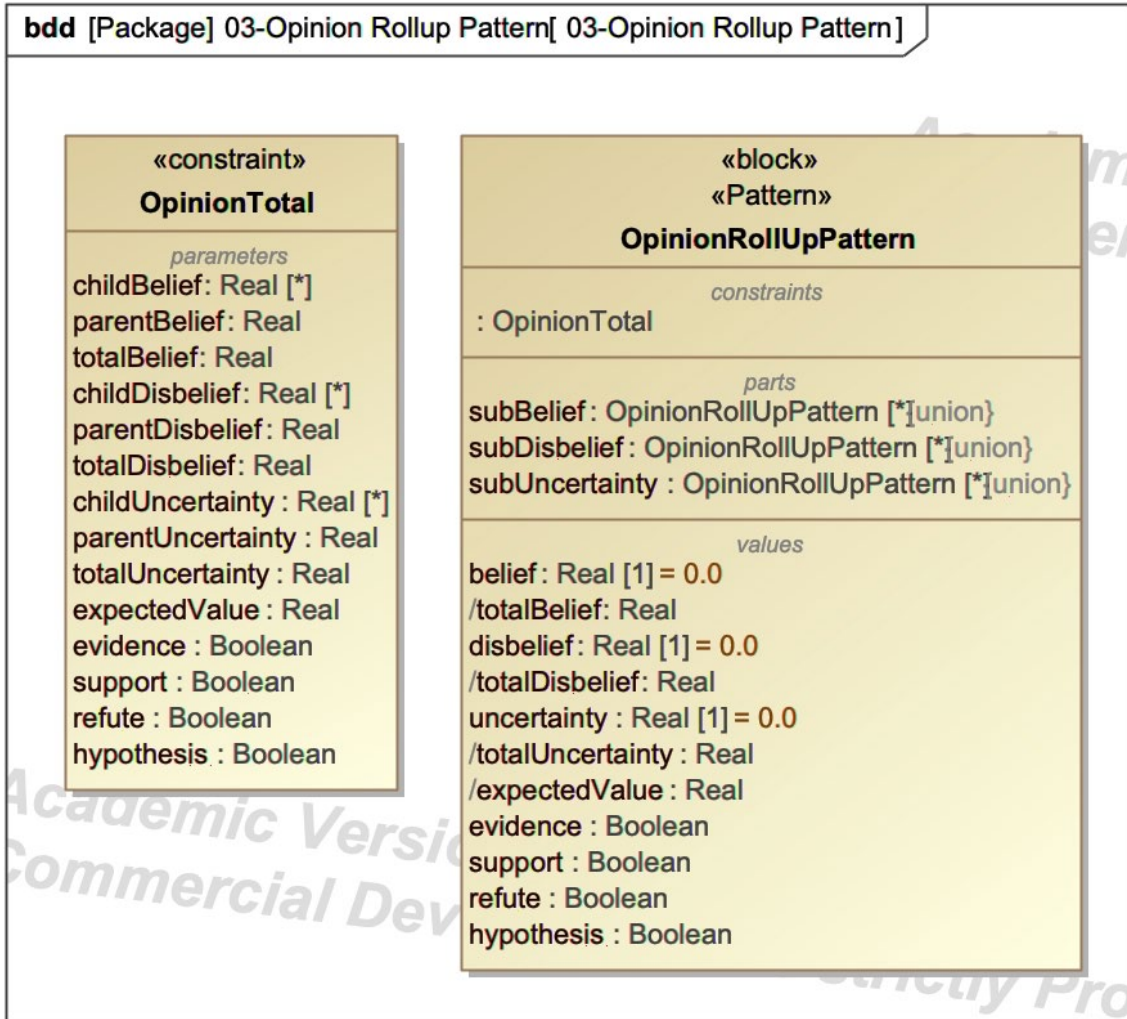


Figure 26: OpinionRollupPattern BDD

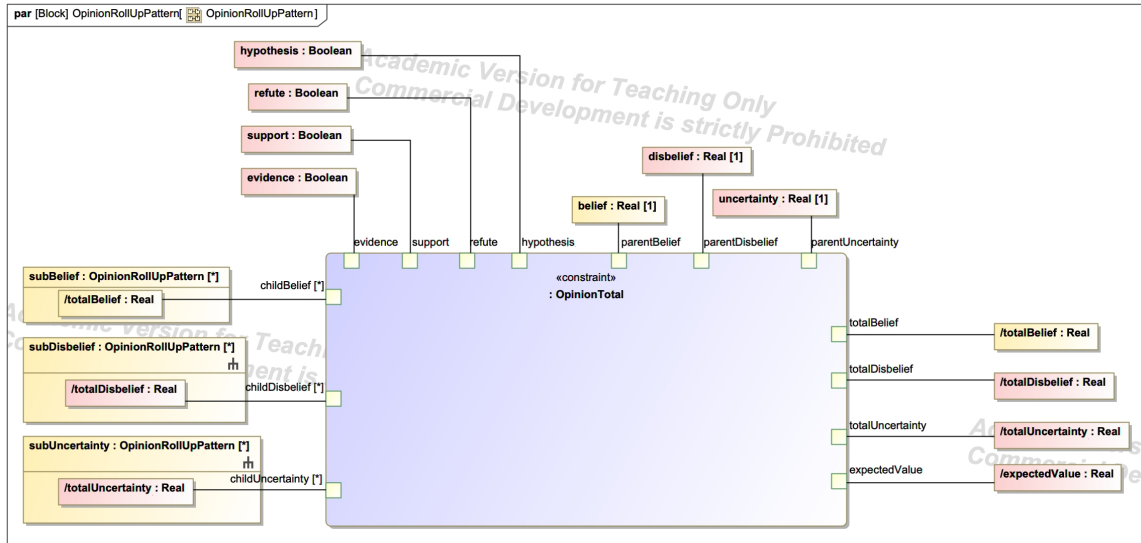


Figure 27: OpinionRollupPattern Parametric Diagram

Constraint Expression in jython scripting language:

```

expectedValue = 0
print(name)
print(len(childBelief))
if len(childBelief) == 0:
    print('length = 0')
    if support == 1:
        totalBelief = 0
        totalDisbelief = 0
    elif refute == 1:
        totalBelief = 0
        totalDisbelief = 0
    else:
        totalBelief = parentBelief
        totalDisbelief = parentDisbelief
        totalUncertainty = parentUncertainty
    a=[totalBelief,totalDisbelief,totalUncertainty]
    expectedValue = totalBelief + 0.5 * totalUncertainty
elif len(childBelief) == 1:
    print('length = 1'); print(evidence, childBelief,childDisbelief,childUncertainty)
    if evidence == 1:
        totalBelief = sum(childBelief) * parentBelief
        totalDisbelief = sum(childBelief) * parentDisbelief
        totalUncertainty = sum(childDisbelief) + sum(childUncertainty) + sum(childBelief)

```



```

* parentUncertainty
  a=[totalBelief,totalDisbelief,totalUncertainty]
  expectedValue = totalBelief + 0.5 * totalUncertainty
elif support == 1:
  print('support')
  totalBelief = 2 * (sum(childBelief) / sum(childUncertainty))
  totalDisbelief = 0
elif refute == 1:
  totalBelief = 0
  totalDisbelief = 2 * (sum(childDisbelief) / sum(childUncertainty))
else:
  totalBelief = sum(childBelief)
  totalDisbelief = sum(childDisbelief)
  totalUncertainty = sum(childUncertainty)
  a=[totalBelief,totalDisbelief,totalUncertainty]
  expectedValue = totalBelief + 0.5 * totalUncertainty
else:
  print('length = *')
  totalBeliefNum = 0
  totalDisbeliefNum = 0
  uncertaintyTerm = 0
  k=0
  if support == 1:
    print('support'); print(childUncertainty)
    totalBelief = 0
    totalDisbelief = 0
    for i in range(len(childBelief)):
      totalBelief += 2 * (childBelief[i] / childUncertainty[i])
  elif refute == 1:
    totalBelief = 0
    totalDisbelief = 0
    for i in range(len(childBelief)):
      totalDisbelief += 2 * (childDisbelief[i] / childUncertainty[i])
  elif hypothesis == 1:
    totalBelief = sum(childBelief) / (sum(childBelief) + sum(childDisbelief) + 2)
    totalDisbelief = sum(childDisbelief) / (sum(childBelief) + sum(childDisbelief) + 2)
    totalUncertainty = 2 / (sum(childBelief) + sum(childDisbelief) + 2)
    expectedValue = totalBelief + 0.5 * totalUncertainty
  else:
    for i in range(len(childBelief)):
      #calculating summation of belief for children
      totalBeliefNum += childBelief[i]/childUncertainty[i]
      #calculating summation of disbelief for children
      totalDisbeliefNum += childDisbelief[i]/childUncertainty[i]
      #calculating uncertainty sum

```

```
    uncertaintyTerm += 1/childUncertainty[i]
k = len(childBelief)-1
totalBelief = totalBeliefNum/(uncertaintyTerm-k)
totalDisbelief = totalDisbeliefNum/(uncertaintyTerm-k)
totalUncertainty = 1/(uncertaintyTerm-k)
expectedValue = totalBelief + 0.5 * totalUncertainty  ""
```

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1. REPORT DATE (DD-MM-YYYY) 05/18/2022	2. REPORT TYPE Master's Thesis	3. DATES COVERED (From - To) August 2020 – May 2022
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4. TITLE AND SUBTITLE Developing a Model-Based Approach to Forecast a Competitor's System	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S) Christopher Del Vecchio	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/EN) 2950 Hobson Way, Building 640 WPAFB OH 45433-7765	8. PERFORMING ORGANIZATION REPORT NUMBER AFIT-ENP-MS-22-J-020
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9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRUBTION STATEMENT A. APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

13. SUPPLEMENTARY NOTES
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14. ABSTRACT
The purpose of this research is to develop a model-based approach to intelligence forecasting of a competitor's system. This analysis currently uses a document-based practice to capture all knowledge of the forecast and its development. A framework of antithesis processes, or Anti-Processes, were derived from the systems engineering technical processes. This was then combined with analytical tradecraft from the field of competitive technical intelligence to build a SysML reference model, which was then applied to a small case study to enhance and refine the model. The Anti-Process framework and SysML reference model provide a rigorous, model-based approach to intelligence forecasts of competitor's systems.

15. SUBJECT TERMS
SysML, MBSE, Competitive Intelligence, Digital Engineering, Model-based Analysis, Intelligence Forecast, Conceptual Layers, Subjective Logic, Analysis of Competing Hypotheses, Scientific and Technical Intelligence

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 103	19a. NAME OF RESPONSIBLE PERSON Ford, Thomas, AFIT/ENV
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (Include area code) thomas.ford.ctr@afit.edu