Operational Analysis and Mission Engineering: A strategy and framework to analyze any industrial ecosystem.

by

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Submitted to the System Design and Management Program

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Abstract

The field of system engineering builds on the principles of system architecture, system engineering, and product management while attempting to balance the sociotechnical and socioeconomic impacts. Today's industries face the ever-increasing business dynamics of changing technologies, competition, and regulations that affect their products, services, and processes. Yet, they all continue spending large sums of money on R&D during and after product launch. These products and services must meet critical financial, sales, and customer targets. The situation has become dire within all industries as they attempt to find the answers to the questions by applying different Product Delivery Processes like stage gate, spiral, waterfall, AGILE, Scaled AGILE, etc.

Through our research looking at the enterprise strategy and its development, enterprises aren't looking at it from and system thinking perspective. This thesis suggests that operational analysis, mission engineering, mission architecture, technology road mapping, portfolio management, product development, order fulfillment, and lifecycle management, we have only focused on the product development perspective without other elements previously mentioned, for the most part, have been siloed.

So, this thesis will explore if system design and management principles and practices are applied upfront in the strategy development process to identify key opportunities within the industrial ecosystem in which the enterprise resides has the potential to allow the product delivery process to reduce the risk of not meeting the enterprise's financial, sales, and customer targets.

We will explore the potential to apply operational analysis and mission engineering within the context of the industrial ecosystem in the enterprise resides to identify opportunities and their subsequent missions and relationships. It will also explore how, through operational analysis and mission engineering; we can further understand the socioeconomic and sociotechnical ramifications providing additional inputs when developing the enterprise strategy. Through this *framework, these building blocks will be critical to the enterprise strategy reducing the risk to the outcomes of any product delivery process.*

Through this understanding, we can clarify how the enterprise sits in the ecosystem and identify our relationship to ensure our strategy and vision meet or exceed our business and customer needs. Through this approach, we also believe that enterprise efficiency, effectiveness, and market penetration enable sustainable growth while embracing technology and minimizing the socioeconomic impact on society.

We have limited the scope within this thesis to an enterprise strategy currently. Future research must apply the framework and structure proposed within the thesis. It can provide an avenue into a more comprehensive understanding of the enterprise's economic benefits and the socioeconomic and sociotechnical impacts as the demands of the 21st century will challenge us as professionals.

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1 Introduction:

In today's complex world, enterprises must look beyond their existing products, processes, and services for business improvement while meeting customer demands and expectations. Technology is changing rapidly; there is increased competition, a desire for more innovation, speed to market, and increased employee expectations from pay to social responsibility to meet the enterprise, customers', societal, and ecosystem needs. Yet, these same enterprises struggle to understand why their products, processes, and services miss key business targets and product volumes. They require additional human and capital resources after producing products to get acceptable customer acceptance. I believe this comes from the lack of an appropriate framework to analyze and fully understand the industrial ecosystem in which their enterprise resides. This leads to poor outcomes because of incomplete strategy development or weak strategies that lack timely input when developing their strategy(s). It could also be that during the strategy development, they failed to understand the primary industrial ecosystem they reside, the relationships internal to this ecosystem, and the external relationships to other ecosystems. This results in missed opportunities due to not understanding their relationship within this more extensive ecosystem, business inefficiencies, stakeholder dissatisfaction, and negative societal impacts.

Over the course of my 40-year career, 25 years in agri-food, 13 years in aerospace and defense, and two within the academic world, I have personally witnessed products, processes, and services that were developed without a clear understanding of their impact on the ecosystem in which they reside within their respective enterprise. Leadership asked many questions like:

- *Why didn't we meet our sales volumes?*
- *Why didn't we meet our financial targets?*
- *Why didn't we meet our schedule goals?*
- *Why did we spend 3-5 years and millions of dollars developing this product or system to discover that the customer needs still need to be fulfilled once in production?*
- *Why are we spending another 1-3 years and millions of dollars more to meet the basic needs of our customers (as prescribed by the Kano model?)*

As a system engineer who, time and time again, was brought in after these issues surfaced to solve these problems, I was directed to fix the system integration issues that had resulted from poor strategy, lack of operational understanding, mission development, mission integration into the ecosystem, technology, etc. During this time, I have observed approaches like a waterfall, stage gate, spiral, AGILE, and Scaled AGILE as development processes deployed, all with similarly poor results. These results reinforce that an Enterprise strategy needs the proper operational understanding to enable mission development, allowing the enterprise to integrate the mission *into the strategy. To gain this operational understanding, we must perform operational analysis starting with the industrial ecosystem. Operational Analysis defines all operations and their relationships within an industrial ecosystem(s) the enterprise aspires its strategy to encompass.*

They also need within the strategy a comprehensive understanding of the industrial ecosystem they reside to provide the necessary linkages between the technology and operational missions to improve the enterprise strategy reducing the risk of facing the issues outlined previously.

On other occasions, much success has been seen when allowed to develop a system using the fundamental methods, language, and tools of System Architecture, Engineering coupled with sound technical project management.

A more holistic way of understanding the ecosystem could result in a better strategy, and I will explore that idea in this thesis. Throughout this thesis, we will talk about industrial ecosystems an enterprise resides in; this implies that industrial ecosystems can be categorized. To further our understanding of an industrial ecosystem, I will discuss a systems-based multidisciplinary description that seeks to understand the emergent properties of value-added and non-value-added behaviors of a complex combination of human/natural systems. Understanding these ecosystems allows us to understand the socioeconomic and sociotechnical implications within a categorized ecosystem. This will allow the enterprise to innovate to maximize technology and minimize the socioeconomic impacts when developing its strategy. Some may initially think this approach will take longer. Yet, looking at your respective industrial ecosystem holistically will allow you to innovate and manage your strategy, technology, processes, services, and ultimately product portfolios while creating a competitive advantage for your enterprise now and in the future with the framework and structure being proposed for the development of the key inputs to the enterprise strategy.

1.1 Motivation:

Industrial ecosystems have long been thought too complicated and complex to manage effectively while understanding the relationships within. An industrial ecosystem is described using a systems-based multidisciplinary approach that seeks to understand the emergent properties of value-added and non-value-added behaviors of a complex combination of human/natural systems. Understanding these ecosystems allows us to understand the socioeconomic and sociotechnical implications within a categorized ecosystem.

Enterprises of all sizes are pressured to develop innovative products, processes, and services while embracing the rapidly changing developments of new technologies within their portfolios. Socioeconomic impacts on the larger ecosystems are being felt worldwide, and social responsibility is now affecting the survival of these enterprises. Business leaders are frustrated that their organizations need more productivity, efficiency, and effectiveness in developing these products, processes, and services. These same leaders also find that once they are developed, significant time and workforce are required to adapt them to meet both business and customers' expectations. Many claims that system architecture and engineering with integrated project *management are the keys to solving this problem at the enterprise strategic level. Yet, I believe the answer lies in understanding this ecosystem, its relationships, and the enterprise's boundaries and relationships within this ecosystem. When developing strategies, enterprises look at the products, processes, and services within their internal ecosystems and develop their missions in this context. Mission engineering is the deliberate planning, analyzing, organizing, and integrating of current and emerging operational and system capabilities to achieve desired mission effects.('DoD Mission Engineering Guide_ httpsac.cto.milwp-contentuploads202012MEG-v40_20201130_shm.pdf', no date) Academic and industrial research has been done in articles and handbooks that treat industrial ecosystems and mission engineering as independent of one another.*

Most recently, the Department of Defense November 2020 released a guide to mission engineering, "Mission Engineering Guide"('DoD Mission Engineering Guide_ httpsac.cto.milwp-contentuploads202012MEG-v40_20201130_shm.pdf') is dedicated to an overall mission and made up of smaller missions all stitched together through the mission thread. Suppose one asks how all the missions fit into the overall ecosystem. Yet, we need to be able to stitch all the missions together within and between ecosystems to understand better the socioeconomic and sociotechnical implications of our enterprise strategy. In many cases, it tends to end up in the individual or enterprise adaptations of what the strategy needs from an internal perspective as looking at the relationships to the industrial ecosystem is too complex. The results to date are that no concrete methods, processes, or examples exist to dynamically develop a strategy to meet these changing demands. Hundreds of individual articles, books, and publications are needed for system architecting and system engineering to mature into recognized disciplines like Calculus, Chemistry, Physics, Mechanical, Electrical, Software, etc. engineering.

To this end, I asked myself if industrial ecosystems can be classified can one decompose this into an ontology which would provide hierarchical categories in an industrial ecosystem to apply the fundamental system design and management principles and tools to enhance our operational understanding with the associated missions and technology needed as an input to the enterprise strategy to improve the potential outcomes within the system development lifecycle. If we start from the definition of Operational Ontology, we decompose industrial ecosystems through a decomposition that would provide hierarchical categories to apply fundamental system design, management principles, and tools to enhance our operational understanding. This has significance in that an industrial ecosystem has a structure that can be characterized and that by characterizing it, you obtain useful information that can be applied to develop more effective strategies.

This motivated me to research, design, develop, and deliver a framework and structure that can be adapted and tailored to any industrial ecosystem as an alternative for developing the inputs for enterprise strategy. The Framework and structure are the organizational building blocks, methods, and metrics that encompass the necessary critical inputs for enterprise strategy development. It uses existing system engineering and architecting principles, architecting *methods, tools, principles, and practices consistent with academic research and governance while satisfying the needs of industry and academia. Through this structure and framework, I will provide an understanding of the inherent relationships within and the dependency between the operations and missions of the studied ecosystem.*

Personal Motivation

Industry and academia have concentrated on system design and management focused on products, processes, and services without much consideration for the industrial ecosystem. These companies' strategies must look at the overall relationship to the ecosystem in which they reside. A few examples are companies like agricultural equipment, airframe manufacturers, health care, construction equipment, forestry, and suppliers: in today's environment of social responsibility, rapid technology integration and evolution, and resource constraints, human and capital. These companies must develop strategies to address the ecosystem's needs in which they operate.

This thesis intends to share how looking at the industrial ecosystem within our proposed operational ontology, transitioning from the traditional system vee diagram to the solution design and management diamond, performing operational analysis, and mission engineering related to the identified ecosystem can result in strategic inputs that allow enterprises to thrive and grow through innovation within their strategy development and efficiently react to the dynamic world in which we live.

By doing this, I believe that enterprises can unlock the following:

- *Innovation*
- *Economic headroom*
- *Minimize socioeconomic impact*
- *Maximize sociotechnical integration*
- *Align mission engineer to the business needs*
- *Engineered missions*
- *Better management of the critical ecosystem relationships*
- *Align and manage the portfolio and technology roadmaps more consistently*
- *Align growth ambitions to stakeholder needs*
- *It balances customer and business needs while adding value to grow and prosper*

1.2 Thesis Goal:

To deliver a framework and structure that provides key inputs that can be adapted and tailored within an industry when developing an enterprise strategy with the industrial ecosystem they reside (Value Needed). Understanding the inherent relationships within and the dependency between the industrial ecosystem and the enterprise (Action Needed). Using existing principles, architecting methods, tools, and practices consistent with academic research and governance. (Process or System Delivering Value). While satisfying thesis requirements for the MITsdm program.

This research will provide the operational ontology, Industrial ecosystem using operational analysis, and mission engineering applied to any industrial ecosystem. This research enables the enterprise to assess and quantify their boundaries and relationships within the overall ecosystem, the impact on existing strategy, and identification of critical opportunities, technologies, etc., needed within their business through innovation while understanding the value-added and non-value-added emergence possibilities to both the enterprise and ecosystem being analyzed.

We will limit our application to operational analysis and mission engineering to enable and deploy a successful enterprise strategy within any industrial ecosystem and understand the impact on emergence. We will apply the principles of system architecting and engineering and touch on project management. This research will leverage my 40 years of experience working in the agricultural, aerospace, and defense industries, along with known managerial sciences, organizational theory, and academic and industrial theory and best practices, to facilitate the advancement of system engineering as it continues to evolve.

Initially, we researched industrial ecosystems and defined in chapter 2 our operational ontology in Chapter 3 to enable the execution of operational analysis in Chapter 4, and subsequently, from the outputs of operational analysis, developing our mission(s) by engineering them to create common themes contained within chapter 5 and mission threads.

Additional research will be needed in the industrial ecosystem operational hierarchy exposed within this research. The areas requiring further research and relationship mapping of the industrial ecosystem operational ontology are mission architecting, technology road mapping, portfolio management, product development, order fulfillment, and life cycle management (chapter 3).

1.3 Research Questions

This framework and structure seek to answer the following questions.

- *Does understanding the architectural ontology levels within any sociotechnical industrial ecosystem enable a more complete identification of the key inputs to the enterprise strategy?*

- *Does understanding the inherent relationships of the architectural ontology at the operational and mission level allow us to identify the inputs to our enterprise strategy better?*

- *Does applying operational analysis improve the enterprise's ability to develop a more consistent strategy?*

- *Does operational analysis provide sufficient insights into the industrial ecosystem to identify opportunities that enable us to engineer our missions more effectively within mission engineering?*

Through the Industrial Ecosystems (chapter 2), we will research to understand what has been done and what might apply to our goals and questions. The Operational ontology (chapter 3) and system engineering methods and principles will allow me to understand the breakdown/decomposition of the industrial ecosystem to the enterprise and the applicability of system design and management fundamentals from a conceptual, physical, and digitalization perspective. Operational Analysis (chapter 4), through the development of a process map using the example of the sugar cane production system within the agri-food industrial ecosystem to identify opportunities needed to develop our missions, provide a more holistic input to strategy to the enterprise strategy. Mission engineering (chapter 5) will then take the opportunities identified through operational analysis to develop a process map to engineer the missions with an understanding of the technology needed as inputs to the enterprise strategy, again using the sugar production system within the agri-food industrial ecosystem. Discussion and Implications (Chapter 6) of the new approach will be discussed, implications and limitations of this research with the research still needed, and provide recommendations of where this research might go next by myself and others. References (Chapter 7) will be shared to assist the reader as a starting point in further exploration of the topics covered in this thesis.

2. Industrial Ecosystems

Chapter Tenets:

- *Industrial ecosystem - A systems-based multidisciplinary description that seeks to understand the emergent properties of value-added and non-value-added behaviors of a complex combination of human/natural systems. Understanding these ecosystems allows us to understand the socioeconomic and sociotechnical implications within a categorized ecosystem.*
  - *The industrial ecosystem encompasses the entire flow of goods and services from the source to consumption; it is not just the individual enterprise that resides within specific industrial ecosystem categorization.*
- *Enterprises tend only to understand where their products, process, and services are used.*
- *They can take advantage of significant opportunities to provide additional value to their stakeholders through an aligned strategy.*
- *They want to understand the sociotechnical and socioeconomic risks over the long term in a socially responsible way, as society demands this in the 21st century.*
- *The need to consider the why, what, and how of the industrial ecosystem when developing an enterprise strategy.*

In today's enterprises, strategies are developed around the programs, projects, products, processes, and services based on the current markets they serve. These markets are part of a more extensive system that could provide opportunities for enterprises they may not have previously considered. As enterprises try to develop and exploit these opportunities, they need to consider the socioeconomic impact on the internal ecosystem in which they reside and the larger external ecosystem they serve. Failing to understand these value-added and non-value-added emergent behaviors can harm these enterprises' reputations, employees, shareholders, customers, communities, and society. In the 20th century, enterprises were focused on maximizing shareholder value; in the 21st century, society is also holding these enterprises socially responsible. At the same time, technological advancements are being designed, developed, and integrated into these internal and external ecosystems rapidly, potentially causing similar effects. This lack of understanding will have sociotechnical and socioeconomic impacts on society now and in the future. Additionally, for these rapid technologies to be developed, these enterprises are currently being self-governed and working independently of each other to innovate more rapidly, as our government is ill-equipped at this time to provide the necessary technical oversights.

2.1 Evidence

Enterprises are constantly searching for opportunities within their growth strategies and are limited to needs within their internal ecosystems. Yet, if they understood where they fit within *their larger ecosystem(s), they might find an unserved niche they could exploit within the growth strategy.*

An example of this gap is in High-Value crops (HVC) such as almonds, grapes, and coffee. The tractor, which is the basic Swiss army knife, has been produced in one consistent physical form for years within a limited view of the equipment providers' internal understanding and ecosystem. Yet, this niche of HVC is a huge opportunity in both the system and configuration to provide growth for the internal ecosystem and the technology to improve the external ecosystems and positively impact society. Additional evidence can be Hobby Farmer and Small Produce Farmers for those who want organic produce at farmers' markets or local grocers. The tractor again can be used here as the small farmers fit within the larger ecosystems of the enterprise and continue to grow in numbers. Yet, enterprises tractors and implements for the large commercial farmer with little consideration for this potential niche market. Some of what this industry calls short liners supply modification kits that serve these niche markets, or the operation owners develop and modify solutions to meet their needs. During the development of this thesis, I wanted to test this methodology wand to test with this context on a confidential project to another institution and enterprise. Although this project is unpublished and confidential, we applied the methods outlined within this thesis with the team I am instructing and coaching. Applying this framework and structure, this project uncovered many opportunities as the equipment manufacturer had just been providing a propulsion unit, sometimes called a tractor. By applying and understanding the operational analysis, stakeholders, and their needs, we could develop a complete understanding of this market at the ecosystem level and find within the niche a multi-billion-dollar market that aftermarket suppliers and the farm owners were serving. The farm owners were doing custom one-off modifications to improve their operations' efficiency, often with significant time and expense to their operations. We developed a set of missions and mission threads within the production system and, with minimal additional research and development, using these elements as input, developed a strategy to realize a significant financial opportunity for the enterprise while increasing customer satisfaction. This information will be published in a separate document in August 2023. I apologize to the reader for not providing more details here; if you would like more information, don't hesitate to contact the thesis author after August 2023. Until recently, these enterprises failed to realize these potential customers and the opportunities to exploit this niche. Still, it was only after their strategic growth plans plateaued that further growth was needed. Yet, they needed to understand that natural and organic farmers were a very socially responsible niche and that they preferred technology applied in a socially responsible way to limit the chemicals required to produce these crops. In the end, because they only looked through the eyes of their respective internal ecosystem, their products, processes, and services did not meet niche market needs within the broader ecosystems that required additional time and resources to provide additional strategic growth.

Impacts on our communities can be seen in automation to autonomy and battery electric vehicles. System safety reviews on self-driving automobiles demonstrate the need for enterprises *to understand the socioeconomic and sociotechnical ramifications. This is essential, yet, governments need more technical knowledge within their ecosystem to provide regulatory requirements without impacting the advancements of these technologies. The potential ramifications to the community are increasingly evident as we see self-driving cars causing accidents while on "autopilot," their battery packs bursting into flames, and injury to drivers, passengers, and community (other vehicles) occurring in both instances. Accordingly, twenty-first-century enterprises must develop skills around these potentials to guard against negative sociotechnical and socioeconomic impacts. To further this understanding, there currently needs to be regulatory standards due to the need for more regulations or self-governance. While the enterprise within each siloed ecosystem may warn the operator, they do not lock out operations. This allows the vehicle operator to, for instance, play video games while in autopilot mode. In addition, the vehicle is only at level 2 (assisted) automation (the driver must assist, not be playing a game or otherwise be distracted), which could be more problematic in and of itself. In the vehicle, the naming convention also has a socio-economic impact on the individual and community (i.e., autopilot) as they assume this means total full autonomy. In this high-level example, you can see a lack of understanding and responsibility to the larger ecosystem wasn't understood yet, nor was the internal ecosystem at the level needed in a socially responsible enterprise. These skills require close reflection and understanding of how much good we are doing and the consequence of socioeconomic impacts, good or bad, in understanding our accountability not just to our shareholders but also to our families and communities. Today enterprises are measured by shareholder value added; in the future, the technology will be considered in the same breath.*

2.2 My Review of the Literature

Based on this understanding, research was conducted to understand the history of industrial ecosystems. The literature reviews and research sought to understand the classification of industrial ecosystems as defined by analytical methods within the research. Our research uncovered A review of the ecosystem concept – toward a coherent ecosystem design (Tsujimoto et al., 2018); this research identified 90 papers providing a comprehensive list of research conducted from 1995 through 2014. We studied the documents to determine the relevance of understanding the classifications of industrial ecosystems. These reviews uncovered several ways to develop an ecosystem.

- *Industrial ecosystems incorporate all participants functioning within a network: from the smallest start-ups to the largest enterprises, from academia to research service providers to suppliers.*
    - *Ecosystems as networks rather than (value) chains and trace the complex links across firms, sectors, and institutions.*
    - *Ecosystems include both public and public activities.*
        - *Public institutions and research centers as key actors in the interactions with firms*
    - *Ecosystems are dynamic and evolve continuously and are not meant to be fixed and discrete.*

- *The notion of ecosystems captures the complex interrelationships and interdependencies among regions and firms spreading globally in a single market.*
- *They allow for a bottom-to-top approach that considers the preciseness of business models, the large portions of at-risk participants, and interdependencies.*
- *Figure 1 (Ref. European Cluster Conference 2020, 10-11 November 2020, Agri-food) Represents complex interconnections between firms, sectors and institutions and well as the interrelationships and is very dynamic with constant shifts within, between, and across them.*

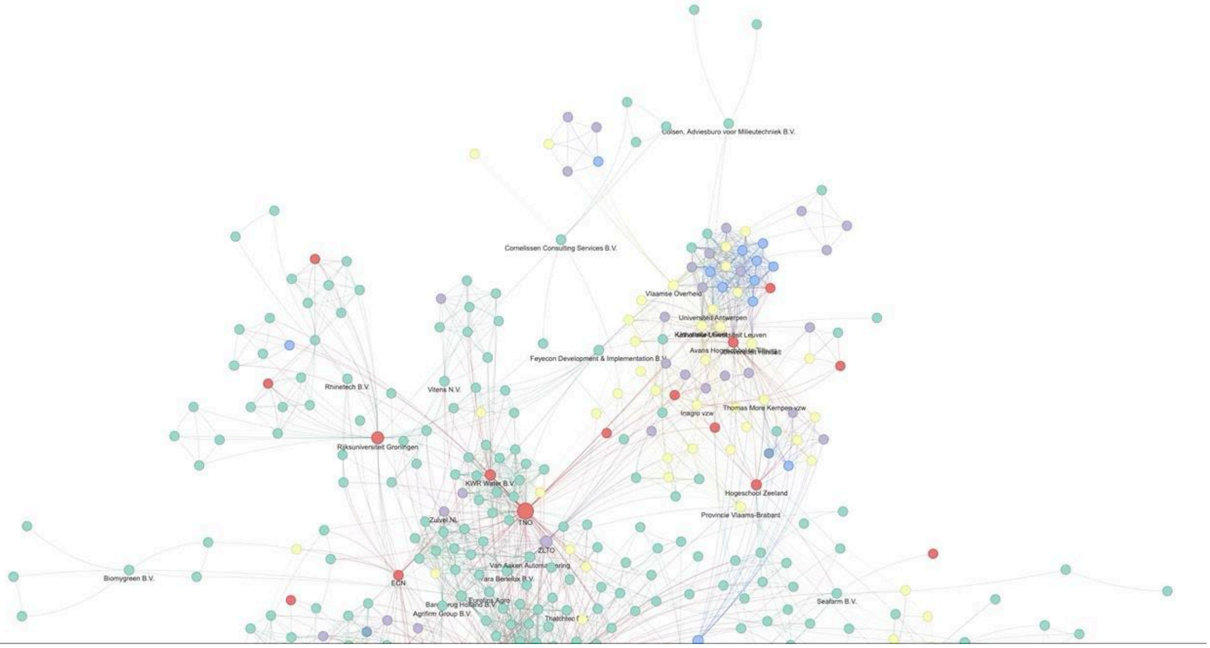


Figure 1 - Example Ecosystem - Tracing of complex links across firms, sectors, and institutions

They left the questions around the classification of the industrial ecosystem. We reviewed several textbooks on industrial ecosystems (Ayres and Ayres, 2002); these reviews uncovered additional aspects of understanding industrial ecosystems but still left the question of the classification and how we differentiate industrial ecosystems.

*The ecosystem concept is of increasing significance in the field of management and technology and innovation (*Tsujimoto et al.*, 2018) seemed appropriate to start with, yet as we reviewed, it was more of a review of the ecosystem concept to design an ecosystem. Yet, more than 90 previous studies were reviewed within one document and summarized through the classification of the previous research. It summarized the five key elements of perspectives as background and theory, key concepts, analytical methodology, attributes of actors, variables between actors, and the number of papers. Each element was then summarized based on industrial ecology, business ecosystem, platform management, and multi-actor network. As we continued through the exhaustive list, we looked at an integrated model of previous research. It was apparent that our questions about the classifications of ecosystems needed to be more evident. This outlined the* *research on the methods and practices for developing the elements contained within an ecosystem, not the classifications of industrial ecosystems.*

Through additional reviews, (Baldwin, 2008) might shed some insight into industrial ecosystem classification. His research states that although typologies and characteristics of industrial ecosystems, symbioses, and eco-industrial parks and networks have been proposed in the literature, there has yet to be a consensus acceptance of a benchmark and/or classification scheme. Others were around individual elements of an ecosystem like the manufacturing (Jelinski et al.*, 1992).*

At this point, we reviewed the "A Handbook of Industrial Ecology" (Ayres and Ayres, 2002) essentially the methods, processes, and tools to develop an ecosystem. In my review the handbook does a very nice job when developing an ecosystem starting with a biological analogy to assist in understanding while using a system perspective, identifying and defining the sociotechnical implications within the ecosystem under development and how the company/enterprise fits into the ecosystem. It is a very good reference for the development of an ecosystem. Yet I was looking to see if anyone had developed industrial ecosystems categorizations and what those are. Again, this is a very good book for the development of an ecosystem at any level, but how that ecosystem categorizes and interacts with other ecosystems was what I was looking for.

Our research took us to the European Cluster Collaboration Platform (Industrial Ecosystems | European Cluster Collaboration Platform), categorizing 14 industrial ecosystems. The notion of the industrial ecosystem came from the European Council in April 2020 because of the Covid-19 crisis. The use of the industrial ecosystem as an analytical approach to factor in risk and resilience, differing dynamics, complexities, and relationships that encompass relevant players. This review found that they contain all the stakeholders operating within a particular value chain, from start-ups, large enterprises, academia, researchers, suppliers, etc. As an example of the breadth and depth of each, Figure 1 is the mapping of the agri-food ecosystem. We can now identify the different clusters as depicted in Figure 2.

Figure 2 - Industrial Ecosystem Classification (Ref: Industrial Ecosystems/European Cluster Collaboration Platform)

The evolution of ecosystems is dynamic, and thus, when socioeconomic or sociotechnical changes disrupt one area, the effects may propagate throughout that ecosystem and affect the inherent relationships on other ecosystems, which, through these analytical methods, provide a means to maintain the existing 14 ecosystems today, while anticipating the evolution of additional ecosystems over time.

2.3 Industrial Ecosystem Categorization

As a result of this understanding and the ability to perform operational analysis and mission engineering at the enterprise level to understand the opportunities not only within the internal ecosystem but also the external ecosystem to provide input to the enterprise strategy throughout this thesis, I will use the 14 categories outlined as part of the framework and structure proposed. The categories can be seen in Figure 2. This understanding of the elements and the interrelationship within the primary ecosystem in the enterprise resides provides an understanding of the stakeholders and elements contained within, as shown in Figure 3.

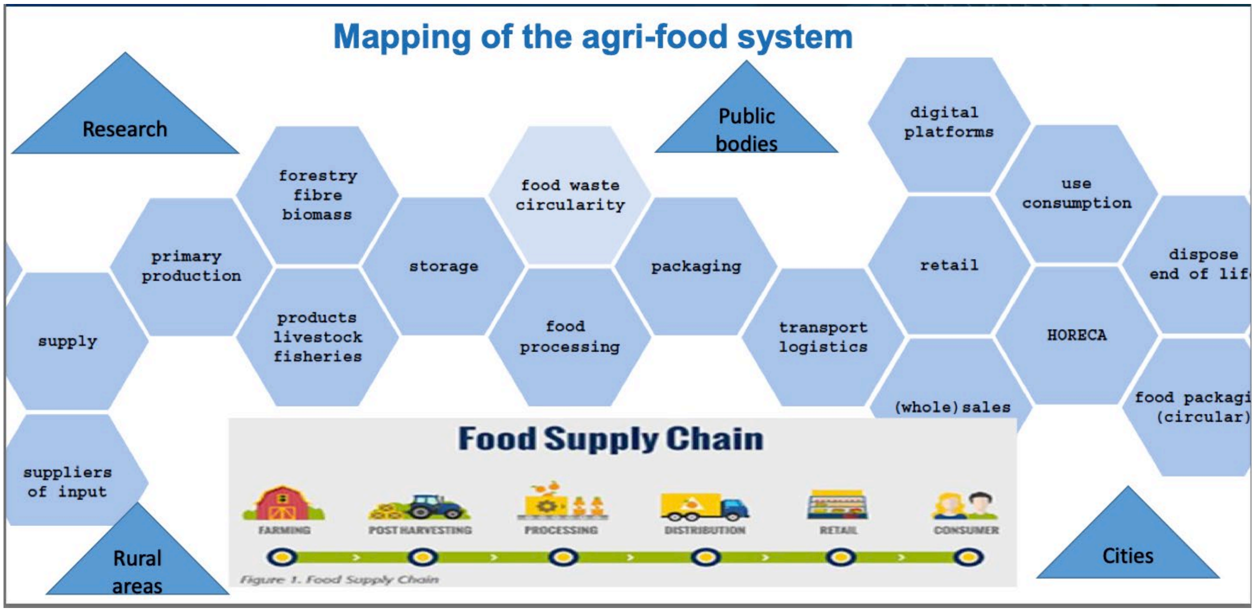


Figure 3 - Agri-Food Ecosystem Mapping ('Valentinova - Needs and opportunities for the Agri-food Ecosyste.pdf', 2020)

An industrial ecosystem lends itself to developing the hierarchical ontology as this will provide the necessary decomposition of the ecosystem to the enterprise and the elements within the enterprise. It provides the strategy team with an understanding of the sociotechnical system, which is all-inclusive of the organizations, stakeholders, relationships, the technology necessary to produce, and the products. Many times, when ecosystems are discussed, they only address the entities and their relationships to one another. We are assuring that all aspects of the enterprise are connected and provide the strategy development team with a structure to identify business opportunities as inputs to their strategy development. In Chapter 3, we will research the operational ontology to provide a hierarchical structure for operational analysis and mission engineering in the coming chapters.

3 Operational Ontology

Chapter Tenets:

- *Operational Ontology – Decompose industrial ecosystems into an ontology that would provide hierarchical categories to apply fundamental system design, management principles, and tools to enhance our operational understanding.*
- *Enterprises, during strategy development, need structures of elements for the classification and explanation of these entities within the context of the systems.*
- *I am capturing the knowledge within a certain domain as a model.*
    - *The enterprise can answer complex questions through the relationships across the domain through this model.*
- *This enables the understanding of the information as a basis for structure.*
- *Enterprises need to consider the why, what, and how of the operational ontology when developing an enterprise strategy in a logical/theoretical yet practical way.*

3.1 My Review of the Literature

As stated earlier in the thesis, I am looking for an ontology that could further analytically decompose an industrial ecosystem for an enterprise to categorize the ecosystem and its domain to show its properties and relationships to the enterprise. The operational ontology bridges the gap from the ecosystem to the enterprise providing the enterprise a logical approach to perform their operational analysis to identify opportunities. These opportunities can then be used to engineer the missions in a cohesive fashion with maintaining all relationship to the enterprise as well as the ecosystem as a logical input to the strategy as well as mission architecture to understand the technology and modularity needed as logical input to develop our technology roadmaps and subsequent development of our portfolio that has the full integration of the enterprise and ecosystem contained within. This provides logical sequence for the development of the products, processes and services enabling order fulfillment and our ability to manage the lifecycle from an ecosystem perspective instead of only the internal enterprise perspective. During this portion of the literature review, many documents showed systematic approaches to developing ontologies with a limited understanding of operational ontology related to an enterprise within an industrial ecosystem. (Savvas and Bassiliades, 2009), (Hofweber, 2023),' ('Ontology', 2023)(Ontology | metaphysics | Britannica,), (Falbo, no date). I reviewed the European Cluster Collaboration Platform (Industrial Ecosystems | European Cluster Collaboration Platform) upon this understanding. We again found very limited operational ontologies utilizing industrial ecosystems and their relationships to an enterprise. Therefore, in Chapter 3, we will propose our architecture for an enterprise operational ontology framework within an industrial ecosystem as it applies to an enterprise.

(Falbo, no date) presents a systematic approach to building ontologies. It focuses on the development of domain ontologies and proposed processes. It distinguishes between reference and operational ontologies, providing activities that apply to the development of both domains. I reviewed the document to understand if an operational ontology of an enterprise within an existing ecosystem existed. it did not. Yet, it provided a sound method for developing an operational ontology through phase one, Identifying the purpose and the modularization needed with the intended use identification. Phase two captures the ontology and formalizes it through a conceptual model that develops the design, starting with the architectural and detailed design of the ontology. Phase three is ontology testing, starting with the testing of the individual or sub-ontological elements, then integration testing, and finally, the overall ontology testing.

I reviewed (Savvas and Bassiliades, 2009), a process-oriented ontology. This paper shared insights into how to build an ontology/decomposition for a knowledge management system with little relevance to an operational ontology for industrial ecosystems from an enterprise perspective. This paper analyzes the elements of a public administration ontology for knowledge management. The structural ontology needs the following elements: a single entity, single strings, multiple procedures, and multiple entities. They then outline the textual aspects of the ontology, starting with laws, regulations, administration, and decisions, and summarizing the procedural ontology for the knowledge management administrative procedures. While this was well done based on what I was looking for, I decided it was a good reference document for possible application in the future, but those future applications were out of the scope of my thesis.

I reviewed (Lee et al.*, 2006) Building an operational product ontology. It was based on the development of building and ontology for an e-commerce system.*

While much of the research shared insights into how to build an operational ontology for a specific product, process, or service, we found none related to the topic of this thesis; therefore, as stated earlier, we will propose our architectural ontology for an enterprise within an industrial ecosystem in within this chapter. Yet, I decided to utilize some of the steps to build an operational ontology using (Falbo, no date) in building an operational ontology to facilitate the development of a hierarchy to perform operational analysis and mission engineering within this thesis. I plan to identify the purpose and the modularization needed with the intended use identification. I will then capture and formalize the ontology through a conceptual model that develops the design, starting with the architectural and detailed design of the ontology. Then proceed to ontology testing, starting with the testing of the individual or sub-ontological elements, then integration testing, and finally, the overall ontology testing. Based on the scope, I will only test the ontology at the industrial ecosystem, operational analysis, and mission engineering levels. Testing the complete ontological levels will continue after the completion of this thesis.

To further understand, the scope of this thesis is an Input, process, output (IPO) with key controls and enablers included; please see Figure 4. Inputs were identified through our research and my

40 years of experience in agriculture, construction, aerospace, and defense. Additional key elements were provided by MIT and Caltech, most notably Dr. Eric Rebentisch (MIT) and Dr. Richard Hefner (Caltech). Other reviews were held with several industry representatives who prefer confidentiality and system engineering consultants.

The IPO is depicted by the inputs being the discovery phase for this thesis, then the development of Operational Analysis and mission engineering with controls and enablers that govern the development and final delivery of a set of outputs. Chapter 4 will go into operational analysis with a notional example from the agri-food ecosystem and the production system for sugar. Chapter 5 will go into mission engineering and, for consistency, continue to follow the notional example from the sugar production system. Chapter 6 will share the discussion, implications, conclusions, summarize our recommendations, limitations, and final thoughts.

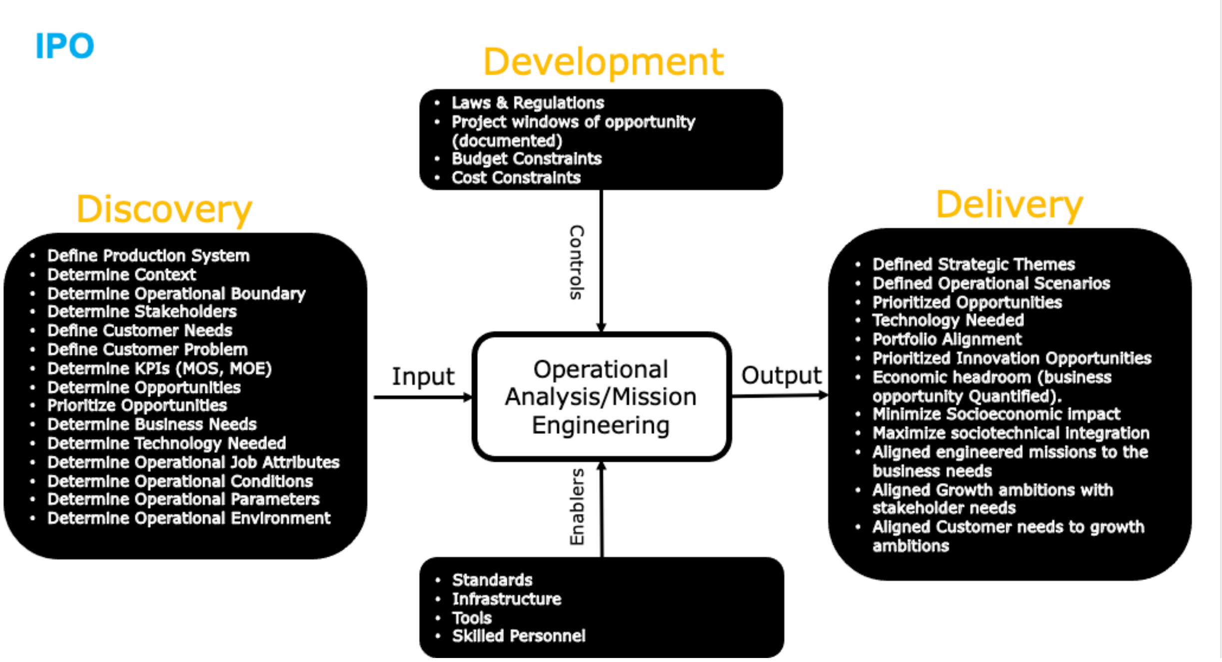


Figure 4 - Operational Ontology - Inputs, Process, Outputs

Figure 5 represents the high-level Object Process Diagram (OPD) used to help develop the functional understanding of the operational ontology. It takes the basic form of Operand (noun) and Process (form) which provide the function of the operational ontology. I will now go through these functions within the scope of this thesis. The red box goes is the system boundary for this thesis of operational analysis and mission engineering of and industrial ecosystem from the enterprise lens. I will go through only those functional at this time. Initially, industrial ecosystem (Noun) + identification (verb) results in the function of industrial ecosystem identification. This is followed operational system analysis with our function being operational analysis. We then *mission engineering. These was completed for the entire ontology to assure a functional understanding prior to developing the form of the operational framework.*

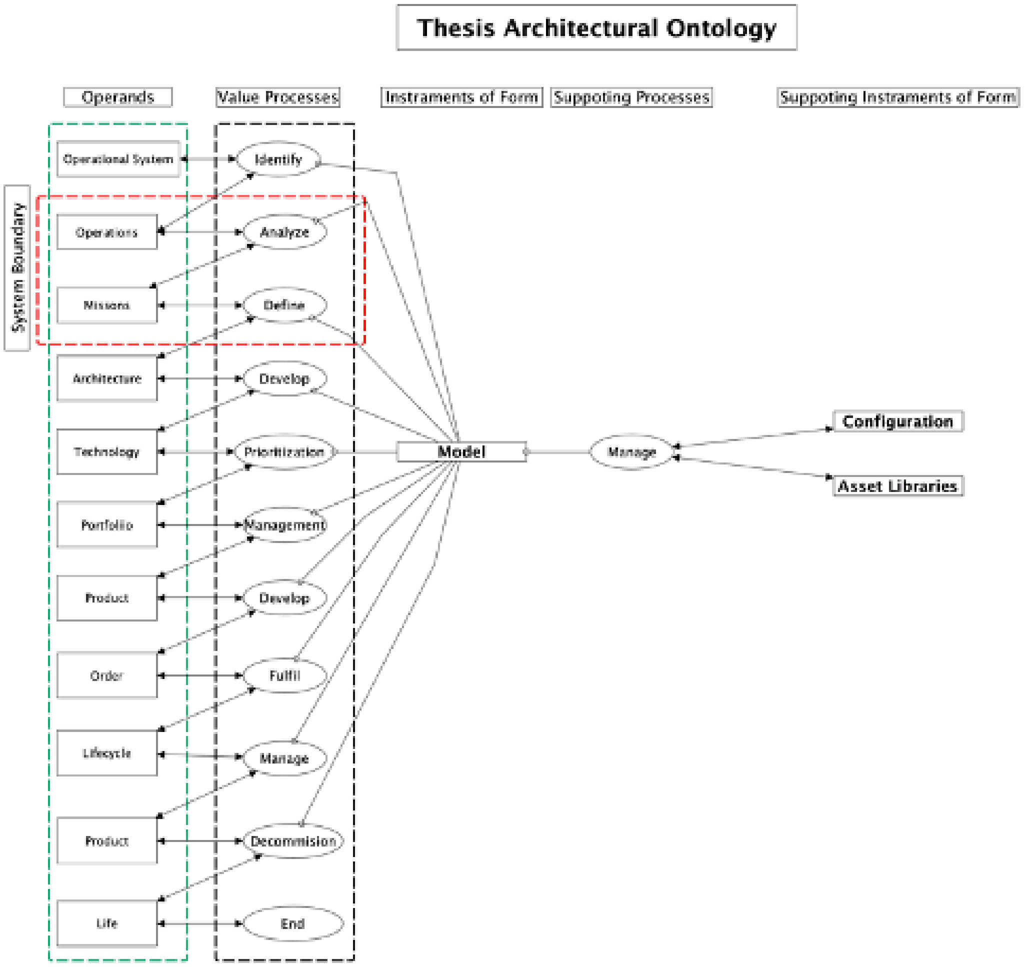


Figure 5 - Operational Ontology Functional Architecture

Figures 6 illustrate the Concept of Operations for this thesis to help further understand this critical ontology for current and future research. Our Concept of Operations outlines the need to understand our ecosystem to perform operational analysis and mission engineering to identify the stakeholder's understanding of their needs within the context of the enterprise to develop the scenarios to provide our opportunities as input to our strategy as well as develop our architecture through our technology needed and features to develop the system. The ConOps for the operational ontology Figure 7 shows the basic model we are proposing and the scope of this thesis: operational analysis and mission engineering.

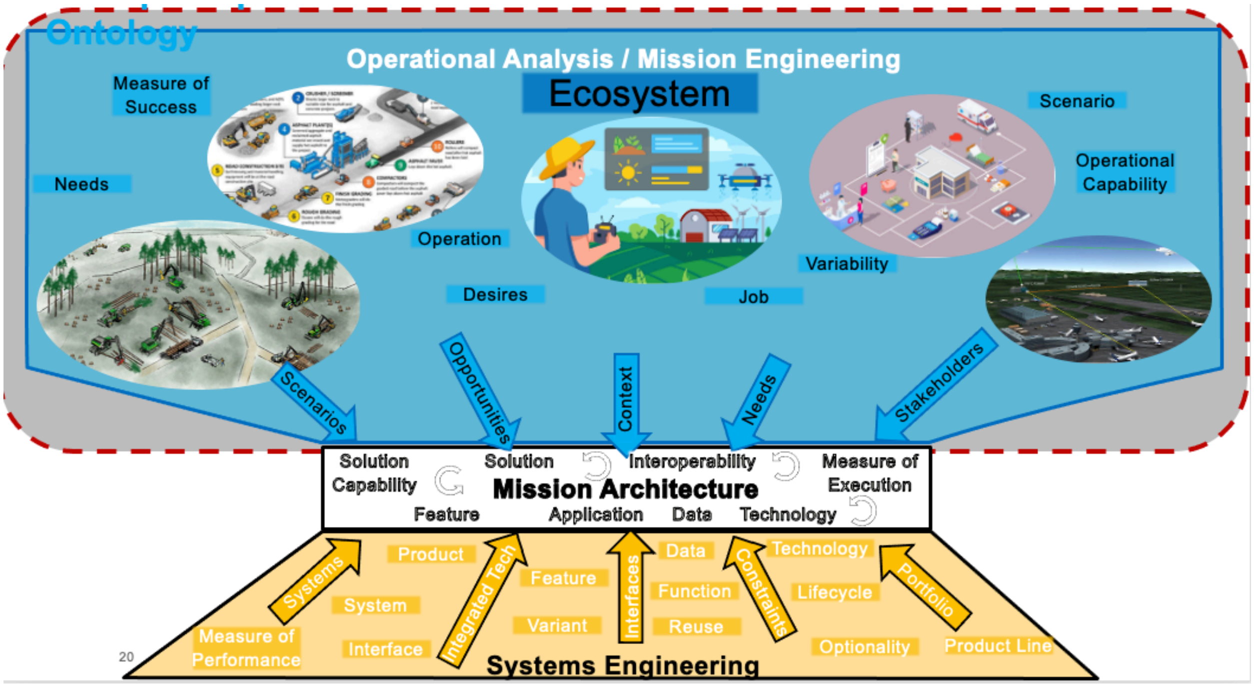


Figure 6 - Thesis Concept of Operation (ConOps)

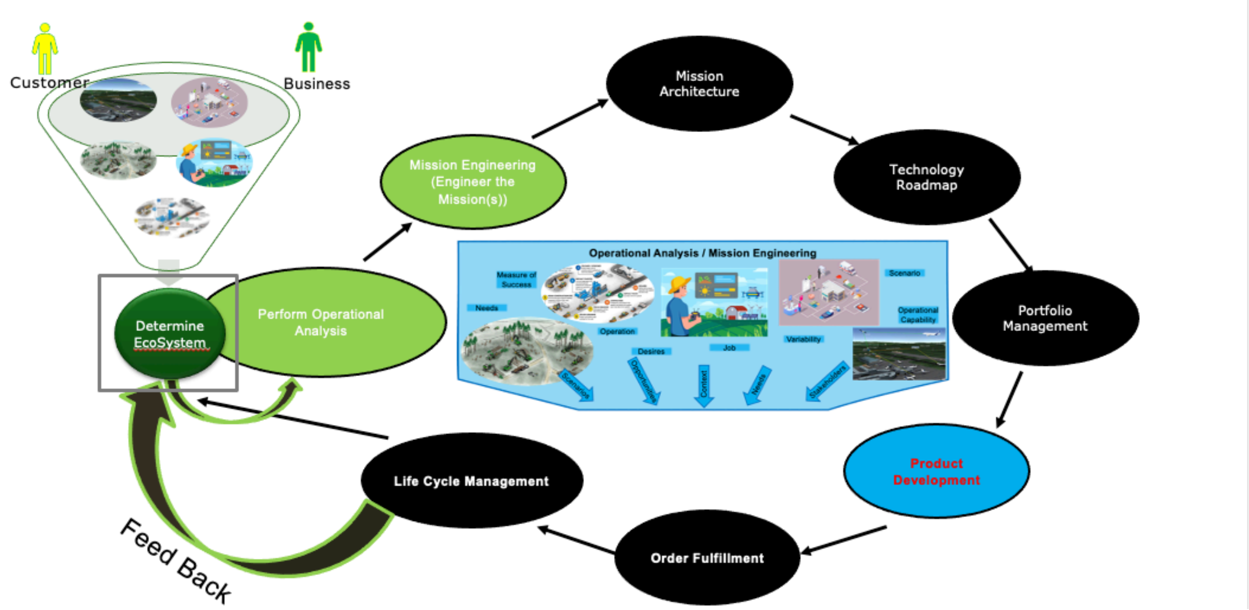


Figure 7 - Operation Ontology Concept of Operation (ConOps)

Suppose we recall the steps to build an operational ontology using (Falbo, no date) to facilitate the development of a hierarchy to perform operational analysis and mission engineering within this thesis. I identified the purpose and the modularization needed with the intended use identification through IPO, functional OPD, and ConOps Figures 4,5, 6, & 7. I then capture and formalize the ontology through a conceptual model that develops the design, starting with the architectural and detailed design of the ontology through the rest of Chapter 3. I then proceed to *ontology testing, starting with the testing of the individual or sub-ontological elements, then integration testing, and finally, the overall ontology testing in chapters 4 and 5. Based on the scope, I will only test the ontology at the industrial ecosystem, operational analysis, and mission engineering levels. Testing the complete ontological levels will commence upon the completion of this thesis.*

3.2 Purpose and Levels of the Ontology

If we begin an industrial ecosystem architectural ontology level 0 (AOL 0), the ontology needs to be decomposed in a way that provides the enterprise with the necessary levels of granularity, therefore, my ontology starts here. Initially, we must select our primary industrial ecosystem (AOL 0) in which we reside. That is not to say we don't have connections to other ecosystems. We do, and that is through the external relationships of our ecosystem. But we need first to understand the network internal to our ecosystem, and the ontology needs to provide the enterprise with the structural decomposition to begin the operational analysis, architectural ontology level 1 (AOL 1) of the enterprise within the context of the primary ecosystem. Operational analysis (AOL 1) is then completed within the context of the enterprise and its industrial ecosystem to identify opportunities and technologies needed as inputs to the mission engineering operational ontology level (AOL 2). Then mission engineering takes these opportunities and engineers their respective missions and mission threads within and between missions. These missions also need to integrate the technology needed to realize each opportunity.

Upon completion of mission engineering (AOL 2), there is a divide where the mission is released to the strategy development team and the mission architecture team architectural ontology level (AOL 3). The mission architecture team develops and finalizes the architecture and the relationships between the missions to ensure the overall strategy can meet the needs of the enterprise from a business and customer perspective while understanding the value added and non-value added to the industrial ecosystem in which they reside. Mission architecture considers the enabling technology and technology modules needed to realize the strategic plan being developed.

At this point, the mission architecture is transitioned to Technology Roadmapping architectural ontology level (AOL 4), where the technology roadmaps are defined. It should be noted here that much of this work is done through AOL 4 recursively and iteratively, much like how we follow this system engineering methodology. Upon completing the technology roadmaps, we transition to portfolio management Operational Ontology Level (AOL 5) to provide a prioritized portfolio that aligns the enterprise strategy, technology, and missions with a full understanding of the relationship at all operational ontology levels.

Once the portfolio has been developed (AOL 5), Product Development architectural ontology level 6 (AOL 6) initiates the development of the systems needed with the technology modules integrated to meet the needs of the enterprise strategy within the ecosystem they reside. As the *system is being developed, Product Development provides input to the order fulfillment architectural ontology level 7 (AOL 7) and engaging lifecycle management architectural ontology level 8 (AOL 8).*

This requires discipline to manage the relationships recursively and iteratively between the AOLs to gain the benefits of the proposed ontology. Figure 8 represents the oncological framework. In the next section, we will discuss some of our findings around the application of system architecture, engineering, and project management within this framework.

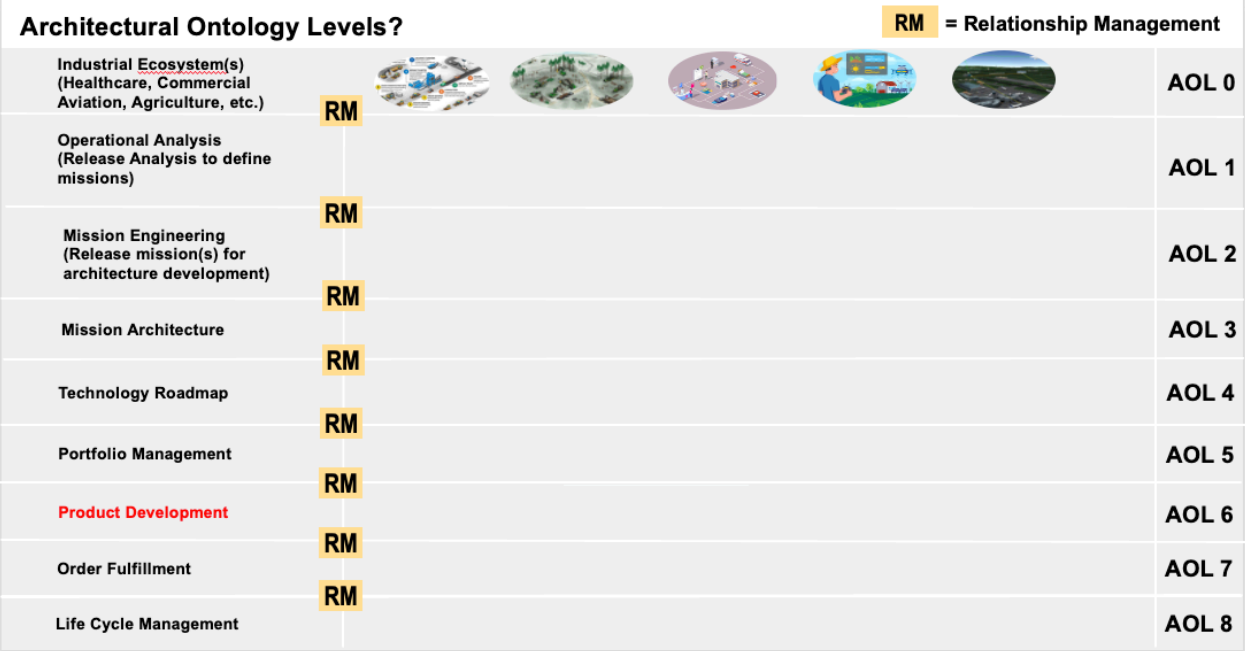


Figure 8 - Architectural Ontology Levels

3.3 Background of Architectural Ontology Levels

Our extensive literature reviews and industry and academic interviews uncovered that most system design applications, management principles, methods, etc., had been developed around product design (AOL 6). To support product design, many processes and services have also been developed within academia, industry, and councils (INCOSE). In line with a product-centric view, we found that many enterprises are pursuing strategies to gain additional market share through technology integration into innovative new systems while simultaneously minimizing their socioeconomic responsibilities as society demands these enterprises' social responsibility. We also found it quite alarming that these same enterprises are in the news daily regarding product, process, or service failures that result in product recall that impact their enterprise bottom line and reputations. This was due to the inability to understand the relationships within their respective industrial ecosystem(s). This forced us to ask ourselves, "How could an enterprise understand its relationship to the overall ecosystem(s) in which they reside?". As we researched this question, using the architectural ontology in the previous section, we identified in Figure 9 the work that has been done to date and where additional research is needed.

Figure 9 - Architectural Ontology Levels, Research Needed

Based on our system design and development research, the focus has been on product development. Within product development, systems are developed with a specific mission and submissions with little understanding of the impact on the industrial ecosystem in which their enterprise resides. Therefore, for tomorrow's enterprises to meet their internal and external stakeholder needs while maximizing innovations, embracing technological change, and minimizing the socioeconomic impact, they need to understand this architectural ontology from AOL 0 to AOL 8.

We found Industrial Ecosystem (AOL 0); many perceive industrial ecosystems as too complicated and complex to understand. A majority of academic and industrial education and applications have been made in Product Development (AOL 6). They will talk about these ontological levels operational analysis, mission engineering, technology road mapping, portfolio management, order fulfillment, and life cycle management as it relates to their respective enterprise rather than the industrial ecosystem(s) in which they reside. This results in a siloed approach versus a holistic approach starting at the ecosystem.

If we look at technology roadmapping on June 22, 2022, Olivier L. De Weck published "Technology Roadmapping and Development: A Quantitative Approach to the Management of Technology" this addresses AOL 4 technology road mapping at the enterprise level. It does touch on the industrial ecosystem in chapter 19. Yet, much of the book is dedicated to aerospace and defense. Yet, without further research, I would be remiss to say this can't be applied to other industrial ecosystems. He offers a graduate-level course at MIT, but he was on sabbatical during my time at MIT; therefore, my understanding is currently limited to his textbook.

We found that further research is needed within the architectural ontology to enable enterprises to truly develop an impactful vision and strategic plan that meets their needs within the ecosystem(s) they reside in the following areas: AOL 1 – Operational Analysis and AOL 2 – Mission Engineering research is within the scope of this thesis. AOL 3 – Mission Architecture, AOL 4 – Technology Roadmapping (Further understanding of recent work needs to be thoroughly vetted), AOL 5 – Portfolio Management needs further research. AOL 6 – Product Development through System Design and Management elements are defined, yet relationship management of AOL 6 to AOL 4 and AOL 5 needs to be researched. We must also research AOL 7 – Order Fulfillment and AOL 8 – Life Cycle Management. The author intends to vet the areas needing further research and understanding fully, but due to time constraints and the scope of this thesis, it will be pursued in the coming years. I will be providing this research to MIT and Caltech, and I intend to publish through white papers at industry and academic symposiums and webinars.

3.4 Definitions of Architectural Ontology Levels

We describe each level in the architecture ontology, starting with the industrial ecosystem (AOL 0).

Industrial Ecosystem – AOL 0 *(see Figure 10). This view of industrial ecosystems focuses on networks rather than (value) chains and traces the complex links across firms, sectors, and institutions. Industrial ecosystems include public activities utilizing these public institutions and research centers as key actors in the interactions with firms. These Ecosystems are dynamic and evolve continuously and are not meant to be fixed and discrete. Every enterprise resides in a primary ecosystem and has secondary and tertiary relationships with others. To perform operational analysis, the first step is to define the primary ecosystem while considering that we may have some relationships with other ecosystems.*

Figure 10 - Architectural Ontology Level 0

Operational Analysis – AOL 1 *(see Figure 11). Operational activities relating to the functioning of the specific ecosystem and relationships of activities within the ecosystem. A system provides capabilities through the execution of operational activities. As an output, the operational analysis provides a prioritized list of opportunities and critical relationships for technology and mission development. The Key elements we define are the Operations, Capabilities, Value Streams, Strategic Themes, System Characteristics, Technology, and System Constraints. The key outputs of the operational analysis, which are key inputs into mission engineering, are business opportunities and a clear understanding of the socioeconomic and sociotechnical impacts on our enterprise and ecosystem(s). More detail on Operational Analysis in chapter 4.*

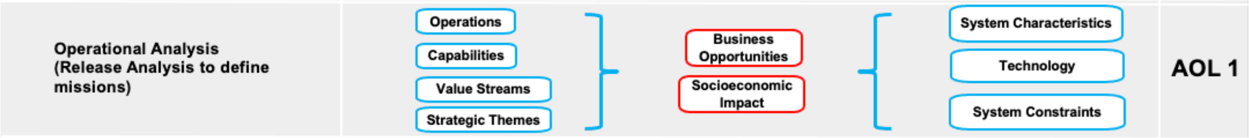


Figure 11 - Architectural Ontology Level 1

Mission Engineering – AOL 2 *(see Figure 12). Mission engineering develops individual missions while maintaining the relationships between the internal enterprise and the external ecosystem. Applying systems engineering methods, principles, and tools in planning, analyzing, and designing mission threads ensures that critical relationships are understood and maintained. The mission(s) describe what the system will do and its purpose. Missions are almost always conducted by multiple systems (mission-oriented system-of-systems (SoS)) coordinating their actions and relationships. The mission-oriented ecosystem could be rapidly conceived, assembled, and deployed. The Key Elements we define are Mission Scenarios, Operational Concepts, Mission(s), Mission Statement, Mission Function, Model Mission, Capabilities Needs, and Mission Analysis. The Key Outputs are our Measure(s) of Success (MOS), Measure(s) of effectiveness (MOEs), and Measure(s) of Performance (MOPs). More detail on ME is in Chapter 5.*

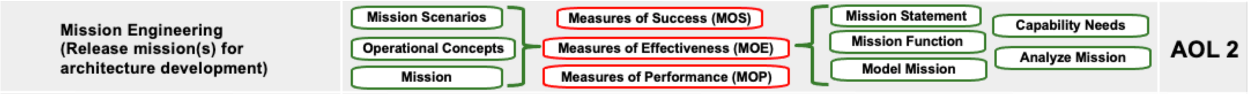


Figure 12 - Architectural Ontology Level 2

Mission Architecture – AOL 3 *(see Figure 13). Mission architecture is the method of developing a theoretical model of the engineered mission(s) and relationships into a system of systems within the context of the ecosystem(s) that the enterprise has a relationship to. The key Elements are the technology, functions, and features needed to the needs of the enterprise strategy while providing additional opportunities from technology dependencies and prioritization. The key outputs of mission architecture with defined relationships internal to the enterprise and the ecosystem, Measure(s) of Effectiveness (MOEs), and Sociotechnical Impact.*

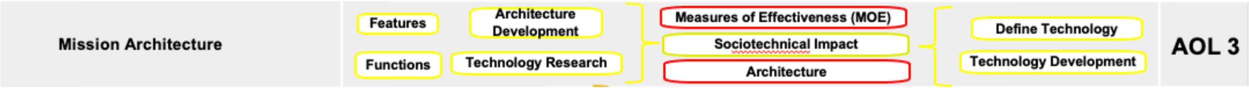


Figure 13 - Architectural Ontology Level 3

Technology Roadmap – AOL 4 *(see Figure 14). A technology roadmap provides a consensus about the needs of the enterprise and ecosystem in which it resides and the technologies required to meet those needs. It identifies the technologies needed for development and system integration and plans for the required technologies. It analyzes and prioritizes the development of existing and emerging technologies in a cohesive enterprise plan. The key Elements are a thorough understanding of enabling technology, technology modularity, technology package(s), and technology Plan. The Key Outputs needed are a technology readiness level (TRL), an integration* *readiness level (IRL), an advanced degree of difficulty (AD^2), and an approved technology roadmap.*

Figure 14 - Architectural Ontology Level 4

Portfolio Management – AOL 5 (see Figure 15). It is the prioritized organization of the mission architecture and approved technology roadmap into an execution plan for the products, processes, and services needed to meet the enterprise and customer needs. It includes the administration and management of projects by authorizing, managing, and controlling projects, programs, and other related elements to achieve enterprise objectives. The key elements are technology integration, resource allocations, enterprise strategy, enterprise ambitions, strategic plans, and strategic goals. The key outputs are key performance indicators (KPIs).

Figure 15 - Architectural Ontology Level 5

Product Development – AOL 6 (see Figure 16). Is defined as the phases or stages involved in bringing a product, process, or service from conceptual idea to market release to support the enterprise objectives while meeting customer needs. The key elements are product design, customer acquisition, engineering standards, supply chain, financial management, manufacturing design, product safety and compliance, program management, product verification, and validation. Please note that this is not an all-inclusive list, as different enterprises may have additional cross-functional elements within their product development teams. The Key Outputs are Key Performance Indicators (KPIs) (at a minimum complete design concept of the system, operational prototypes, and demonstration with an understanding of the project plan, risks, and risk mitigation strategy).

Figure 16 - Architectural Ontology Level 6

Order Fulfillment – AOL 7 (see Figure 17). It is defined as the phases or stages of producing a product, process, or service, from receiving the final design to delivering it to the final sales location. The key elements are making orders, configuring orders, metal forming, assembly, programming, calibrating, testing (hardware and software), shipping, quality, logistics, and material acquisition. This is not an all-inclusive list, as different enterprises may have additional cross-functional elements within their order fulfillment process. The key outputs are Key Performance Indicators (KPIs), products delivered to the customer, and financial returns to the enterprise.

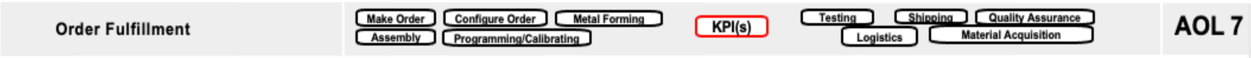


Figure 17 - Architectural Ontology Level 7

Life Cycle Management – AOL 8 (see Figure 18). It is defined as the phases or stages of a product, process, or service after the initial sale until retirement. Please note that for this paper and the scope, this definition will be used only for a conceptual understanding of AOL 8. The key elements are products, vehicle health, vehicle support, parts, processes, services, and retirement. The outputs are Key Performance Indicators (KPIs).

Figure 18 - Architectural Ontology Level 8

3.5 Complete Architectural Ontology Levels

The overall development of the proposed architectural ontology has now been defined, allowing users to understand the elements at each level, and key outputs, with the final graphical representation below in Figure 19.

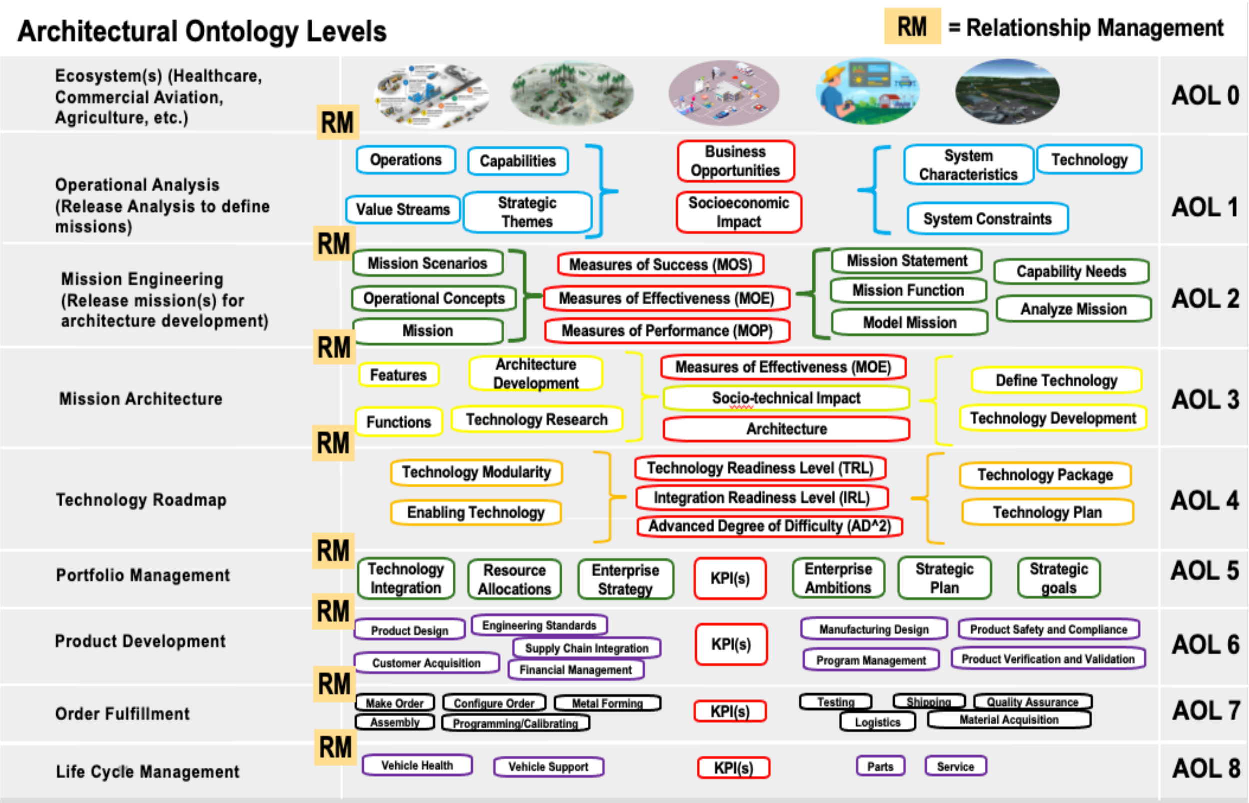


Figure 19 - Summary Architectural Ontology Levels

The research was divided into nine architectural ontological levels based on the objectives. First, a comprehensive literature review was conducted, including discussions with industry experts and academic researchers at the Massachusetts Institute of Technology (MIT) and California Institute of Technology (Caltech). Second, this research found that while extensive enterprise applications of system design and management have been applied to products, processes, and services under system engineering and architecture, integrated product management applications were confined to product development, Architectural Ontology Level 6 (AOL 6). Third, while the aerospace and defense industry applies mission engineering principles, our research sought to understand whether operational analysis or mission engineering is applied to industrial ecosystems to enable more effective management of the ecosystems and the overall socio-economic and sociotechnical impacts. Fourth, we found that most enterprise strategy development and methods are solely based on the products, processes, and services they provide without looking broadly at social responsibilities that are today being demanded of all enterprises. This thesis provides a framework and structure for identifying the ecosystem (AOL 0), performing operation analysis (AOL 1), and mission engineering (AOL 2) to facilitate the advancement and education of system design and management as a discipline.

While I would have liked to have provided an extensive exploration of AOL 0 through AOL 8, as shown in Figure 19, due to constraints and needing to limit the scope, we will provide the framework and structure for AOL 0 through AOL 2 see Figure 20.

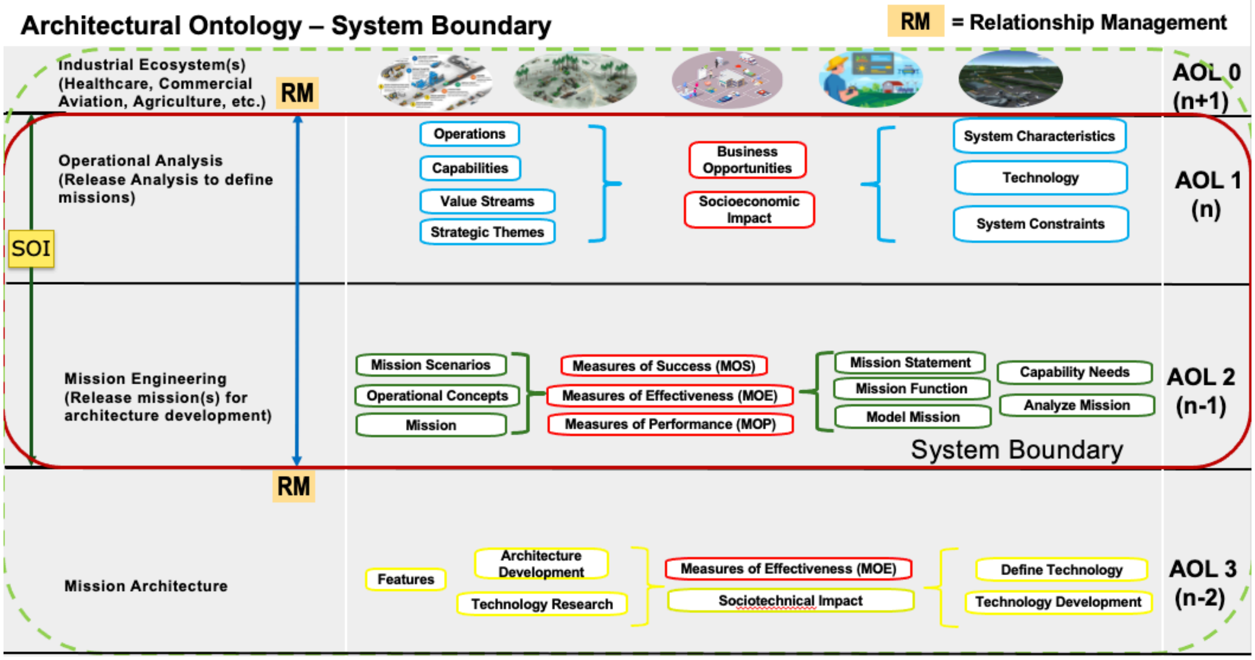


Figure 20 - Architectural Ontology, Boundary, and Scope

I will touch on all architectural ontological levels for understanding and background. AOL 0 through AOL 2 are strategic for an enterprise to understand how they fit within a particular ecosystem or several ecosystems, i.e., Deere & Company resides in the industrial ecosystems of

Agri-Food. Yet, within these ecosystems, they provide products, processes, and services but desire to identify, develop, and deploy additional innovation within their strategy. These opportunities often come with risks to the enterprise's core values, shareholders, employees, and customers. To lessen that risk, they must understand the industrial ecosystem within which they reside (AOL 0) and perform operational analysis at (AOL 1) to identify opportunities and relationships to better engineer their respective missions and relationships (AOL 2) to provide a comprehensive strategy that leads to the development of the respective mission architectures (AOL 3), Technology Roadmaps (AOL 4) to optimize their respective portfolio management (AOL 5) allowing the development of innovative products, processes, and services, (AOL 6) and through order fulfillment process (AOL 7) and lastly manage the lifecycle (AOL 8).

4. Operational Analysis

Chapter Tenets:

- *Operational Analysis – Defines all operations and their relationships within an industrial ecosystem(s) to which the enterprise aspires its strategy to encompass.*
- *Enterprises, during strategy development, need to identify opportunities within the business as well as performance improvement opportunities.*
- *It can be used as an assessment tool based on current performance.*
    - *It can also assess the sociotechnical and socioeconomic value-added and non-value-added impacts.*
- *It is a process mapping method used to visually represent the steps within the ecosystem needed to identify opportunities.*
- *It is not strategic management; it identifies opportunities within the ecosystem for inclusion in strategy development and subsequent management through annual assessments.*

To develop a comprehensive strategy for their respective products, processes, and services, enterprises must understand their boundaries within this ecosystem and the critical operational parameters and relationship to this ecosystem to remain a market leader with innovative products, processes, and services. At the same time, they must generate business results by integrating advanced technological solutions that meet current and future customer needs and minimize the socioeconomic impact on their respective industrial ecosystems.

If companies execute their strategies without this understanding, the leaders may be left to wonder why these products, processes, and services fail to meet the business and customer needs with time and resources, both human and capital required after the start of production to meet these needs sometimes never reaching the enterprise strategic goals.

The operational analysis defines the necessary operational characteristics and relationships within the larger context of the industrial ecosystem. Thus, enabling us to discern opportunities and threats to the enterprise while maintaining the critical relationships within the broader industrial ecosystem of the enterprise.

Starting with the ecosystem and performing the operational analysis will allow an enterprise to understand the boundaries within its industrial ecosystem(s) more clearly. Yet, more importantly, understanding the relationships at these boundaries to the industrial ecosystem is more beneficial to provide additional opportunities within their enterprise while genuinely understanding the customer and business needs resulting in a more comprehensive strategy with a higher level of fidelity.

In the short term, this will take more time, human resources, and business capital; in the long term, it will be easily updated, providing new opportunities and value in the areas of innovation, and integration of disruptive technology, while delivering socially responsible advances to both the enterprise and the ecosystem that improves the image and reputation of the company and ultimately providing strategies that allow the enterprise to execute more consistently.

We perform operational analysis to assist the enterprise's understanding of how its internal environment fits into the industrial ecosystem(s) they reside. It forms the foundational element to define the boundaries of its products, processes, and services within this industrial ecosystem. To enable their profitability within the constantly changing industrial ecosystem. The operational analysis allows the operational activities of the respective industrial ecosystem and relationships to be identified, which is imperative to understanding. It is an external look at how the enterprise fits within the industrial ecosystem.

Operational analysis is an external view to recognize gaps and opportunities to identify emerging needs, technology, etc., for sustainability and innovation within an enterprise. This method allows you to identify critical operations in the larger industrial ecosystem to understand the dynamics of the enterprise and the critical relationships within the industrial ecosystem. It is the first crucial step in understanding what opportunities have yet to be considered now and in the past. It is not for developing products, processes, and services.

Key deliverables from the operational analysis are as follows:

- *Understanding existing gaps and future opportunities based on current and future strategies*
- *Opportunities and critical relationships for technology and mission development.*
- *Enterprise environment aligned with the industrial ecosystem before engineering our missions.*

- *A ranked list of opportunities, relationships, and technologies needed for mission engineering.*

4.1 My Review of the Literature

This area proved to be a challenge at this point; I wanted to understand if, from the industrial ecosystems and with an operational ontology as related to an enterprise can execute an analysis of the operations needed of the industrial ecosystem be developed to identify opportunities for further research by the enterprise as an input into their strategy? Numerous publications were reviewed, most notably at Lawrence Livermore National Laboratory (Operations Analysis of Engineering Sciences, Cutburth, October 2018). While this book was very beneficial for understanding how a laboratory performs operational analysis, it provided little applicability to operational analysis in industrial ecosystems. Furthermore, we reviewed the INCOSE Systems Engineering Handbook 4th edition, 2015, NASA Systems Engineering Handbook, Rev 2, Updated January 27, 2020, as well as the System Engineering Body of Knowledge (SeBoK) (Category: SEBoK) along with books other papers had very little on operational analysis other than at the product, process, and service level in the artifacts of Concepts of Operation (ConOps) and Operational Concepts (OpsCon). Therefore, in Chapter 4, we will propose our framework as a process for operational analysis of an industrial ecosystem to identify opportunities within an enterprise.

To expand further on the Lawrence Livermore National Laboratory (Operations Analysis of Engineering Sciences, Cutburth, October 2018). It explores the administration and management engineering sciences as operations. It analyzes the strategic planning of sciences, looking at knowledge production. It was more an internal assessment versus what I was researching with limited applicability of performing operational analysis on the industrial ecosystem(s) to develop opportunities to understand through engineering our missions to provide additional inputs to the enterprise strategy.

I wanted to expand the literature reviews to look at INCOSE Systems Engineering Handbook 4th edition, 2015, NASA Systems Engineering Handbook, Rev 2, Updated January 27, 2020, and the System Engineering Body of Knowledge (SeBoK) (Category: SEBoK). As I reviewed these documents, definitions around operational, operational capabilities, operational concept, the operational environment, operational mode, and operational scenarios were reviewed. I wanted to see if these concepts and definitions could be stitched together to provide insight into how operational analysis can be performed on an industrial ecosystem to better guide the enterprise in strategy development. I found little relevance to the goal and questions my thesis was trying to identify; the closest area was operational scenarios, which were very specific to products and services with specifically to the environment of today's users and was very specific to products. However, none of these documents assisted me with applications to systems. I was able to piece together that operational analysis utilizes various tools and techniques, such as process mapping, flowcharting, data collection, and statical analysis. The primary focus is to develop a process *map to visually represent the steps in the analysis to understand gaps or opportunities within the context of the subject being analyzed.*

Through all my research within this area, as stated earlier, we will propose a process within our framework for operational analysis of an industrial ecosystem to identify the opportunities within an enterprise.

4.2 Operational Analysis Approach

To allow us to perform operational analysis (AOL 1), we must first determine which industrial ecosystem(s) (AOL 0) our enterprise resides within. As defined by the European Commission (Hofweber, 2023), the industrial ecosystems are tourism, creative and cultural industries, energy Intensive Industries, renewable energy, aerospace and defense, textiles, electronics, mobility, transport & automotive, retail, proximity and social economy, agri-food, health, digital, and construction. Therefore, the enterprise must understand its industrial ecosystem(s); refer to Figure 3. To further elaborate on this point, look at a large multi-national company like Deere & Company (John Deere) (Ref. John Deere US | Products & Services Information) residing in agri-food, energy, defense, mobility and transport, defense, construction, etc. If we break down agri-food, Deere & Company provides products, processes, and services within these industrial ecosystems, as shown in Figure 21, and products, processes, and services to numerous other industrial ecosystems.

Figure 21 - Equipment Provider Products (Ref:Deere.com)

4.3 Operational Analysis Details

Operational analysis has three key elements of discovery wherein we determine the industrial ecosystem(s) where the enterprise resides (inputs). Development of our operational analysis understanding the controls and enablers (process). The ecosystem's delivery within the enterprise context (outputs) see IPO Figure 22.

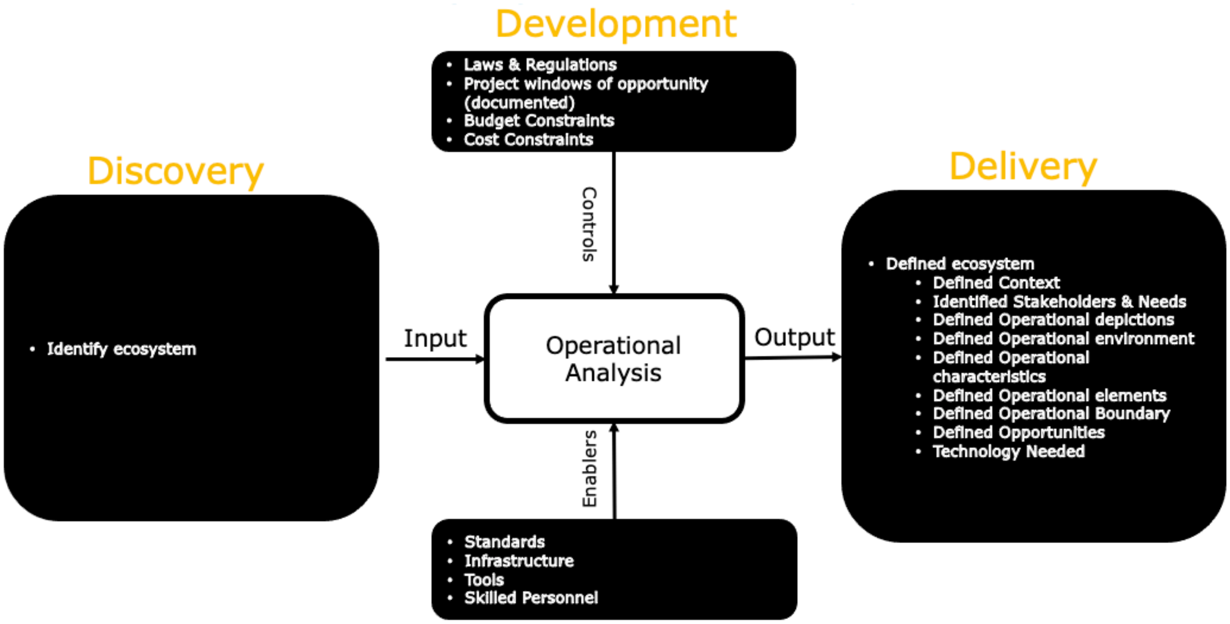


Figure 22 - Operational Analysis IPO

To perform operational analysis effectively in developing the enterprise strategy, we must develop many of the same system artifacts we create when following the principles and methods of system architecture, system engineering, and project management in developing products, processes, and services at AOL 5 & 6. Yet, our perspective is at levels AOL 0 and 1. Initially, we want to identify the industrial ecosystem(s) within which our strategy will be developed.

To effectively communicate within the strategy development cross-functional team, an operational concept (OpsCon) is generated. The OpsCon is a high-level description of the characteristics of the proposed sequence of the operational analysis from the viewpoint of the individuals on the cross-functional team that will be completing the analysis. When developing systems, we use the OpsCon to provide a system-centric description of the intended users, uses, how the system will be used, and the external parameters while using the system. We apply the same concept here, from a process OpsCon perspective versus a systems OpsCon. Therefore, with a general understanding of the operational analysis method from our operational concept (OpsCon figure 23). This provides the understanding of defining the ecosystem(s) "Get Ready", Understanding the needs "Get Set", Performing the analysis "Go", Prioritizing the opportunities based on the needs "Get Unset", defining technology needed, and preparing the documentation to transition to mission engineering "Get Unready".

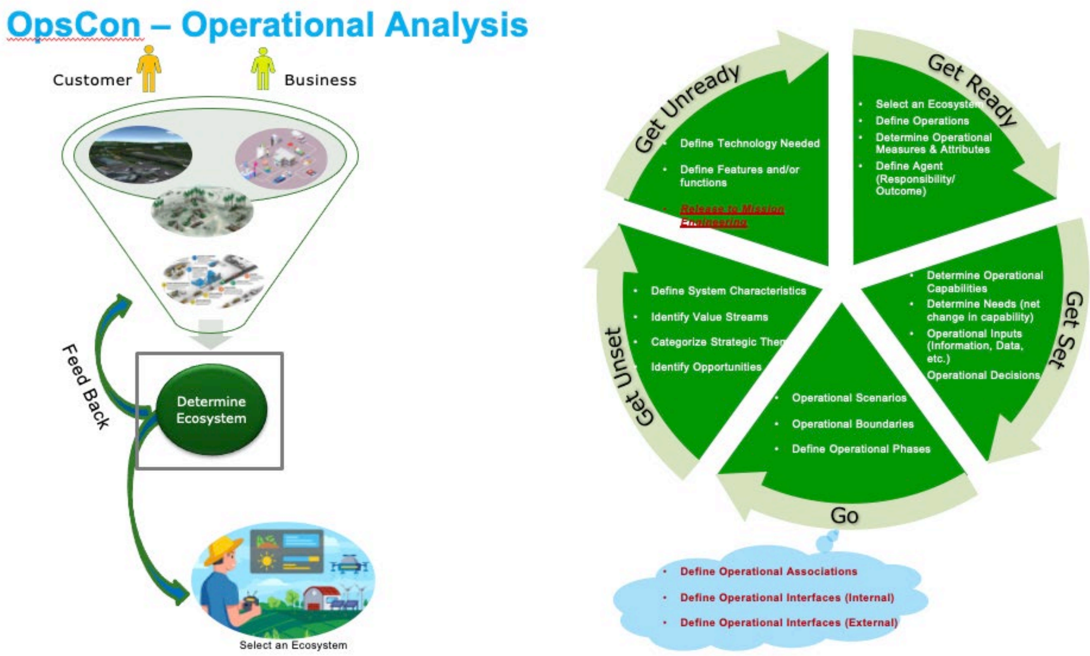


Figure 23 - Operational Concepts, Operational Analysis

We need to identify our stakeholders from a customer and business perspective related to the industrial ecosystem(s). The key project stakeholders and value flows (needs) are detailed in (Figure 24). The value flows were identified and categorized by demand ranking of "Must be", "Should be," and "Might be". Also, the dimension of supply importance was added to help prioritize needs across stakeholders. The stakeholder network representation is shown in Figure 24. The stakeholders were categorized into Market Stakeholders, those with a financial interest in the operational analysis, Non-Market Stakeholders, those with non-financial interests, the Focal Point of the analysis, and End Users, Users of the analysis.

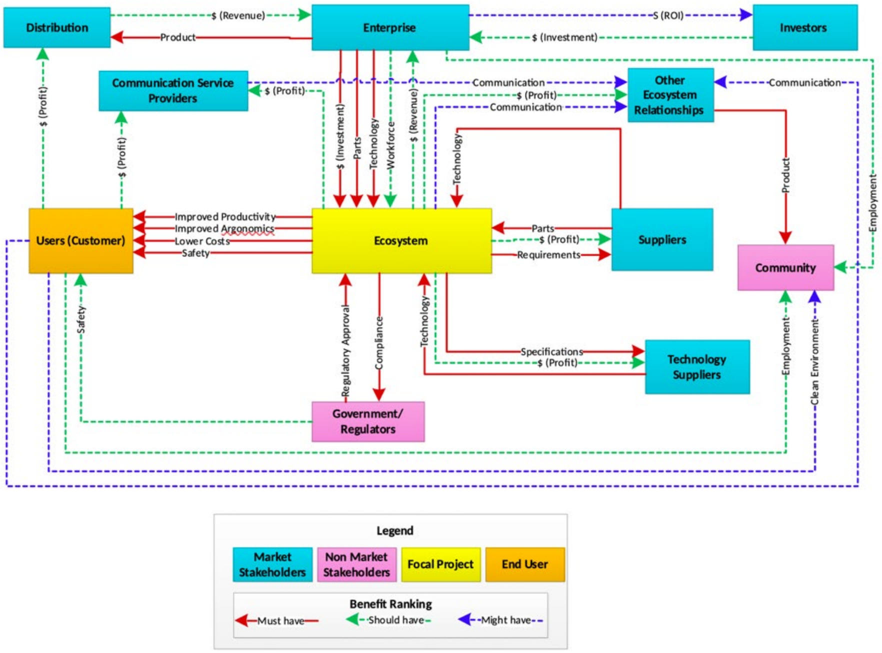


Figure 24 - Operational Analysis, Stakeholder Value Network

Stakeholder needs are shown in Figure 25. The needs were categorized using the Kano model to visualize and prioritize needs. Key Insights and stakeholder analysis provided a system boundary to develop and verify our functional architecture for the operational analysis and an example that will be used to demonstrate our methods and process for the Sugar Cane example. The activities are carried out early in developing our operational analysis within our industrial ecosystem(s), with the socio-economic and technological context, to allow us to execute our operational analysis effectively.

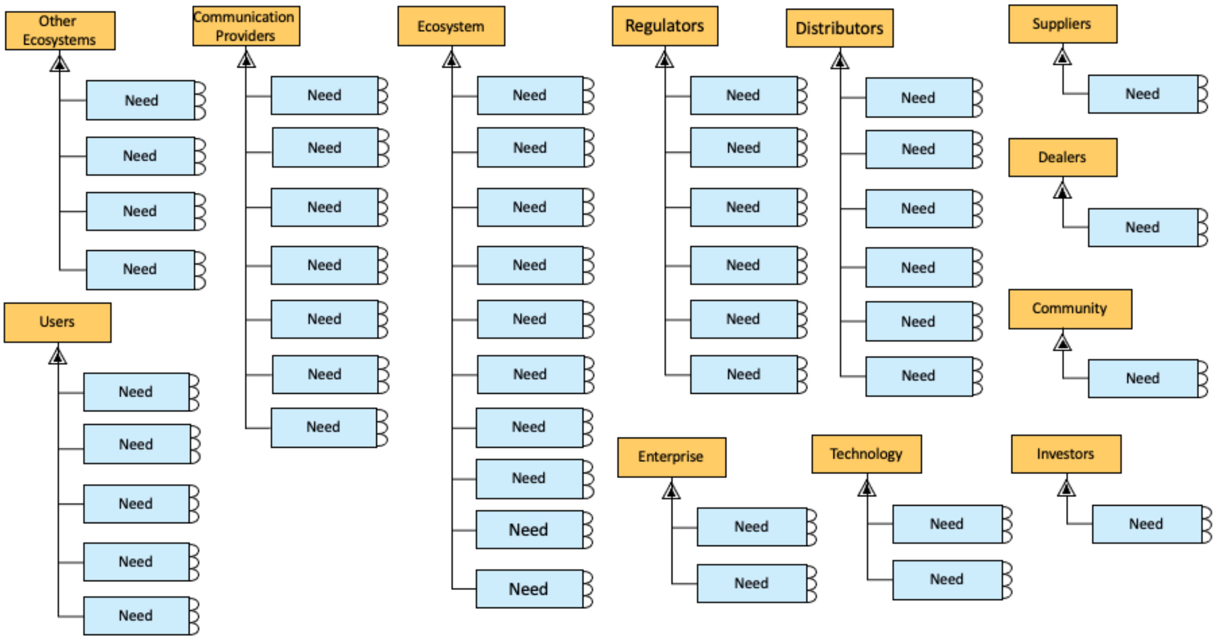


Figure 25 - Operational Analysis, Stakeholder Needs

The process map for operational analysis is shown in Figure 26. I start with understanding and selecting the ecosystem(s) in which the enterprise resides and any secondary or tertiary ecosystem relationships. At this point, we identify the operational stakeholders and their needs. Develop and define the operation depictions (vignettes) and the operational environment. Then we develop and define the operational characteristics and break them into operational elements. At the same time, we simultaneously identify the operational relationships throughout to enable us to understand and define our operational boundaries. Through our development, we noticed a repeating pattern that allows the operational analysis to repeat the same steps at the enterprise and production systems levels. After we have completed the analysis at these three levels, we take the identified opportunities and trace them back through an operational review for completeness and understanding of the operational interfaces and prepare to release to mission engineering. Mission engineering and its process with be shared in Chapter 5.

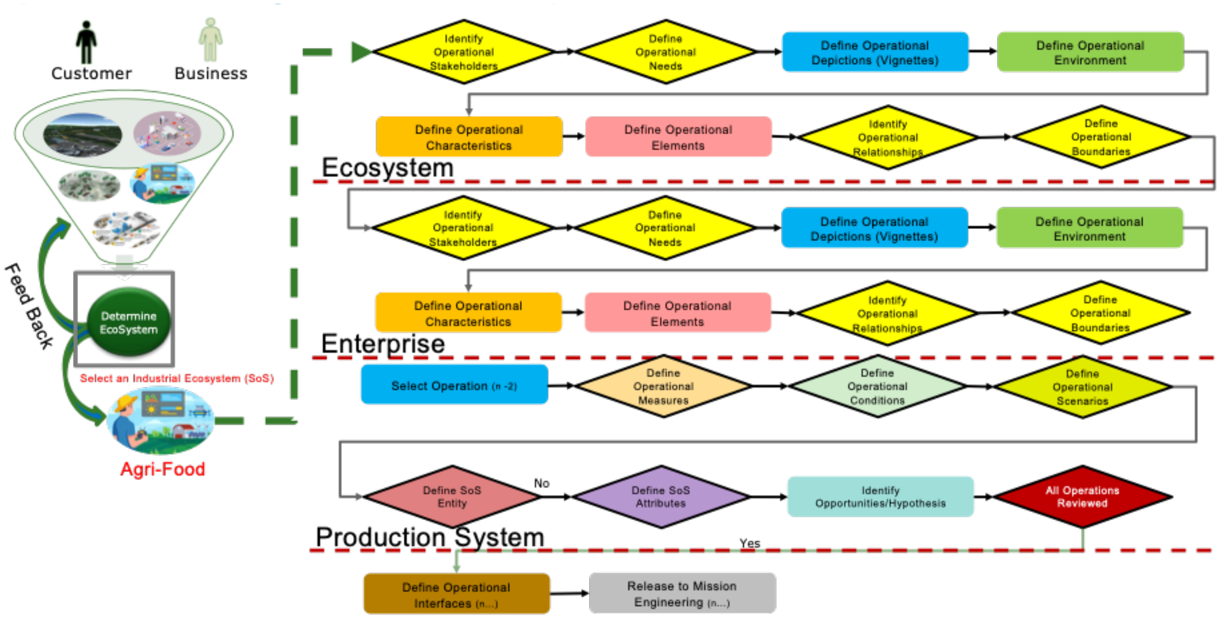


Figure 26 - Operational Analysis, Process Map

Now with our industrial ecosystem(s), operational concept, stakeholders, needs, and process map understood, let's begin our operational analysis by breaking down the process map into sub-elements. While the initial intent of this research within the context of this thesis is from an academic researcher's perspective, the writer felt it also necessary to utilize a real-world notional example to enable the academic research and theory to be applied practically by enterprises in their strategy development. To further elaborate, we have selected Agri-Food as our industrial ecosystem to use our researched methods.

4.4 Operational Analysis - Ecosystem

We identify the operational stakeholders and their needs starting at the ecosystem level. Develop and define the operation depictions (vignettes) and the operational environment. Then we develop and define the operational characteristics and break them into operational elements. At the same time, we simultaneously identify the operational relationships throughout to enable us to understand and define our operational boundaries. This is represented in Figure 27 and shows the process map for the ecosystem.

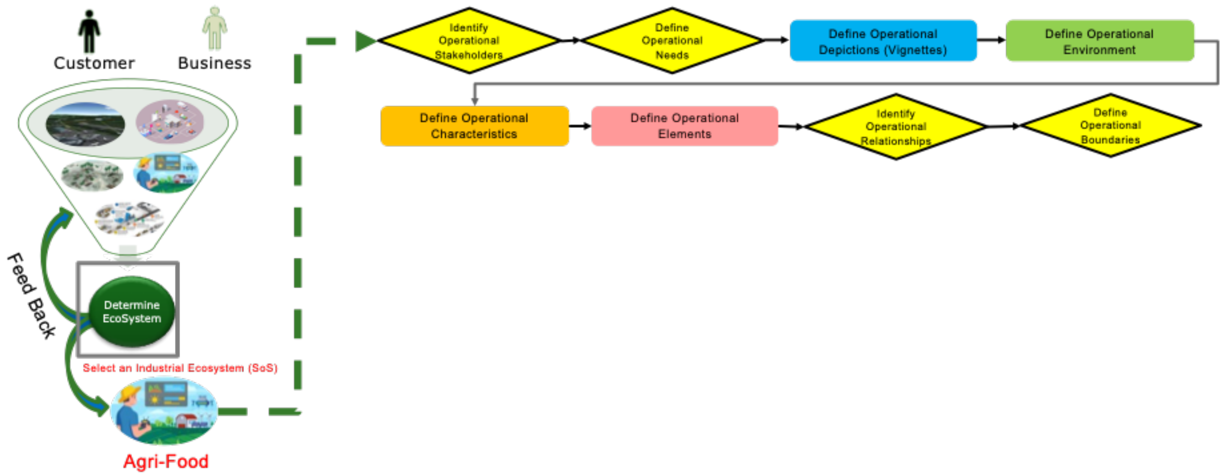


Figure 27 - Operational Analysis Process Map, Ecosystem

I will use the notional example's Agri-Food industrial ecosystem with this thesis. Operational Analysis begins by identifying our operational depiction(s) (Vignette(s)), shown in Figure 28. This provides a structured decomposition method of the analyzed industrial ecosystem(s). Operation depiction(s), sometimes called vignettes, identify all operations with their relationship to each other and the ecosystem, as depicted in Figure 27.

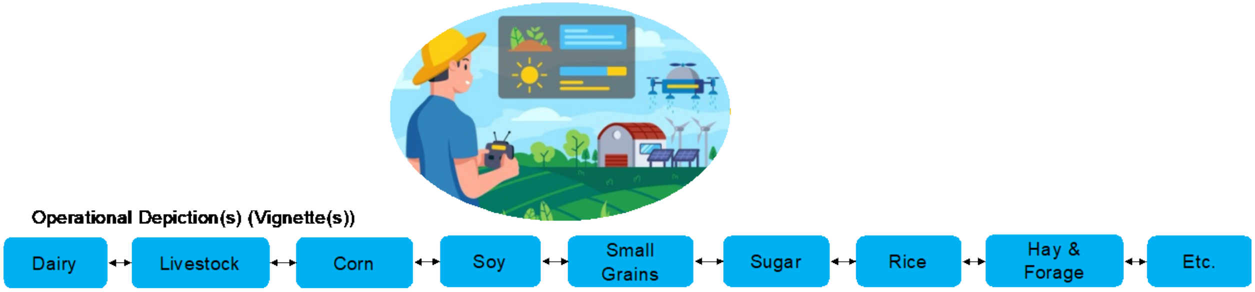


Figure 28 - Operational Depiction(s) [Vignette(s)]

We then analyze the operational depictions within the operational environment and their associated relationships, as shown in Figure 29.

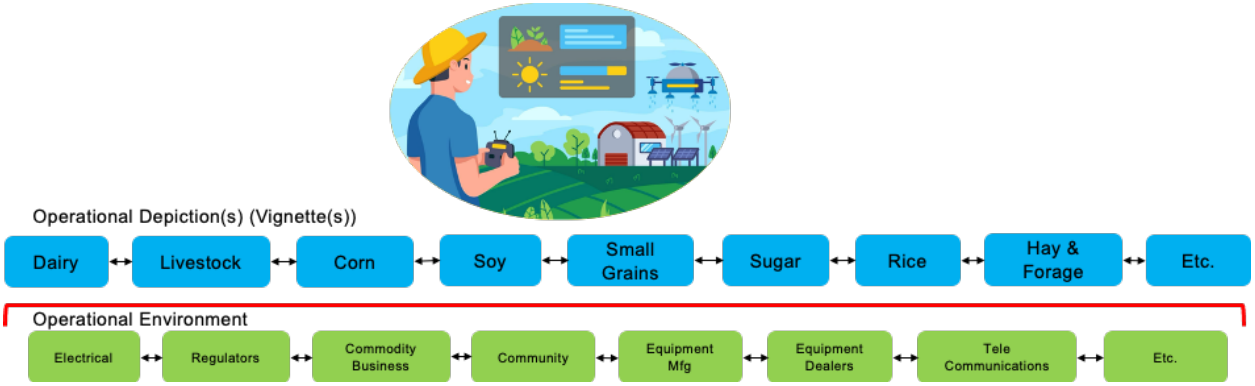


Figure 29 - Operational Environment

The operational environment has specific operational characteristics and relationships Figure 30 that must be defined within the industrial ecosystem to allow further refinement of the operational elements.

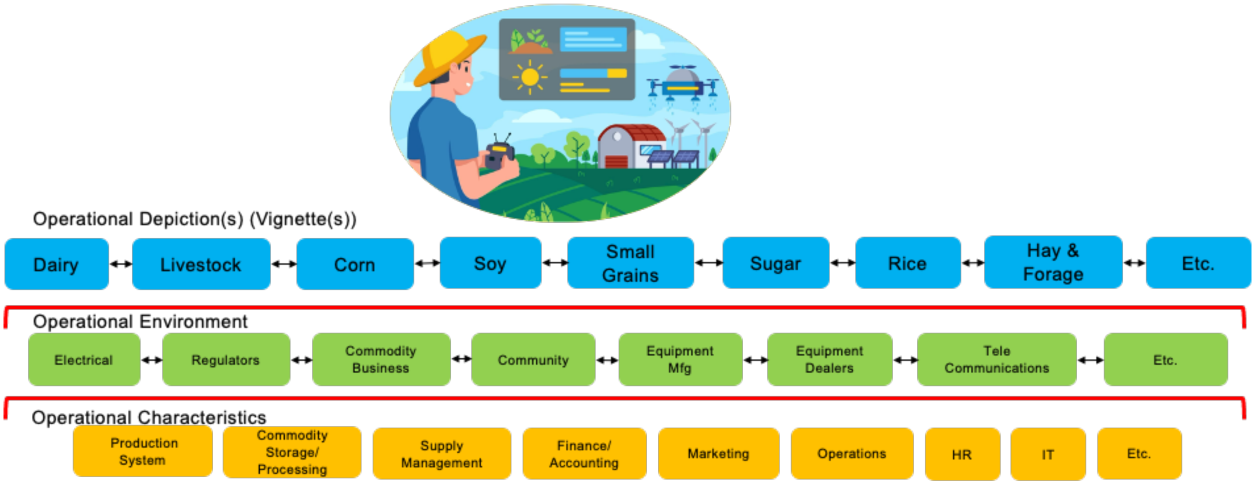


Figure 30 - Operational Characteristics

The operational characteristics have operational elements and relationships (see Figure 31). These are used to establish our enterprise relationship within the context of our industrial ecosystem of agri-food; we define the depiction, environment, characteristics, and elements in which our enterprise resides.

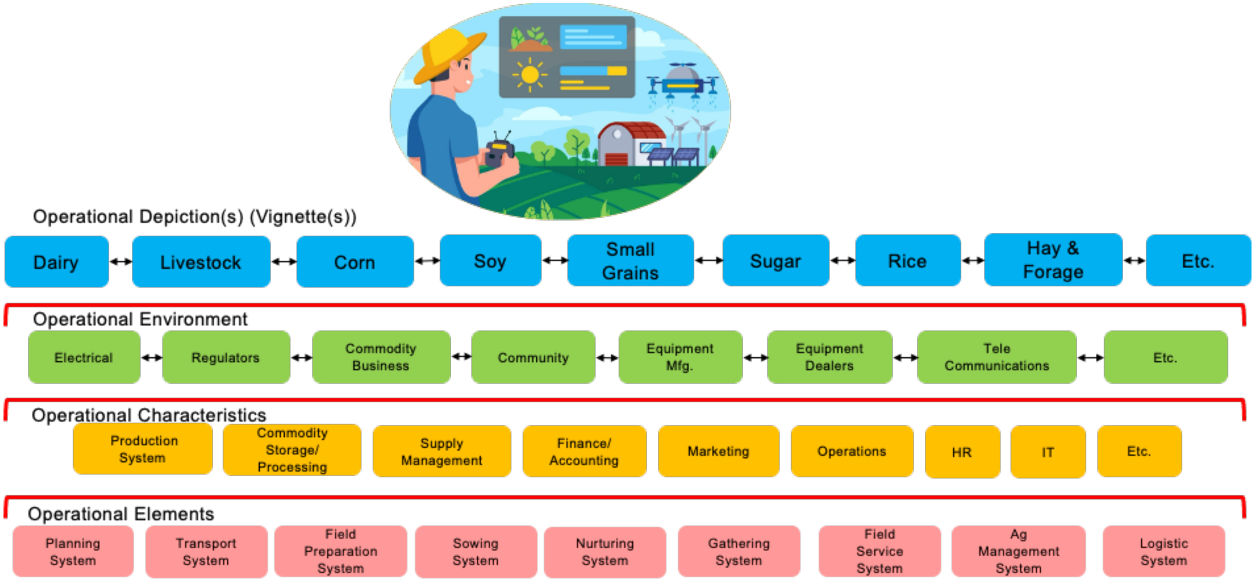


Figure 31 - Operational Elements

Therefore, let's take an agri-food operational environment of a commodity business to refine our relationships within the agri-food ecosystem further to demonstrate. The depiction will be sugar; the operational environment we want to understand is the commodity business, in the context of the operational characteristics of a production system and the operational elements associated with our agri-food ecosystem while maintaining an understanding of critical relationships within and between as can be seen in figure 32.

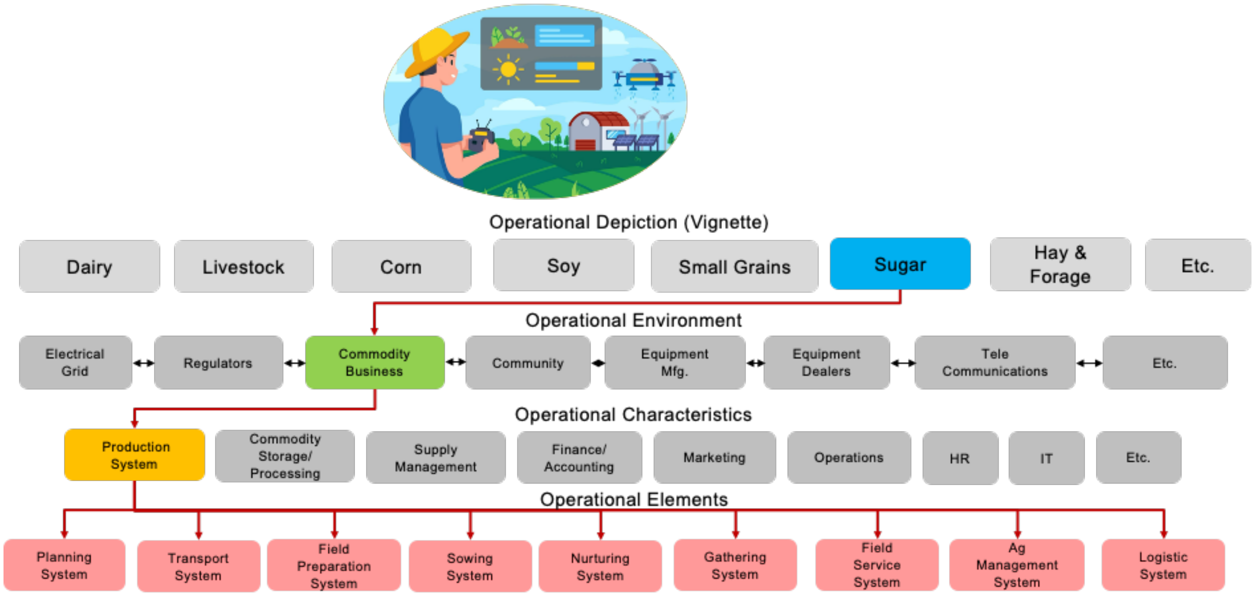


Figure 32 - Operational Analysis Relationship Map

At this point, the commodity business is the operational environment, and the characteristics are a production system. Our enterprises produce agri-food equipment in machinery; the commodity business operating environment has a critical relationship with the equipment manufacturer and dealers, as shown in Figure 33. Thus, with a complete understanding of the Operational depiction (sugar), Operation environment (commodity business), and relationships (equipment manufacturers and dealers) as related to operational characteristics (production system), we can now identify the operational elements we are bounded by from the perspective of the agri-food equipment provider enterprise.

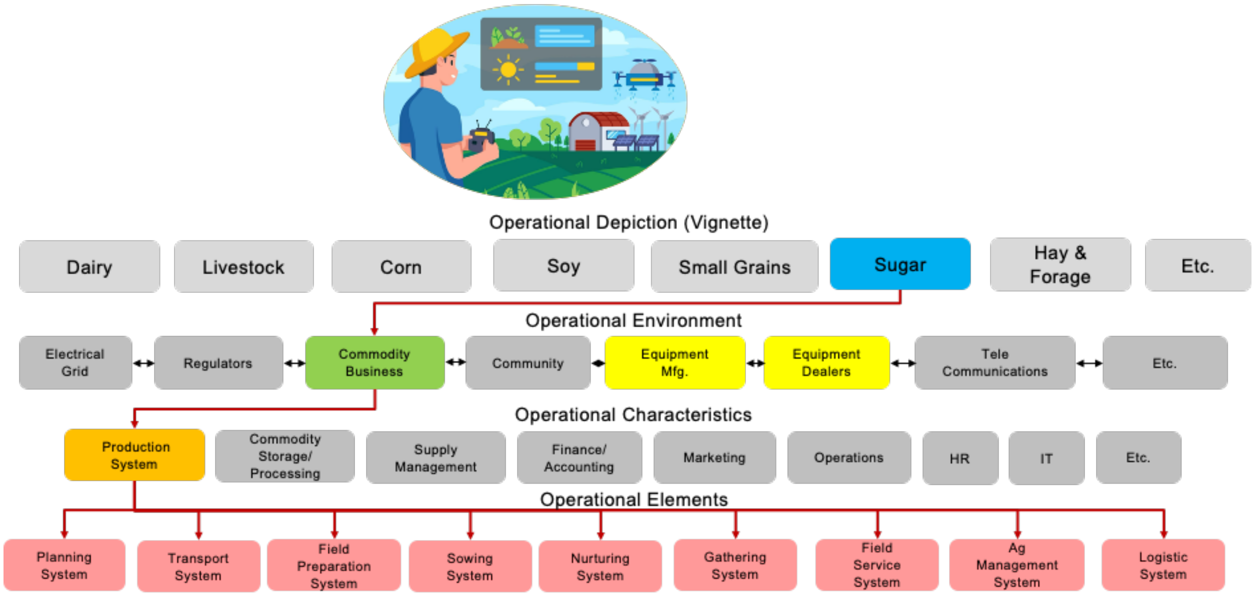


Figure 33 - Operational Analysis Relationship Map, secondary relationships

The selection of the operational elements within our enterprise is determined, enabling the establishment of the boundaries within our enterprise see Figure 34. It should be noted that while our boundaries have been defined, our relationships within the agri-food ecosystem must be maintained. One additional note about the agri-food equipment provider in certain operational elements – they only provide the element that meets the function of propulsion (tractor) but no other elements within that element. To further explain this scenario, the element transport system comprises a propulsion device (tractor) provided by the equipment manufacturer Still, when it comes to the haulage device within the element, it is left to a lower-tier provider. This is depicted in Figure 34 also.

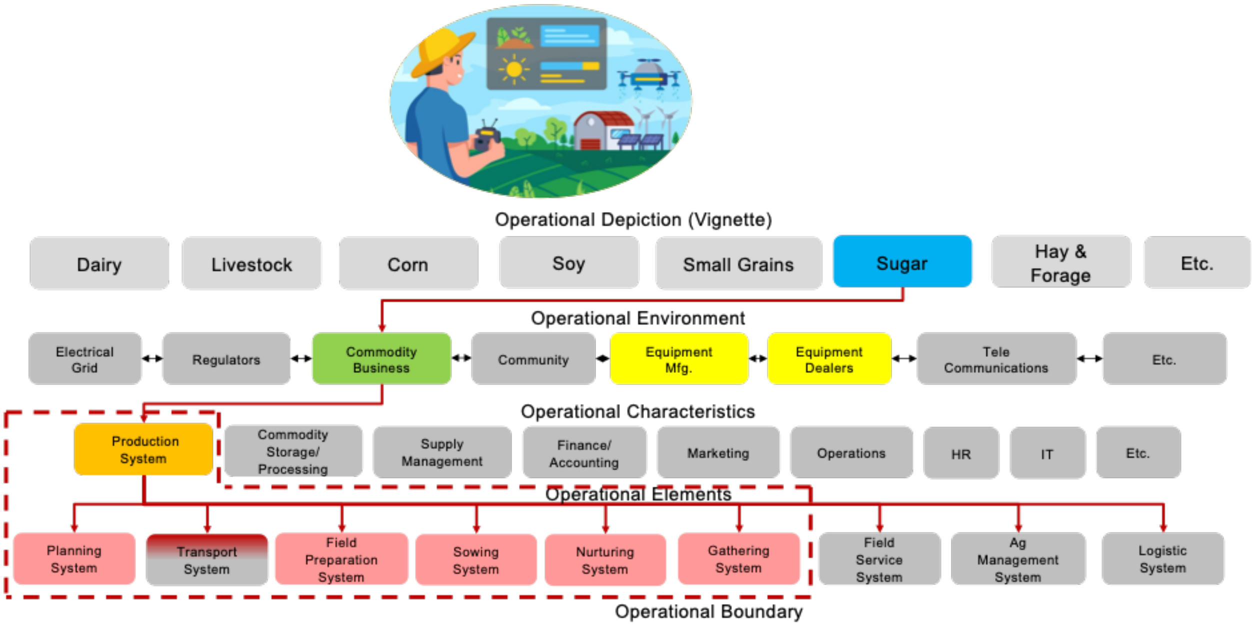


Figure 34 - Operational Analysis Relationship Map, Exceptions

At this point, we have established the operational analysis of the agri-food industrial ecosystem within the operational depiction (sugar), within the operating environment of a commodity business associated with a production system (sugar), and the operational elements of the enterprise and relationships within the established boundaries of the enterprise as an equipment provider (see figure 34). These boundaries are based on the industrial equipment provider (enterprise) within the sugar production system as an operational characteristic, with only the key elements and relationships within the operational boundaries. We thus need to refine our stakeholders within the industrial equipment provider, as seen in Figure 35. During this refinement of our stakeholders, we need to drill down to the specific needs of the enterprise's stakeholders, as depicted in Figure 36.

Through the stakeholder value network, since we decided to use sugar production as our example, we identified the stakeholders as the focal point: the sugar production system at the center and its relationships with the other stakeholders. Then the end users are the customer and their relationships with the focal point and the market and non-market stakeholders.

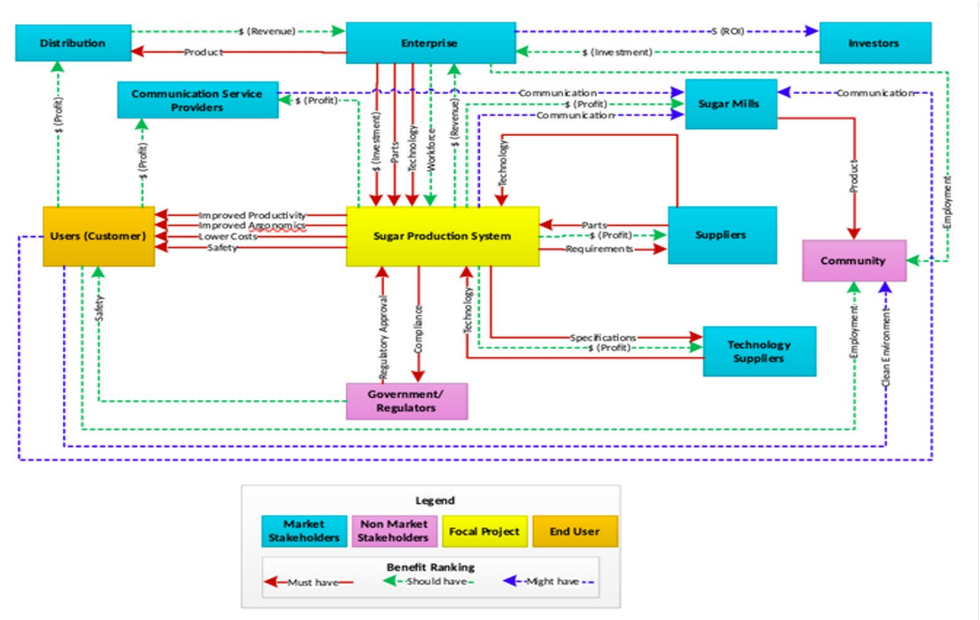


Figure 35 - Sugar Production System Stakeholder Value Network

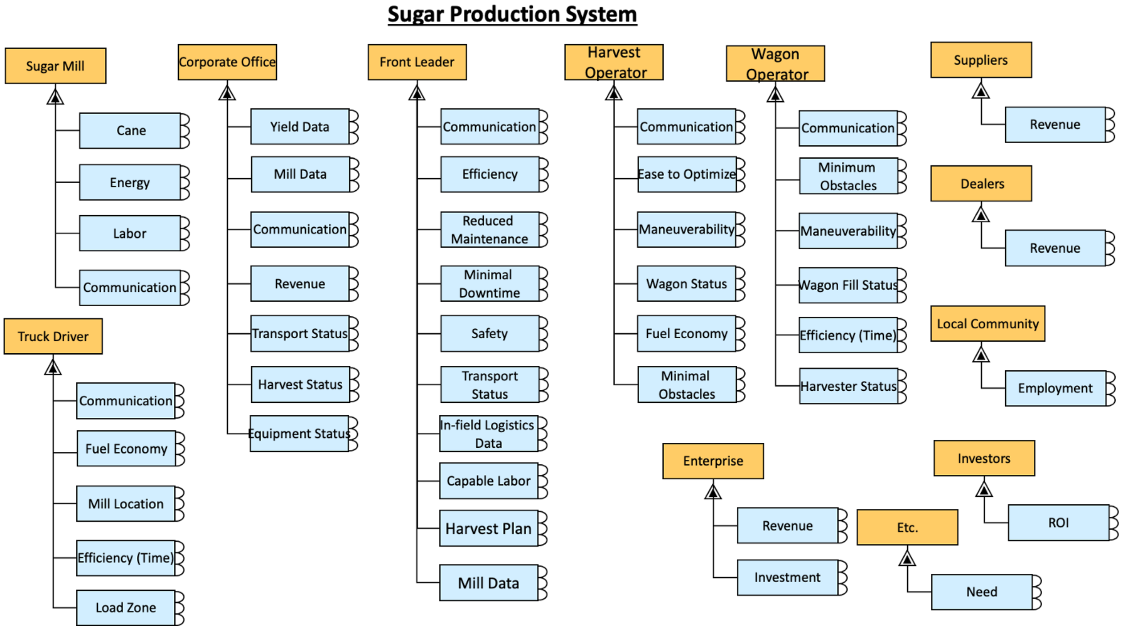


Figure 36 - Sugar Production System Stakeholder Needs

In the past, an equipment manufacturing (enterprise) would easily look at its strategy from that perspective without a complete understanding of the commodity business related to sugar and the Agri-food ecosystem. Their products, processes, and services are artificially bound within this perspective. Already we can see a more holistic view of the ecosystems demonstrated starting from the ecosystem level, and they understand they are part of many operational depictions. When broken into the environment they operate, these operational depictions show many relationships they may need to take advantage of in the form of opportunities for business *growth. This continues to propagate with additional opportunities at the characteristic and element levels. This holistic view has the potential to unlock the key to many opportunities for an enterprise. It also provides a broader look at the stakeholders. There is a need for the entire ecosystem to be in a structured fashion and to benefit from this understanding in the form of additional opportunities.*

4.5 Operational Analysis - Enterprise

In the past, enterprises often attempted to map out their products, processes, and services bounded by their operational elements only. They would attempt to model their production processes and services to other elements, characteristics, environments, or depictions within an ecosystem or production system using conventional tools to map these elements without a process or method to do so. This led to many variations and complexity that were so vast, as shown in figure 37 that would result in frustration. Figure 37 represents the traditional methods to try accessing the network connections related to the ecosystem within which the enterprise resides. So, with our understanding of the industrial ecosystem, we applied the same mapping approach at the enterprise level, shown in Figure 38.

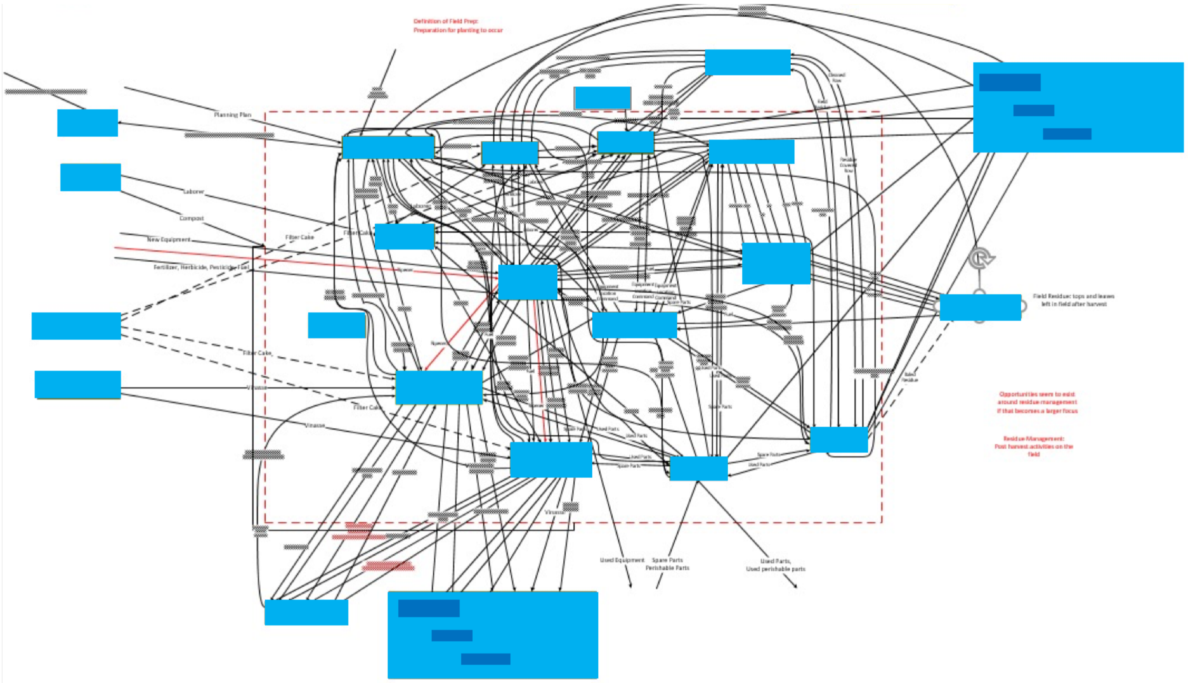


Figure 37 - Operational Analysis Complexity

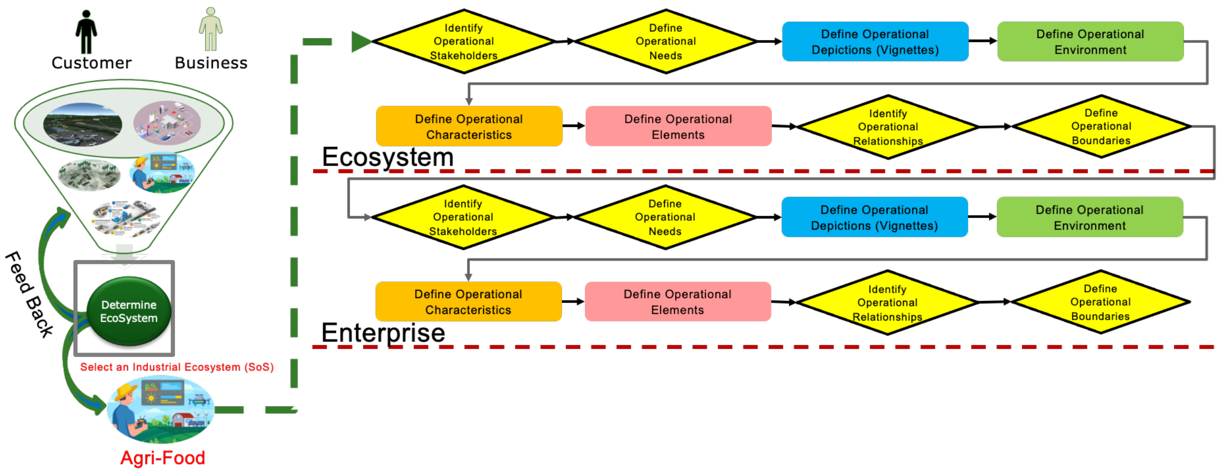


Figure 38 - Operational Analysis Process Map, Ecosystem & Enterprise

Applying these methods and techniques allowed us to drill down effectively, efficiently, and operationally understand the operational depictions (producing sugar), the operational environment of the production system (produce cane, raw, sugar, ethanol, and electricity), and the ability to define our operational measures and operational conditions quickly (see figure 39). Our operational measures and conditions result from understanding the operational analysis of the "produce sugar" (blue), and operational environment "produce cane" (green) in this notional example of the sugar cane production system. We only looked at "produce cane" within this notional example. Yet the same steps here and in the following example would be performed for the other operational environment "Product Raw Sugar", "Refined Sugar", "Produce Ethanol", and "Produce Electricity".

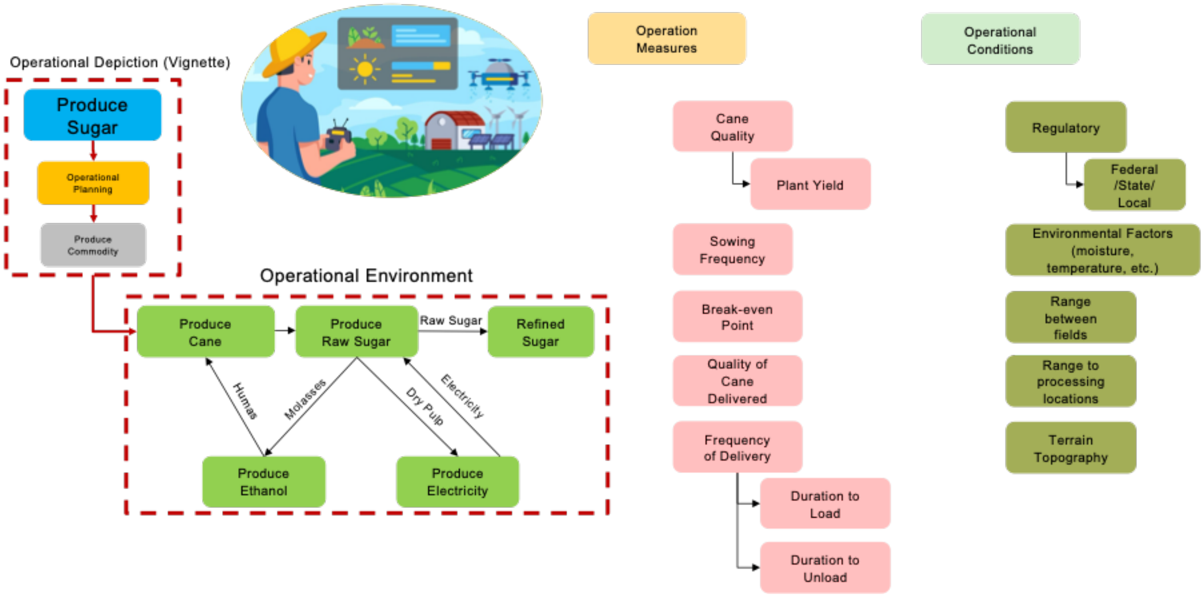


Figure 39 - Operational Analysis Framework, Produce Sugar

We again deployed this approach when decomposing the enterprise further. We found that within the operational environment, our enterprise as an industrial equipment provider has a primary relationship with producing cane but a managed relationship with the other environmental elements—figure 40. This determination was made from the perspective of an equipment manufacturer as our direct relationship is to the production of sugar cane in the field to deliver to the sugar mill that produces the raw sugar, refined sugar, ethanol, and electricity. The understanding that we have a relationship to these may provide opportunities to further assist in the production of sugar, ethanol, and electricity but only through this understanding can we begin to identify opportunities. In the past equuipment manufacturer would consider the production of cane within the field.

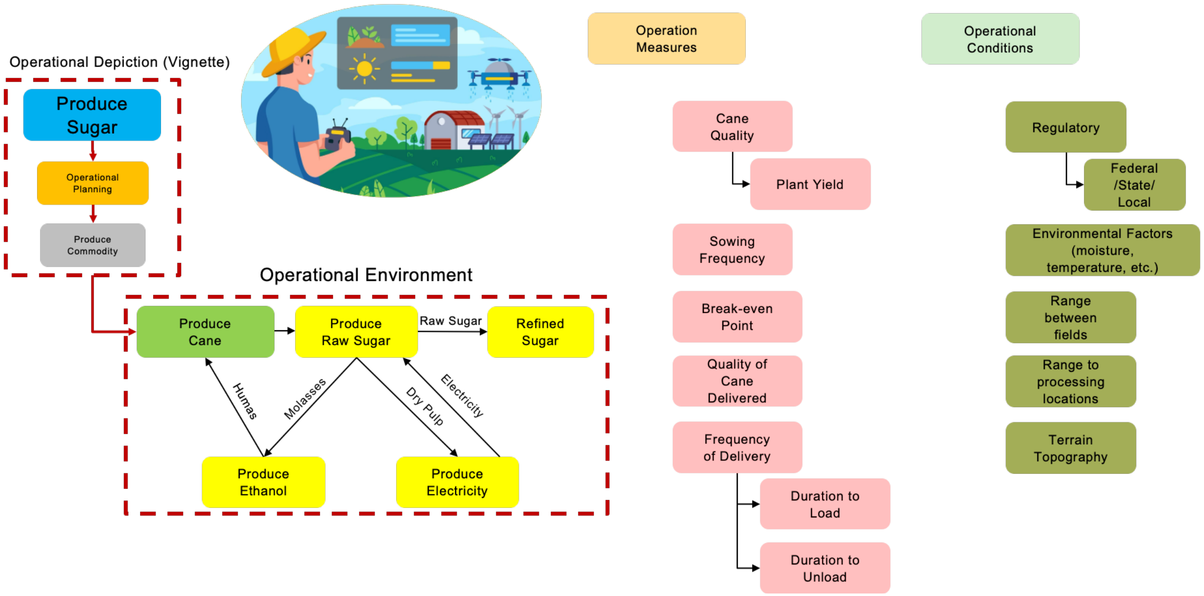
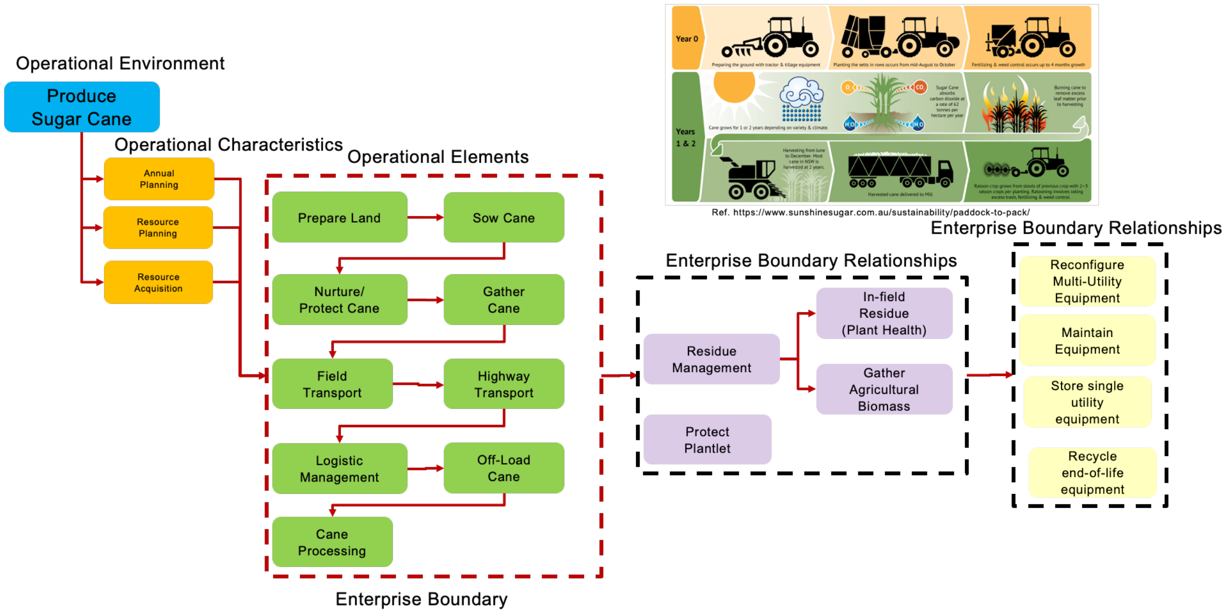


Figure 40 - Operational Analysis Framework, Produce Cane

4.6 Operational Analysis – Production System

At this point in our research, we noticed a pattern emerging which indicates our methods and practices using system thinking principles and techniques will yield a simplified method for developing the enterprise strategy. Since we have defined the operational environment and the key entry point within it, figure 40. We will now continue our operational analysis with the operational environment (produce cane), understanding its operational characteristics, elements, and relationships. We could have just as quickly picked any of the items within the operational environment; our selection was based on our enterprise as an industrial equipment provider providing equipment within the agronomy of the commodity for our enterprise strategy.

Again, assuming my research is correct, I will follow the same pattern outlined in the process map. As was depicted in our operational environment, we selected to produce sugar cane with *the operating characteristics, elements, and relationships. This allowed us to quickly identify the primary operations of the enterprise, its boundaries, and its relationships, as shown in Figure 41.*



Ref. https://www.sunshinesugar.com.au/sustainability/paddock-to-pack/

Figure 41 - Operational Elements Selected

While all the operational elements are essential to our enterprise strategy overall, we find certain elements are performed less frequently than annually due to the agronomics of our example. Sugar plants have a perennial versus an annual growth pattern; therefore, preparing the land and sowing the seedling (billet) may be considered less important to the enterprise. It was also found during our research when performing this operational analysis that these elements often need to be included during strategy development. Hence, the enterprise could miss a meaningful relationship and opportunity. It should be noted that I have other projects within the agri-food ecosystem as separate research (not part of this thesis, and unpublished) that have demonstrated this approach with similar outcomes. Yet, currently, due to confidentiality agreements with those enterprises, I cannot include them.

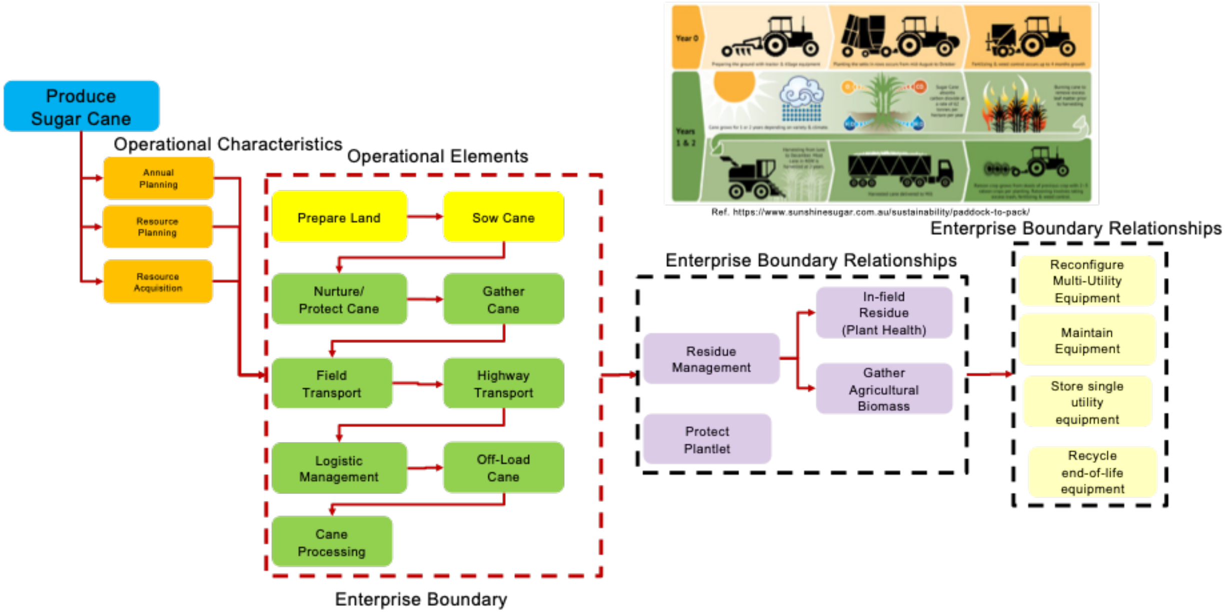


Figure 42 - Operational Elements Exceptions

To illustrate this and with Figure 42 in mind, the areas of two operational elements of prepare land and sow could have resulted in less mechanization and have not been considered or, at a minimum, been excluded as the strategy due to cane being a perennial plant. I've spent most of my life in agri-food ecosystems as a producer or engineer with an industrial equipment manufacturer. I studied the sugar ecosystem and high-value crops extensively. In sugarcane, many seedlings called billets are still planted manually or by semi-mechanical methods. Yet, they contribute to the overall ability of the land to produce a high-value crop. These same oversights were found in other production systems involving high-value commodities such as almonds, grapes, and coffee. While there are limitations to our research and approach, our hypothesis needing additional research is "Does this same assumption or oversight occur when something within the operational environment infrequently happens in other industrial ecosystems and enterprises?".

We will perform our operational analysis by following our systematic approach and thinking further about the operating characteristics, elements, and interfaces. In other words, all operational characteristics, elements, and relationships will be completed. Yet, within this thesis, we will demonstrate the use of an operational concept and summarize all of them at the end.

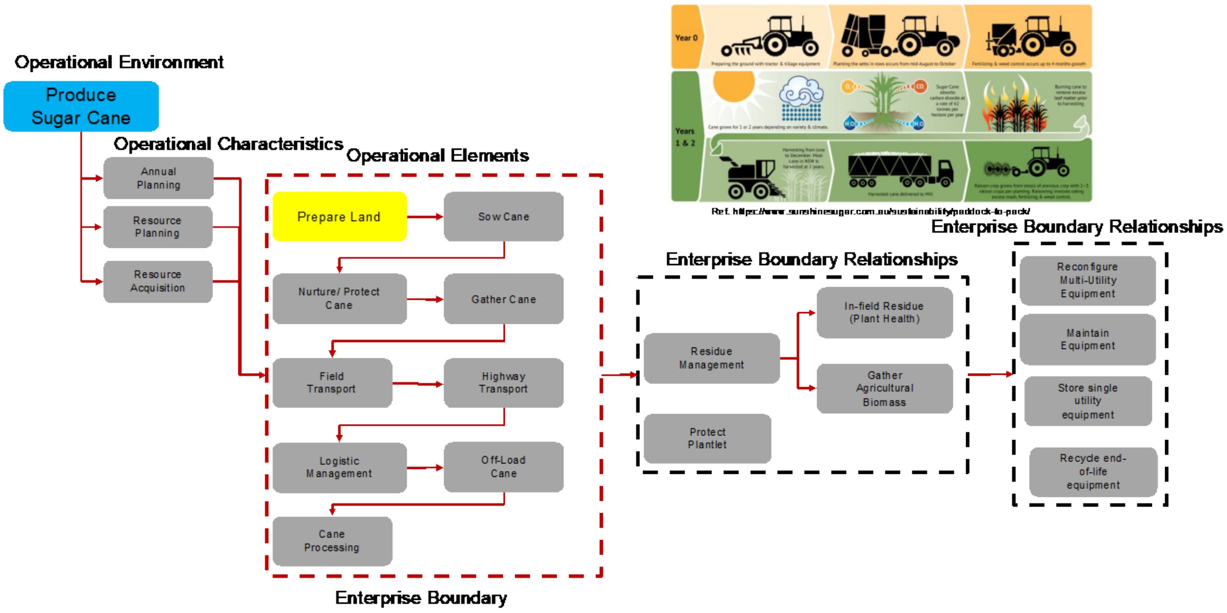


Figure 43 - Operational Analysis, Prepare Land

Figure 43 shows the operational element of prepared land, which we can break down into its operational measures, which specify a measurement procedure for measuring external, observable behavior and conditions in the system's settings, as shown in Figure 44.

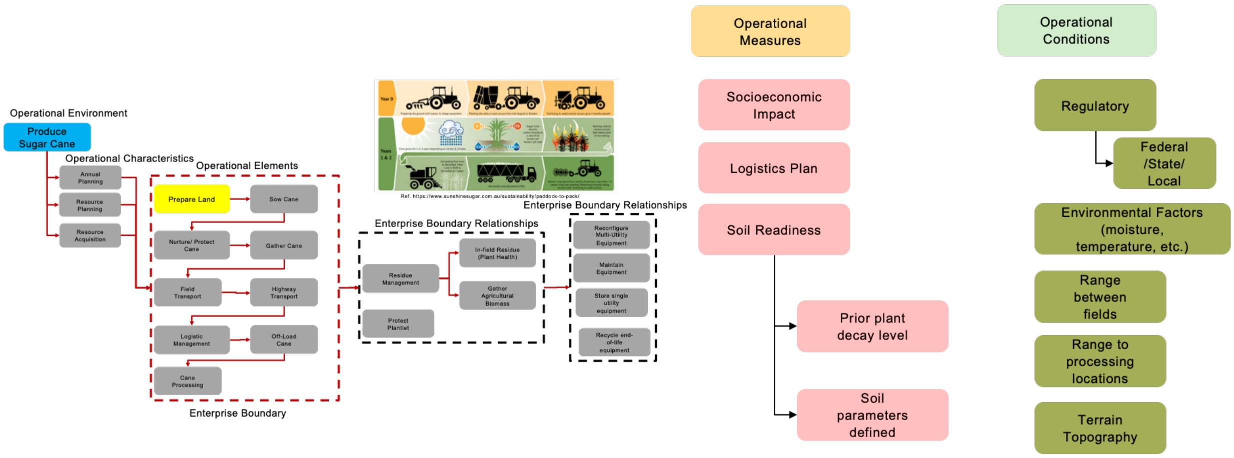


Figure 44 - Operational Analysis Prepare Land, Operational Measures & Conditions

We need to understand the operational scenarios by identifying the parameters used to evaluate the situations the system must operate within or which describe the expected utilization of the system in terms of actions Figure 45 (SEBoK, no date). This may imply that we have different sugar cane production methods globally, which we do, so we need to consider this as we identify opportunities and their relationships. We also know from this notional example that the methods of sowing are also different in global environments.

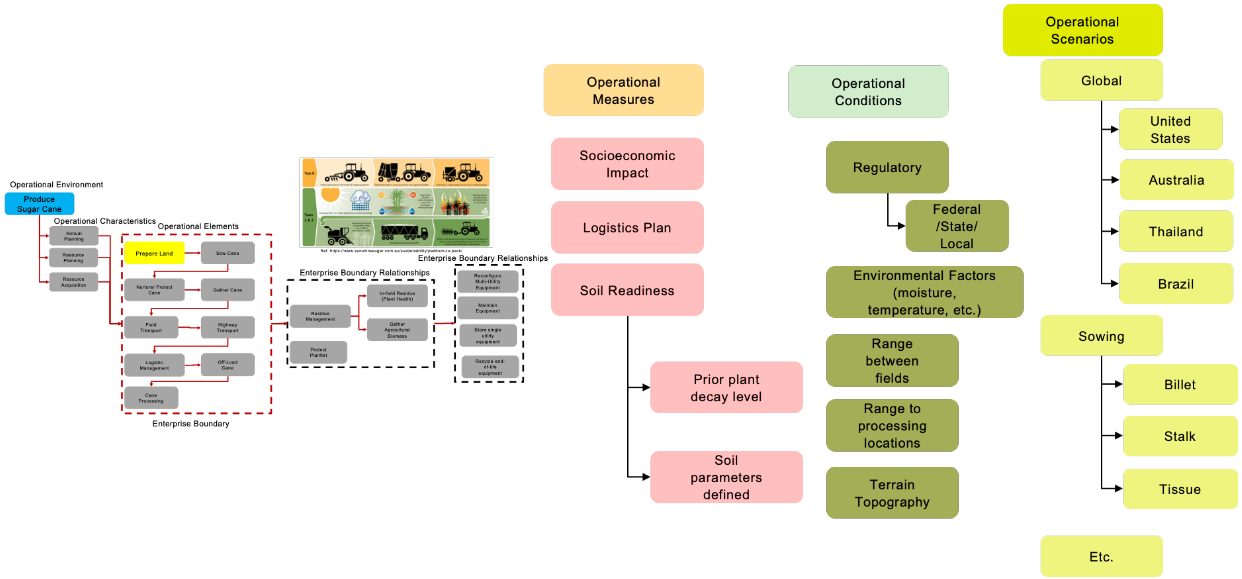


Figure 45 - Operational Analysis Prepare Land, Operational Scenarios

As a result of the scenarios, we identify the System of System Entities, the constituents that comprise the organizational system of systems and can be persons, places, or things. Often the person is part of the stakeholder analysis. Yet, within our research, I didn't want to limit our research until further research could be completed (see Figure 46). So if I take the explanation from Figure 45, understanding globally different agronomic practices and the available acreage allocation, and the types of products grown and variety provide and understanding of the attributes that are important globally in the notional example. In the past, we may have only looked at a particular area like the United States and missed attributes important to other regions. This notional example shows that all areas have variety, and that plant erectness is common globally. This understanding will assist the team when developing opportunities.

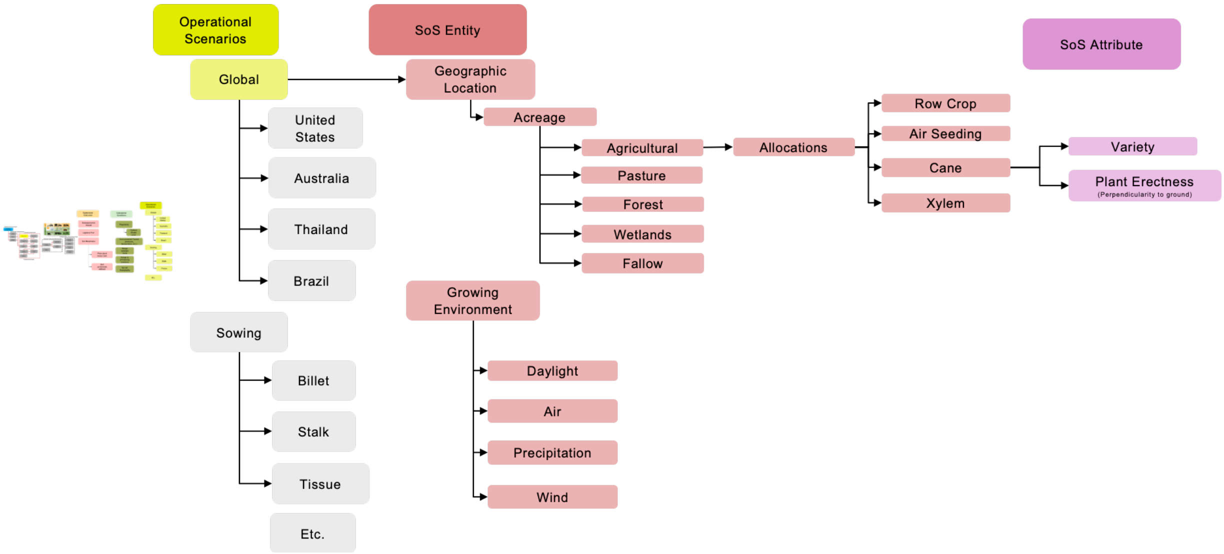


Figure 46 - Operational Analysis Prepare Land, Operational Entities, and Attributes

Please note that the operational scenarios were repeated to facilitate the understanding and flow of operational analysis. The constituents all have a system of system attributes that are fundamental to the knowledge of the system(s). In operational analysis, the attributes enable the understanding allowing the cross-functional team to identify opportunities.

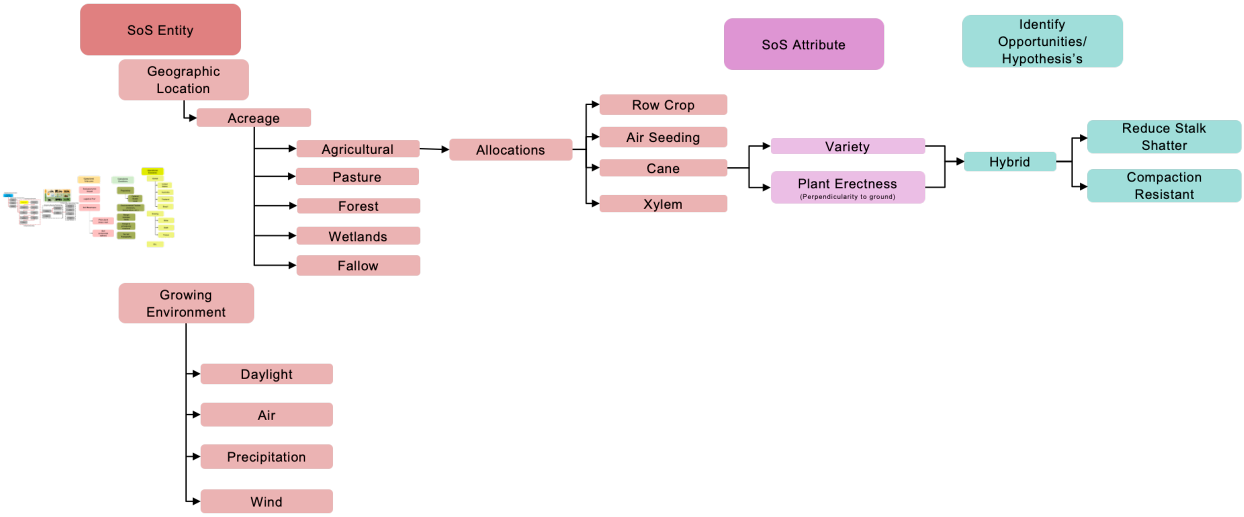


Figure 47 - Operational Analysis Prepare Land, Operational Opportunities

These attributes are the minute properties of the system that provide the necessary granularity to understand what is essential in the operational element for the customer (see Figure 47). For example, we are in the operational environment of "produce sugar cane," and we want to complete our operational analysis on the operational element "prepare land" following our process map for the methodology. With our attributes understanding, we can begin developing our opportunities (Figure 47). Opportunities are items that would provide the attributes that *need to be met in a potential solution. Here we see that based on the variety and plant erectness, the opportunity exists to develop a hybrid of sugar cane that is resistant to stack shatter as well as ground compaction. This is of particular importance as you remember from earlier preparing the ground and sowing only happen every three to seven years (perennial plant). So I want a robust hybrid with the characteristics previously stated to minimize the effects of traveling in the field during the nurturing, harvesting, and transportation operations.*

At this point within the operational method, the operational analysis process map can be seen in Figure 48. It starts with understanding and selecting the ecosystem in which the enterprise resides and any secondary or tertiary ecosystem relationships. We then identify the operational stakeholders and their needs and develop and define the operation depictions (vignettes) and the operational environment. Then we develop and define the operational characteristics and break them into operational elements. At the same time, we simultaneously identify the operational relationships throughout to enable us to understand and define our operational boundaries.

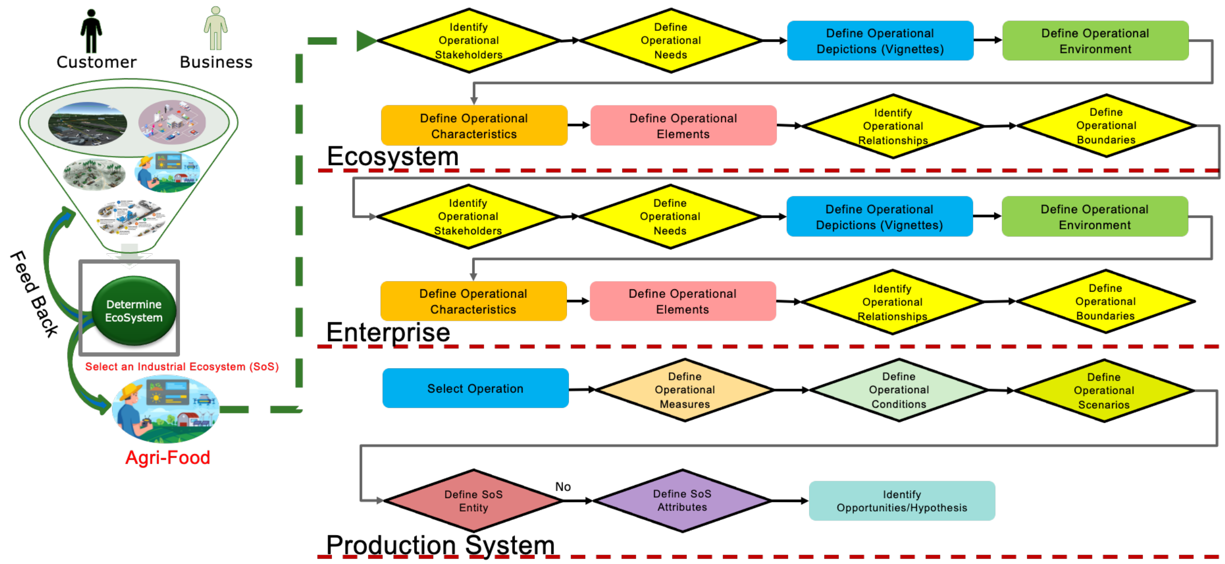


Figure 48 - Operational Analysis Process Map, Ecosystem, Enterprise, Production System

Through our development, we noticed a pattern that allowed the operational analysis to repeat the same steps at the enterprise and production systems levels. After we have completed the analysis at these three levels, we take the identified opportunities and trace them back through an operational review for completeness and understanding of the operational interfaces and prepare to release to mission engineering. Mission engineering and its process with be shared in Chapter 5.

4.7 Operational Analysis – Process Map

Operational Analysis is complete once every operational characteristic, element, and relationship has been analyzed (figure 43) with every opportunity and hypothesis captured, following the process map shown in Figure 49. At this point, I have stepped through this process for all the operational elements of "produce cane" within the "produce sugar operational environment", identifying all the opportunities. We now need to review and consolidate all the opportunities to understand their operational interfaces (relationships).

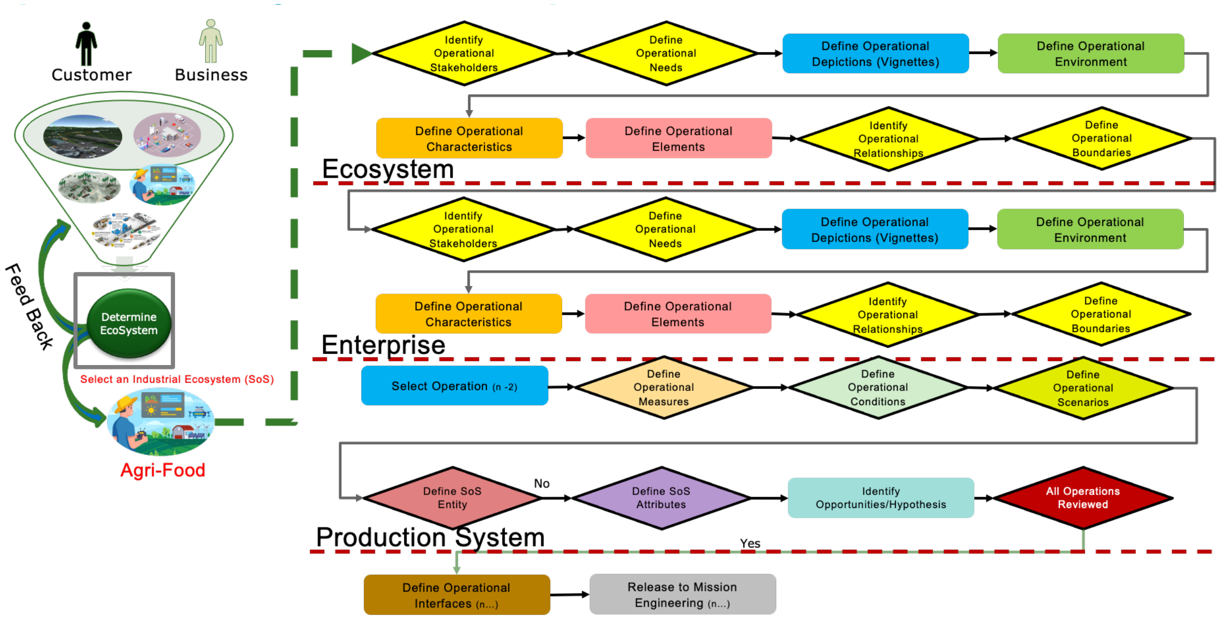


Figure 49 - Operational Analysis Process Map, Release to Mission Engineering

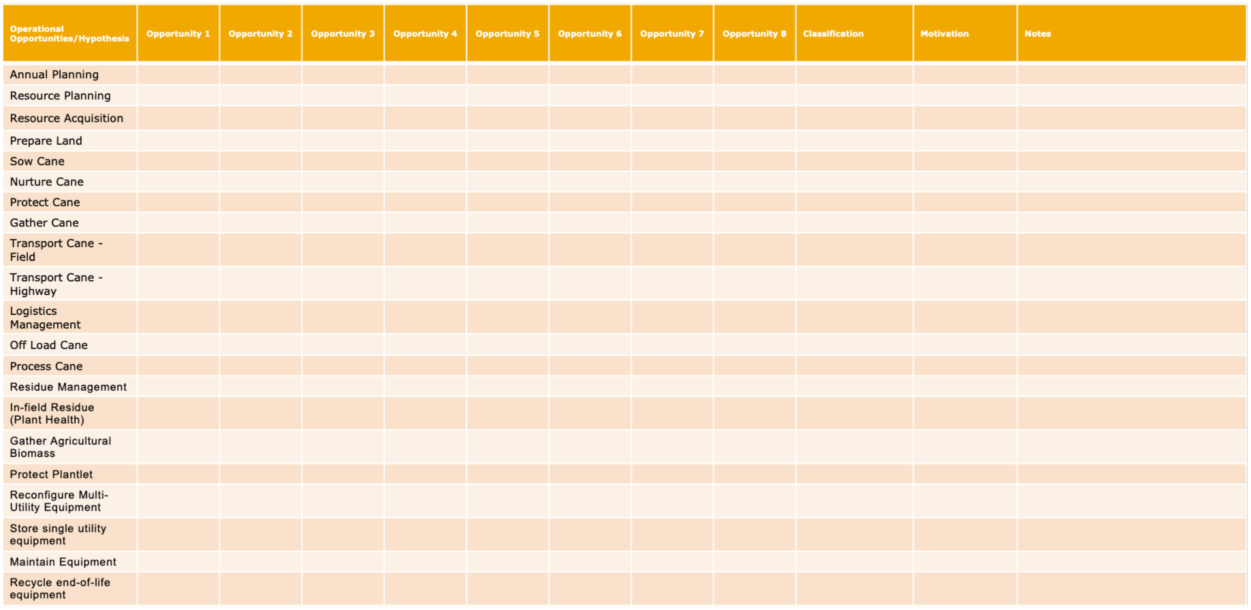
My experience found that if the operational analysis has been completed, many enterprises' cross-functional teams use these opportunities independently and irrespective of one another. It tends to be in a functional discipline, or a specific product yet lacks a holistic enterprise or ecosystem view. This information was provided in the ecosystems of aerospace and defense, agri-food, mobility, transport, and automotive. Our research found that these opportunities, many times, need to be refined within the context of their market to drive a deeper understanding of the opportunities that have been identified. Through further refinement, we can capture the impacts, success measures, and macro drivers within the industrial ecosystem. In reflection on the operational analysis just performed within our ontology, we found that within the operational environment of producing sugar and the operational elements of preparing the land, and sowing cane, multiple different methods are deployed globally. In the past, we looked at the global areas independently. As I then proceeded to analyze these operational elements, I found that it doesn't matter where you are globally in the prepare land; the opportunity needed is to reduce shatter and be resistant to ground compaction could possibly be achieved through hybridization. This same analysis was performed on all operational elements (prepare land, sow cane, nurture/protect cane, gather cane, field transport, highway transport, logistics *management, off-load cane, and cane processing). All the opportunities are captured in Figure 50.*

As I progress to mission engineering in Chapter 5, this information will be crucial documentation in developing the enterprise strategy and the missions to support it. It has surfaced from the operational analysis into a prioritized list to build our missions around. This also allows us to track the opportunities and relationships internal and external to the operational depiction being analyzed, in our case, sugar. This further enables the cross-functional team to take an entrepreneurial view of potential opportunities understanding the target market, key metrics, and measurable functional performance customers value.

Starting with understanding and selecting the ecosystem in which the enterprise resides as well as any secondary or tertiary ecosystem relationships. At this point, I identify the operational stakeholders and their needs. Develop and define the operation depictions (vignettes) and the operational environment. Then I develop and define the operational characteristics and break them into operational elements. At the same time, I simultaneously identify the operational relationships throughout to enable me to understand and define our operational boundaries. Through our development, I noticed a pattern that allowed the operational analysis to repeat the same steps at the enterprise and production systems levels. After I have completed the analysis at these three levels, I take the identified opportunities and trace them back through an operational review for completeness and understanding of the operational interfaces and prepare to release to mission engineering. Mission engineering and it process which be shared in Chapter 5.

4.8 Operational Analysis – Transition to Mission Engineering

The operational analysis in the enterprise strategy development at the ecosystem level has yet to be completed; only a partial list of opportunities exists and tends to be siloed, with all opportunities residing in separate documents. Herein lies one of the many advantages of this approach. After the operational analysis, a defined list of the opportunities can be prepared, listing all the opportunities, the classification, motivation, and any additional information in the form of notes to transition to mission engineering (chapter 5) for further development of the opportunities (Figure 49). I have also included a notional example from our sugar operational analysis Figure 50. I will now transition my research finding from operational analysis to mission engineering chapter 5 and continue the refinement using the example of sugar within the Agri-Food industrial ecosystem.



Operational Opportunities/Hypothesis	Opportunity 1	Opportunity 2	Opportunity 3	Opportunity 4	Opportunity 5	Opportunity 6	Opportunity 7	Opportunity 8	Classification	Motivation	Notes
Annual Planning											
Resource Planning											
Resource Acquisition											
Prepare Land											
Sow Cane											
Nurture Cane											
Protect Cane											
Gather Cane											
Transport Cane - Field											
Transport Cane - Highway											
Logistics Management											
Off Load Cane											
Process Cane											
Residue Management											
In-field Residue (Plant Health)											
Gather Agricultural Biomass											
Protect Plantlet											
Reconfigure Multi-Utility Equipment											
Store single utility equipment											
Maintain Equipment											
Recycle end-of-life equipment											

Figure 50 - Operational Opportunities Identification

5 Mission Engineering

Chapter Tenets:

- *Mission engineering - Deliberate planning, analyzing, organizing, and integrating current and emerging operational capabilities as developed in the operational analysis.*
- *Mission engineering is the detailed planning, analyzing, organizing, and integrating current and emerging system capabilities to achieve desired mission effects.*
- *Analyzes the opportunities of emerging operational systems and their interactions and interrelationships to provide input into strategic planning.*
- *Prioritization of the missions and the missions' threads based on sociotechnical and socioeconomic factors within the ecosystem.*
- *It is also a key input into mission architecture that is out of this thesis's scope.*
- *It is a process mapping with analysis methods to visually represent the relationships between the mission, mission threads, and the ecosystem to identify potential sociotechnical and socioeconomic impacts.*
- *It is not mission architecting; it prioritizes missions based on enabling technologies needed to realize technology within the ecosystem for inclusion in strategy development and subsequent management through annual technology assessments.*

5.1 My Review of the Literature

In this area of the literature review, I was looking for methods and practices of performing operational analysis within the operational ontology, starting at the industrial ecosystem identifying the opportunities allowing us to engineer our missions (mission engineering), and identification of the sociotechnical and socioeconomic relationships providing key input to the enterprise strategy. I was looking for research in mission engineering around industrial ecosystems. The literature review around Mission Engineering found numerous papers, handbooks, textbooks, and educational materials exist. I started with handbooks the INCOSE Systems Engineering Handbook 4th edition, 2015, NASA Systems Engineering Handbook, Rev 2, Updated January 27, 2020, and the System Engineering Body of Knowledge (SeBoK) (Category: SEBoK). The INCOSE handbook refers to mission analysis after we have engineered our mission(s); it also has an aerospace and defense theme and associated products, processes, and services. There was very limited research related to the topic of this thesis withing the INCOSE handbook related to operational analysis as related to mission engineering with an industrial ecosystem. We also found this trend in the NASA Handbook, as its essence was very good when developing a product. We then proceeded to research the textbooks System Engineering Guidebook "A Process for developing systems and Products" James N. Martin, 1997, System Engineering Management, Benjamin S. Blanchard, fourth edition 2008, System Engineering Principles and Practice, Alexander Kossiakoff and William N. Sweet, 2003 and finally System Engineering Analysis, Design, and Development: Concepts, Principles, and Practices 2nd edition, Charles S. Wasson, 2016.

While the books are good resources when it comes to the fundamentals of developing systems within the product, process, and service areas and spends considerable time on mission profiles and mission scenarios as they relate to a specific predetermined mission, they did not address many of the core research questions we are trying to answer when it comes to the enterprise strategy. Finally, our literature review took us into the professional papers and research that have been done, where we analyzed and found about 30 articles. Yet, they were very much in line with the handbooks and textbooks that focus more on accomplishing a given mission and performance related to operational parameters within the context of a product, process, or service. They did not directly address our research questions from Chapter 1. The research found one document published in November 2020 by the Department of Defense, "Mission Engineering Guide." While this document again focuses on the product, process, and service and at more the tactical level versus a strategy, many of its methods could be adapted to developing the mission themes after operational analysis has been performed within the operational ontology of an industrial ecosystem. This chapter will reference certain areas of the Mission Engineering Guide for engineering our mission and relationships to developing the enterprise strategy within the context of an industrial ecosystem.

As I explored numerous papers, I found Mission Engineering and Analysis: Innovations in the military decision-making process (Hern et al.*, 2017). It was specific to defense and the execution of the mission related to border security. How would that fit into the more extensive aerospace and defense industrial ecosystem and its multiple aspects? This paper had very little relevance to the goal and questions posed by my thesis. Mission Engineering and Analysis: Innovations in the military decision-making process (Hernandez and Karimova, 2017) was very specific to the development of physical and virtual systems. Again, I was looking for how mission engineering is applied within an industrial ecosystem(s) through operational analysis and identifying opportunities as more comprehensive inputs into an enterprise strategy. Framework for Mission Engineering Competencies (Hutchison* et al.*, 2018) was specific to the system engineering competency identification and gaps. This paper had little relevance to our goal and questions. However, it might be beneficial as a follow-on in understanding the competencies needed within an enterprise to execute the areas addressed in this thesis but out of our scope here.*

Through all my research within this area, as stated earlier, I will propose a process within our framework for mission engineering of an industrial ecosystem to engineer the missions from the opportunities identified in operational analysis for inclusion in the enterprise strategy.

During my research into mission engineering being used to develop an enterprise strategy, I found numerous examples from projects, products, processes, and services, with none addressing the development of an enterprise strategy using operational analysis of the industrial ecosystem as an input to develop missions and missions' threads within the enterprise aligned to the industrial ecosystems (Chapter 2). I am not saying there isn't any; my research didn't uncover any. This brought me back to one of our initial questions "Could we use mission engineering in the development of our enterprise strategy for the industrial ecosystem(s) we work in?". I want to cite a few of the many publications we reviewed here. (Mission Engineering Guidance Provides Framework for Work With Industry, no date), (Butler, no date), ('DoD Mission Engineering Guide_ httpsac.cto.milwp-contentuploads202012MEG-v40_20201130_shm.pdf', no date). Figure 51 best summarizes this through mission definition elements and identified metrics. I found that most enterprises develop individual projects, products, processes, or services when developing missions. I could not uncover where the mission was developed considering the overall enterprise strategy or at the ecosystem level.

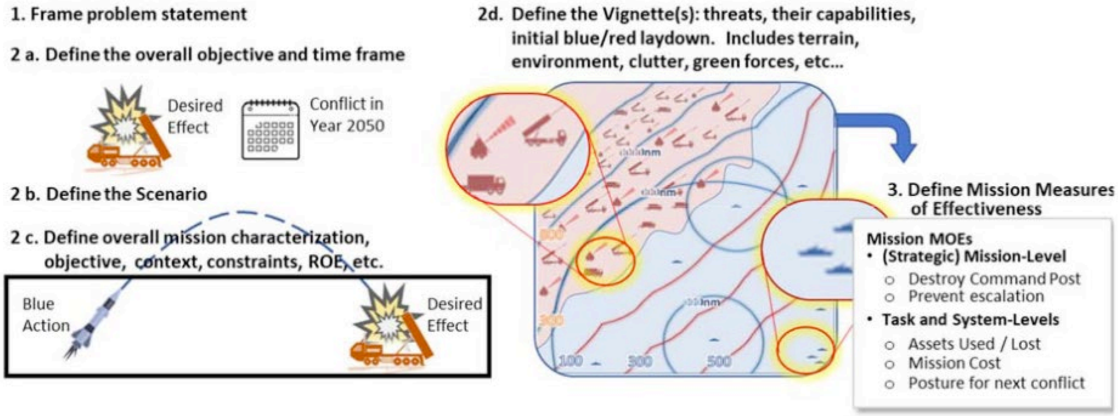


Figure 51 - Mission Definition Elements and Identified Metrics ('DoD Mission Engineering Guide_ httpsac.cto.milwp-contentuploads202012MEG-v40_20201130_shm.pdf', no date)

Upon completing my operational analysis of the industrial ecosystem, we identified the potential opportunities as applied to the enterprise. I was now challenged with the need to take all these opportunities and prioritize, develop the missions, understand the technology needed and the relationships between missions, understand the allocations of the opportunities to the different missions and bring all the missions and their relationships to one another through N^2 diagram or similar tool. From this, I can develop a mission thread to ensure that our missions can be clearly understood within the context of the enterprise strategy and socioeconomic and sociotechnical impacts on the industrial ecosystem(s) the enterprise operates. Limited experience and knowledge exist with all industrial ecosystems other than possibly aerospace and defense, as referenced earlier. Yet, I also believe from our research that aerospace and defense are looking at the operational analysis of a project, product, process, or service and its sub-mission and bringing that together then from the context of the industrial ecosystem of aerospace and defense with our perspective of the different branches of the military being like enterprises. So, we need to have a process to enable the following:

- *Align the industrial ecosystems' operational opportunities and the respective relationships to the missions with the operational ontology.*

- *Assess the disruptive technology and competitive threats, with the socioeconomic influences to avoid business risk to the enterprise from a financial and customer perspective.*

- *Mission engineering is the key step in aligning the industrial ecosystem and enterprise strategy to the missions providing the ability to access the sociotechnical and socioeconomic impacts.*

- *Very few attempts have been made to develop an enterprise strategy using the outputs of operational analysis at the industrial ecosystem related to the enterprise to create missions and their relationships.*

- *The research, experience, and knowledge are minimal with all industrial ecosystems as well as enterprises; thus, we need to perform operational analysis and mission engineering to address the complexity of the current and future industrial ecosystems and enterprises. We can then apply our current methods and practices within this framework to reduce risk to the industrial ecosystems while developing a complete enterprise strategy that is devoid of today's focus on only projects, products, processes, and services.*

5.2 Mission Engineering - IPO

I will execute this by taking key outputs from our operational analysis and analyzing the opportunities, relationships, and technologies to enable the deliberate planning and organizing of the key industrial ecosystem(s) capabilities needed. I want to ensure our engineered mission(s) are aligned with the internal enterprise and our external industrial ecosystem(s). The outputs from mission engineering feed the development of our internal mission architecture and technology roadmaps while maintaining alignment with the industrial ecosystem(s). Mission engineering analyzes the operational opportunities and their priorities and relationships to technology while understanding the acquisition needs through integration to achieve the enterprise and industrial ecosystem's mission(s) goals. It is the critical input to mission architecture. It is not mission architecture, as that is performed at the next level (AOL 3, figure 13). Mission Architecture combines the missions, technology, and mission threads related to the industrial ecosystem. At the same time, ensure relationships are maintained between the engineered mission and the industrial ecosystem, all within the enterprise context. Mission engineering develops individual missions while maintaining the relationships (mission threads, the relationships within a mission, and the external relationships to other missions along with the association to the industrial ecosystem) to all the missions while maintaining the relationship between the enterprise and the industrial ecosystem(s). The mission threads are integrated together to understand the enterprise and industrial ecosystems tradeoff better. We also develop a detailed understanding of the sociotechnical and socioeconomic impacts and documents through this understanding. This enables us to develop measures of success, effectiveness, performance, relationship risk to the enterprise, and the impact on the industrial ecosystem(s). Upon completion of engineering our missions, our key deliverables to mission architecture are:

- *Enterprise Mission(s)*

- *Enterprise mission(s) relationships (i.e., mission thread)*

- *Enterprise mission(s) relationships to the industrial ecosystem as defined in our operational analysis.*
- *Measures of Success (MOS)*
- *Measures of Effectiveness (MOE)*
- *Measures of Performance (MOP)*

The key inputs are shown in the IPO figure 52; it should be noted that the identified opportunities are all from our operational analysis brought into mission engineering. Some might have the desire to eliminate opportunities at this stage. This should be avoided as this could lead to missed opportunities within the enterprise strategy and understanding of the technology needed.

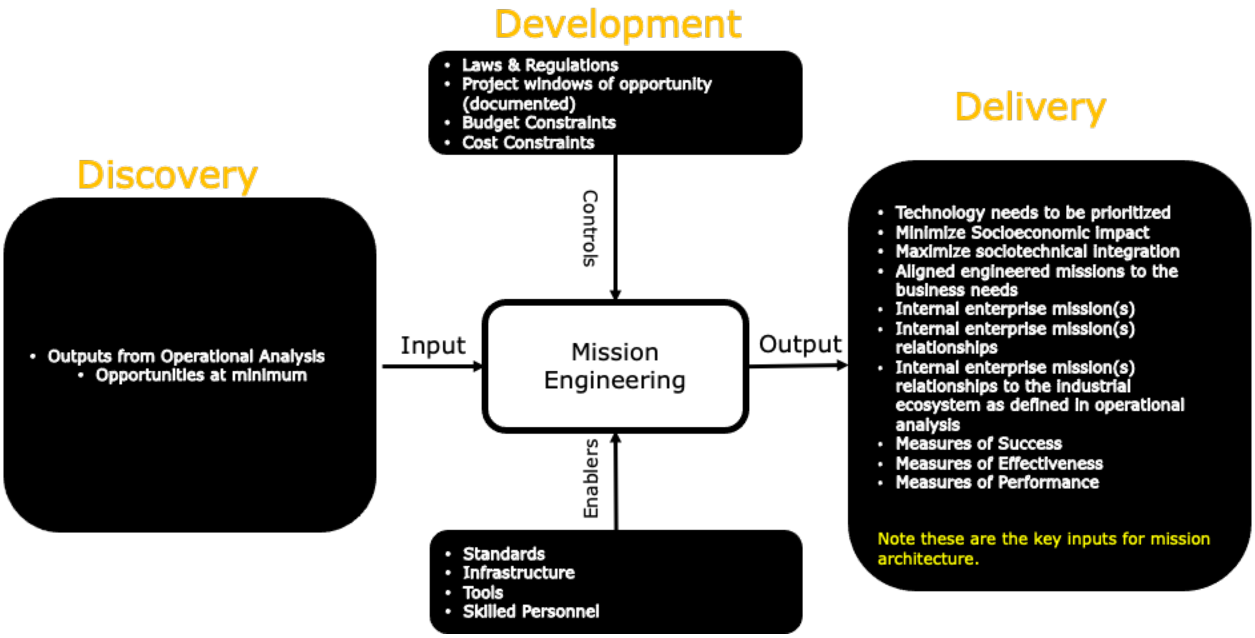


Figure 52 - Mission Engineering IPO

5.3 Mission Engineering - Background

To perform mission engineering effectively in developing the enterprise strategy, we must develop many of the same system artifacts we create when following the principles and methods of system architecture, system engineering, and project management in developing products, processes, and services at AOL 5. Yet, our perspective is at level AOL 2. We have identified the industrial ecosystem(s) within which our strategy will be developed and completed operational analysis identifying opportunities (AOL 0 & 1).

To effectively communicate within the strategy development cross-functional team, an operational concept (OpsCon) is generated (see Figure 53). The OpsCon is a high-level description of the characteristics of the proposed sequence of mission engineering from the viewpoint of the individuals on the cross-functional team completing the analysis. When developing systems, we use the OpsCon to provide a system-centric description of the intended users, uses, how the system will be used, and the external parameters while using the system. We apply the same concept here, from a process OpsCon perspective versus a systems OpsCon. Therefore, with a general understanding of the mission engineering method from our missions (OpsCon figure 53). This provides the understanding of defining the ecosystem(s) "Get Ready", Understanding the mission scenarios "Get Set", Performing the analysis "Go", Prioritizing the opportunities based on the needs "Get Unset", defining technology needed, and preparing the documentation to transition to the strategy development team as well as mission architecture "Get Unready".

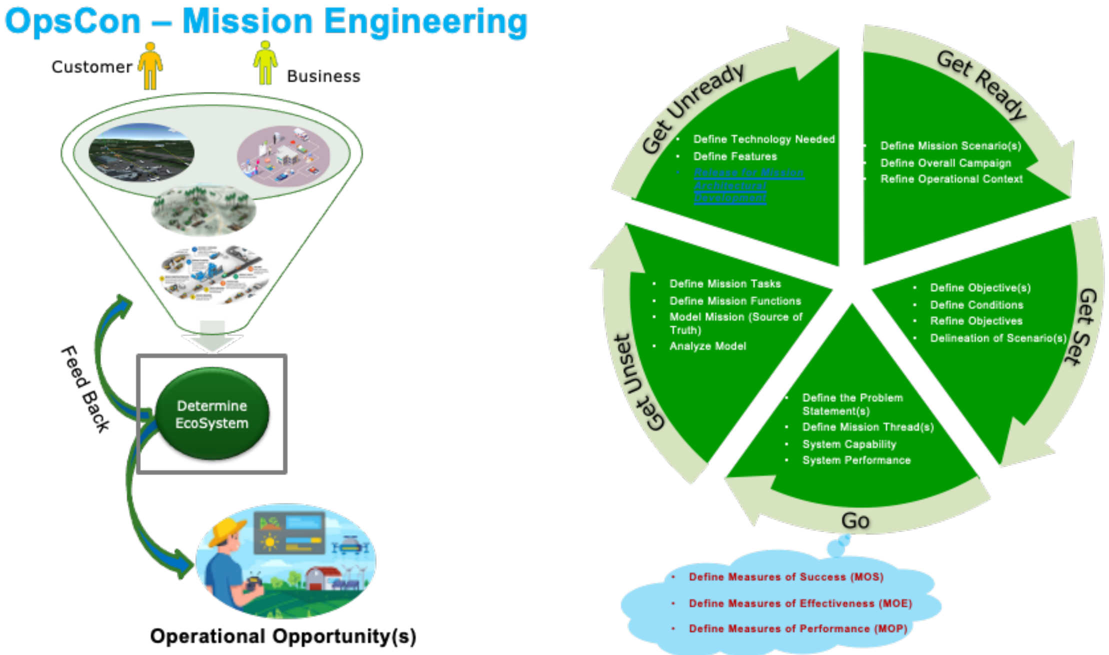


Figure 53 - Mission Engineering Operational Concept

Therefore, with a general understanding of the mission engineering method from our operational concept (OpsCon figure 53), we need to verify our stakeholders from a customer and business perspective from our operational analysis (Figure 54).

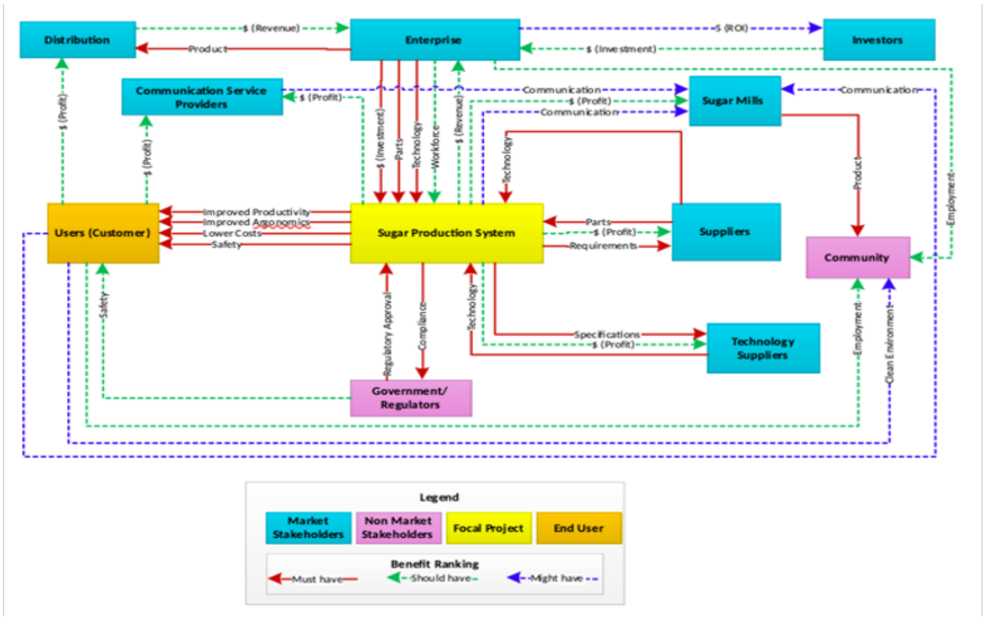


Figure 54 - Sugar Production System, Stakeholder Value Network – Refined

Furthermore, we must verify or refine the needs (Figure 55). We are just verifying our needs from a customer and business perspective from our operational analysis to ensure any needs have not changed or been missed. The activities are carried out in engineering our mission within our industrial ecosystem(s) and enterprise to further our understanding of the socio-economic and technological context and to allow us to engineer our missions effectively. The process map for mission engineering was developed progressively throughout Chapter 5, explained through this progression, and finalized at the end.

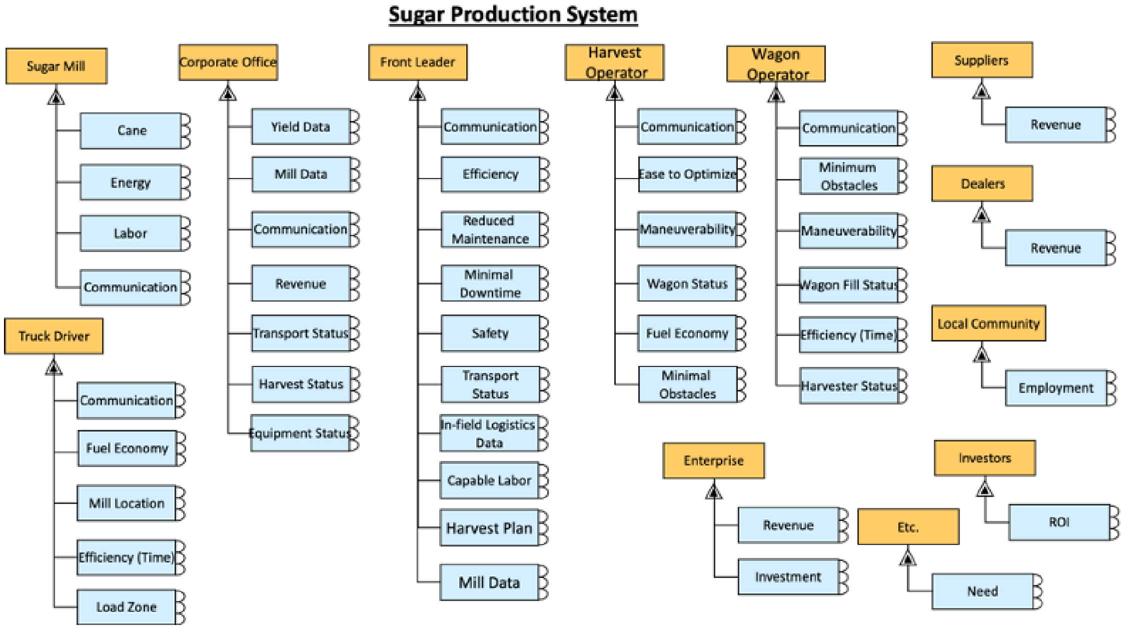
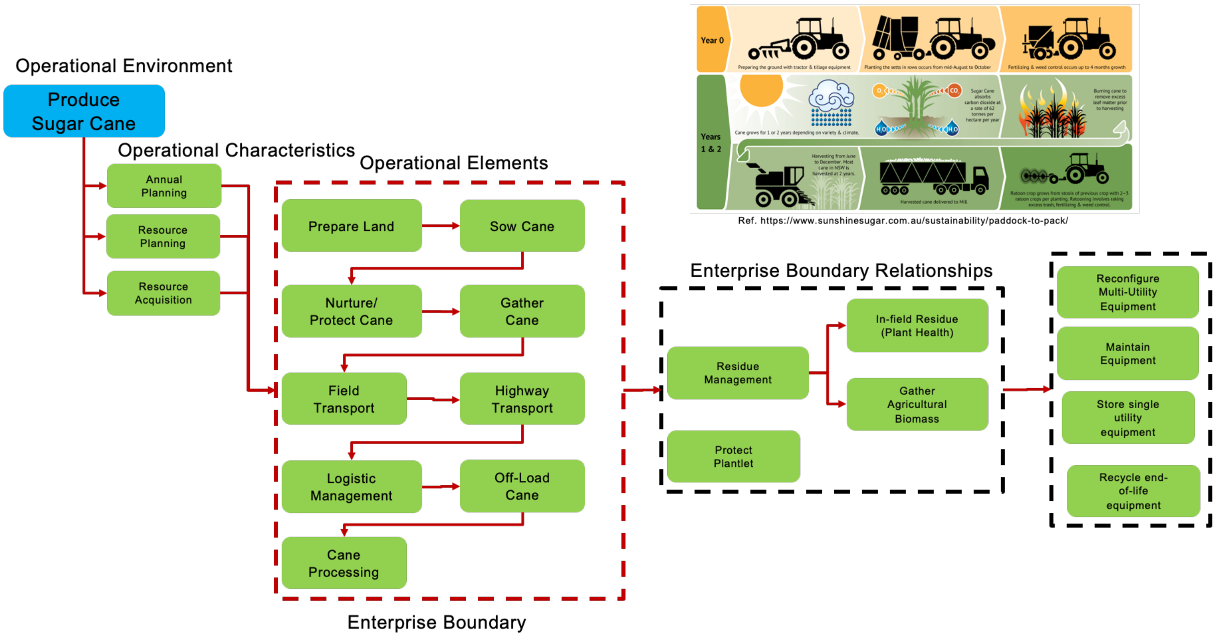


Figure 55 - Sugar Production System Stakeholder Needs – Refined

5.4 Mission Engineering – Opportunities Prioritization

As you may recall from Chapter 4, we performed our operational analysis by following our systematic approach while thinking further about the operating characteristics, elements, and interfaces. In other words, all operational characteristics, elements, and relationships performed operational analysis (see Figure 56). Based on this, the operational analysis identified opportunities for our operational characteristics, operational elements, and enterprise boundary relationship for the operational environment within the industrial ecosystem. These opportunities are captured in Table 1; we will continue to use the produce sugar cane example to assist the reader in understanding our framework within the context of a real example.



Ref. https://www.sunshinesugar.com.au/sustainability/paddock-to-pack/

Figure 56 - Operational Elements Analyzed

The outputs from our operational analysis in the form of opportunities are the basic building block of mission engineering. In this thesis, I will demonstrate the use of the opportunities only of the operational elements, as shown in Figure 56. Based on the operational analysis in Chapter 4, we share in Table 1 the operational opportunities generated.

Table 1 - Operational Opportunities Expanded

Operational Opportunities/Hypothesis	Opportunity 1	Opportunity 2	Opportunity 3	Opportunity 4	Opportunity 5	Opportunity 6	Opportunity 7	Opportunity 8	Classification	Motivation	Notes
Prepare Land	Manage Compaction	In-Field Logistics	Residue Management	Automation	Autonomy				Tillage	Minimize Compaction Reduce Shater	Preparing is only done every 3-7 years based on yield.
Sow Cane	Manage Compaction	In-Field Logistics	Plant Spacing	Mechanization	Automation	Autonomy			Sowing/Planting	Minimize Compaction	Sowing is only done every 3-7 years based on yield.
Nurture Cane	Manage Compaction	In-Field Logistics	Plant Spacing	Job Optimization (Single Pass)	Nutrient Management	Automation	Autonomy		Plant Health	Maximize Yield	If we maintain the health of the plant through-out its lifecycle we maintain high dextrose level
Protect Cane	Manage Compaction	In-Field Logistics	Plant Spacing	Job Optimization (Single Pass)	Pest Management	Weed Management	Automation	Autonomy	Plant Health	Maximize Yield	If we maintain the health of the plant through-out its lifecycle we maintain high dextrose level
Gather Cane	Manage Compaction	In-Field Logistics	Plant Spacing	Residue Management	Commodity Health	Automation	Autonomy		Commodity Viability	Maximize Dextrose Level Minimize time	Sugar Cane has a unique character as it has finite time from harvest to process (<24)
Transport Cane - Field	Manage Compaction	In-Field Logistics	Plant Spacing	Automation	Autonomy				Commodity Viability	Maximize Dextrose Level Minimize time	Sugar Cane has a unique character as it has finite time from harvest to process (<24)
Transport Cane - Highway	Highway Logistics	Automation	Autonomy						Commodity Viability	Maximize Dextrose Level Minimize time	Sugar Cane has a unique character as it has finite time from harvest to process (<24)
Logistics Management	Orchestrated Logistics (Gather to processing)	Artificial Intelligence	Virtual Reality	Automation	Autonomy				Commodity Viability	Maximize Dextrose Level Minimize time	Sugar Cane has a unique character as it has finite time from harvest to process (<24)
Off Load Cane	Temporal Logistics	Maximize Dextrose Level	Automation	Autonomy					Commodity Viability	Maximize Dextrose Level Minimize time	Sugar Cane has a unique character as it has finite time from harvest to process (<24)
Process Cane	Temporal Logistics	Maximize Dextrose Level	Automation	Autonomy					Dextrose Yield	Maximize Sugar Content	Sugar Cane has a unique character as it has finite time from harvest to process (<24)

The opportunities for each operational element are listed in rows. To be very prescriptive in our mission, we further define the opportunities with their respective classification related to the enterprise and the industrial eco-system they reside in. The classification can be defined as the category related to the operational element. The motivation is based on the operational environment associated with the operational depiction we have selected within our enterprise's industrial ecosystem. So, for our example, we reside in the industrial ecosystem of agri-food; our operational environment is to produce sugar cane, shown in blue in Figure 57, with the operational elements shown in Figure 57 in green.

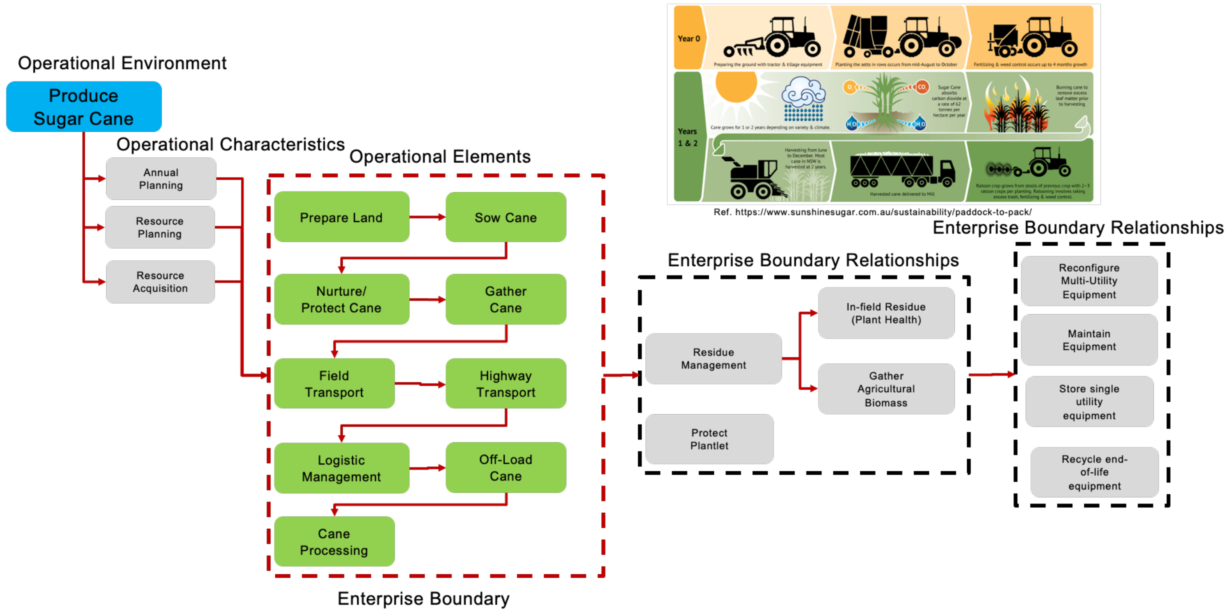
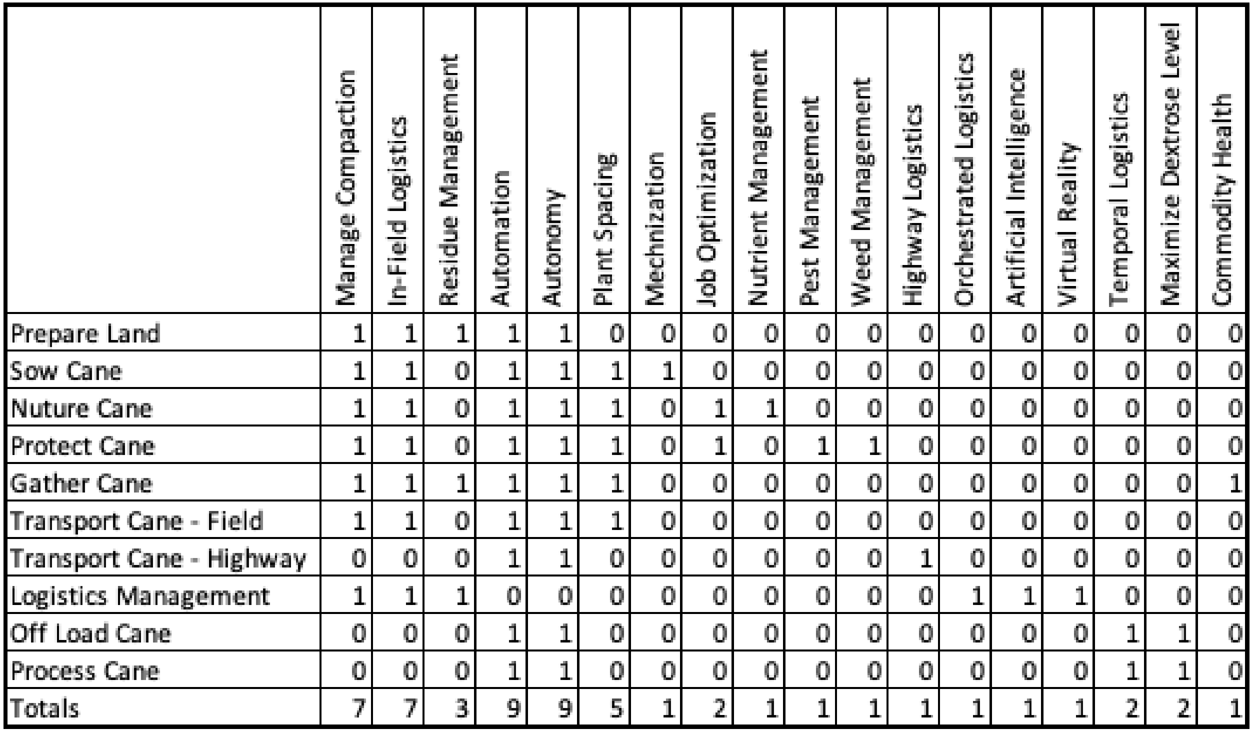


Figure 57 - Operational Elements Boundary, Mission Engineering

Prioritizing the opportunities are currently required to assist in engineering our missions. We also can note from Table 1 that there is significant commonality within the operational opportunities; therefore, some categorization is needed. We looked at the relationships of the operational elements to the opportunities, as seen in Table 2, to understand which opportunities crossed multiple operational elements. This was done if a relationship existed between the opportunity the nomenclature used was one (1), and if no relationship existed, then a 0 was noted. This provides us with an initial analysis of which opportunities have the most impact on our operational elements. This will assist in further classifying and prioritizing the opportunities into the respective missions while maintaining an understanding of the ecosystem and enterprise context.

Table 2 - Operational Opportunities Analysis



	Manage Compaction	In-Field Logistics	Residue Management	Automation	Autonomy	Plant Spacing	Mechnization	Job Optimization	Nutrient Management	Pest Management	Weed Management	Highway Logistics	Orchestrated Logistics	Artificial Intelligence	Virtual Reality	Temporal Logistics	Maximize Dextrose Level	Commodity Health
Prepare Land	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Sow Cane	1	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
Nuture Cane	1	1	0	1	1	1	0	1	1	0	0	0	0	0	0	0	0	0
Protect Cane	1	1	0	1	1	1	0	1	0	1	1	0	0	0	0	0	0	0
Gather Cane	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1
Transport Cane - Field	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Transport Cane - Highway	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Logistics Management	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
Off Load Cane	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0
Process Cane	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0
Totals	7	7	3	9	9	5	1	2	1	1	1	1	1	1	1	2	2	1

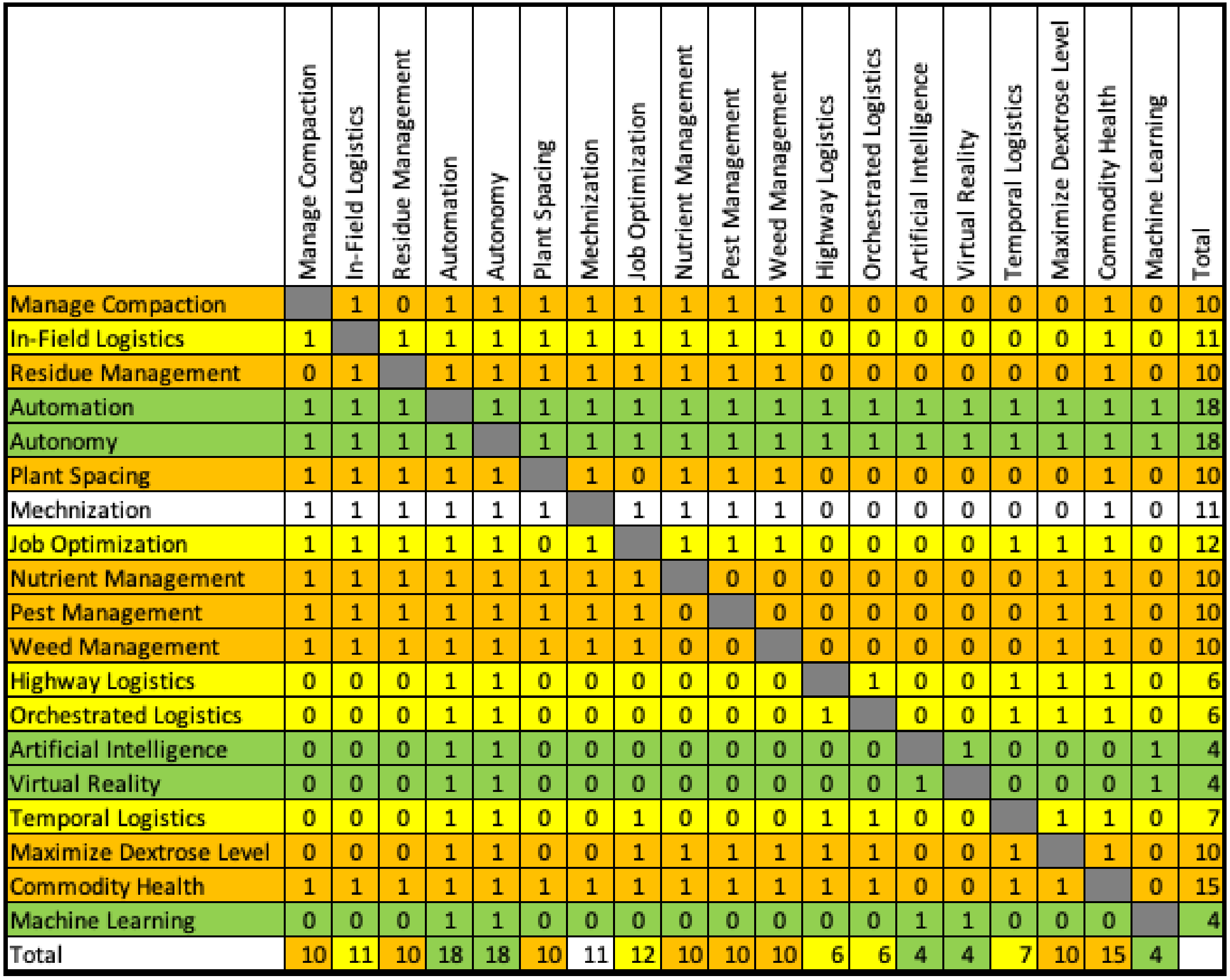
At this stage, it will be evident that further understanding of these operational elements and the relationship to the opportunities needs additional consolidation. While many tools are available, I chose a simple N^2 to consolidate the opportunities, as shown in Table 3. To further refine this and understand our stakeholders and their needs, the enterprise can categorize the opportunities for our customers and the enterprise as a business. The customer desires to maximize the output while minimizing inputs (efficiency); this will assist the cross-functional team in prioritizing the mission opportunities through categorization.

Table 3 - Operational Opportunities Analysis N^2

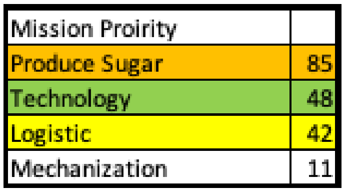
	Manage Compaction	In-Field Logistics	Residue Management	Automation	Autonomy	Plant Spacing	Mechnization	Job Optimization	Nutrient Management	Pest Management	Weed Management	Highway Logistics	Orchestrated Logistics	Artificial Intelligence	Virtual Reality	Temporal Logistics	Maximize Dextrose Level	Commodity Health	Total
Manage Compaction		1	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	10
In-Field Logistics	1		1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	10
Residue Management	0	1		1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	10
Automation	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	16
Autonomy	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	16
Plant Spacing	1	1	1	1	1		1	0	1	1	1	0	0	0	0	0	0	1	9
Mechnization	1	1	1	1	1	1		1	1	1	1	0	0	0	0	0	0	1	10
Job Optimization	1	1	1	1	1	0	1		1	1	1	0	0	0	0	1	1	1	11
Nutrient Management	1	1	1	1	1	1	1	1		0	0	0	0	0	0	0	1	1	9
Pest Management	1	1	1	1	1	1	1	1	0		0	0	0	0	0	0	1	1	9
Weed Management	1	1	1	1	1	1	1	1	0	0		0	0	0	0	0	1	1	9
Highway Logistics	0	0	0	1	1	0	0	0	0	0	0		1	0	0	1	1	1	6
Orchestrated Logistics	0	0	0	1	1	0	0	0	0	0	0	1		0	0	1	1	1	6
Artificial Intelligence	0	0	0	1	1	0	0	0	0	0	0	0	0		1	0	0	0	3
Virtual Reality	0	0	0	1	1	0	0	0	0	0	0	0	0	1		0	0	0	3
Temporal Logistics	0	0	0	1	1	0	0	1	0	0	0	1	1	0	0		1	1	7
Maximize Dextrose Level	0	0	0	1	1	0	0	1	1	1	1	1	1	0	0	1		1	10
Commodity Health	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1		14
Total	10	10	10	16	16	9	10	11	9	9	9	6	6	3	3	7	10	14	

These categories are based on understanding which opportunities are related to output and which are enablers for the customer's desired output. To better understand this, refer to our sugar cane production and refine our N^2, table 4. I have efficiently found that we have prioritized the mission we needed to engineer to develop our enterprise strategy around producing sugar. This prioritization is based on the rows and column totals from Table 3. This prioritization, is based on both our engineering and agronomic understanding. To produce sugar, we have eight opportunities with 85 relationships within these opportunities; enabling technology has five opportunities with 48 relationships; Logistics has five opportunities with 42 relationships; and finally, mechanization has one opportunity (in the sowing operation) with 11 relationships. This now allows us to formalize four missions around these themes. These themes are shown in Figure 58 with the opportunities.

Table 4 - Operational Opportunities Categorization with Prioritization



	Manage Compaction	In-Field Logistics	Residue Management	Automation	Autonomy	Plant Spacing	Mechnization	Job Optimization	Nutrient Management	Pest Management	Weed Management	Highway Logistics	Orchestrated Logistics	Artificial Intelligence	Virtual Reality	Temporal Logistics	Maximize Dextrose Level	Commodity Health	Machine Learning	Total
Manage Compaction	▨	1	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	0	10
In-Field Logistics	1	▨	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	0	11
Residue Management	0	1	▨	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	0	10
Automation	1	1	1	▨	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	18
Autonomy	1	1	1	1	▨	1	1	1	1	1	1	1	1	1	1	1	1	1	1	18
Plant Spacing	1	1	1	1	1	▨	1	0	1	1	1	0	0	0	0	0	0	1	0	10
Mechnization	1	1	1	1	1	1	▨	1	1	1	1	0	0	0	0	0	0	1	0	11
Job Optimization	1	1	1	1	1	0	1	▨	1	1	1	0	0	0	0	1	1	1	0	12
Nutrient Management	1	1	1	1	1	1	1	1	▨	0	0	0	0	0	0	0	1	1	0	10
Pest Management	1	1	1	1	1	1	1	1	0	▨	0	0	0	0	0	0	1	1	0	10
Weed Management	1	1	1	1	1	1	1	1	0	0	▨	0	0	0	0	0	1	1	0	10
Highway Logistics	0	0	0	1	1	0	0	0	0	0	0	▨	1	0	0	1	1	1	0	6
Orchestrated Logistics	0	0	0	1	1	0	0	0	0	0	0	1	▨	0	0	1	1	1	0	6
Artificial Intelligence	0	0	0	1	1	0	0	0	0	0	0	0	0	▨	1	0	0	0	1	4
Virtual Reality	0	0	0	1	1	0	0	0	0	0	0	0	0	1	▨	0	0	0	1	4
Temporal Logistics	0	0	0	1	1	0	0	1	0	0	0	1	1	0	0	▨	1	1	0	7
Maximize Dextrose Level	0	0	0	1	1	0	0	1	1	1	1	1	1	0	0	1	▨	1	0	10
Commodity Health	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	▨	0	15
Machine Learning	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	▨	4
Total	10	11	10	18	18	10	11	12	10	10	10	6	6	4	4	7	10	15	4	



Mission Proirity	
Produce Sugar	85
Technology	48
Logistic	42
Mechanization	11

Based on the themes and understanding the complexity of the relationships to each theme, Technology is needed to enable logistics for job optimization. Job optimization is needed to enable more efficient sugar production to maximize dextrose levels while maintaining commodity health Figure 58. As stated earlier, these themes are based on our engineering and agronomic understanding. We need technology and its elements to enable our logistics, allowing us to optimize seasonal logistics through job optimization. This job optimization enables us to produce sugar to maximize dextrose level while maintaining the commodity (sugar cane plant) health within the field, as sugar cane is a perennial plant.

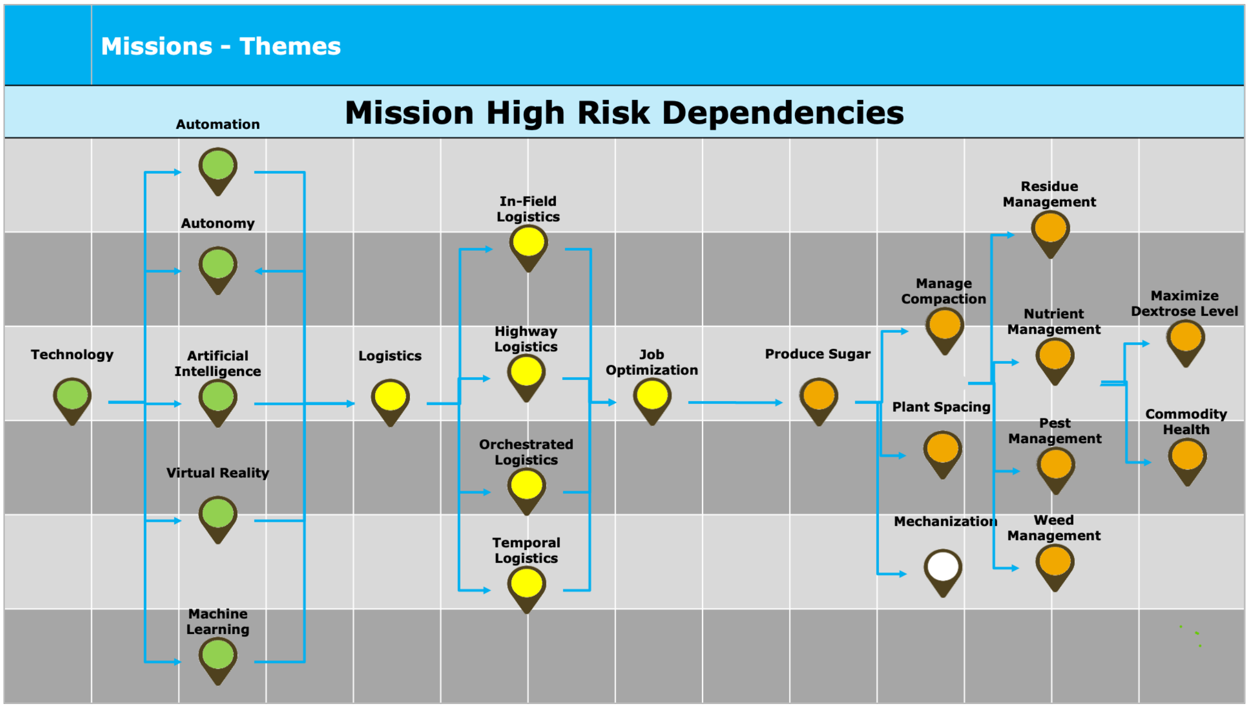


Figure 58 - Operational Opportunities Analysis Priority Dependencies

In summary, I have taken the operational elements from operational analysis and identified different potential opportunities through the classification and motivation of the sugar production system. Mapped the opportunities to the operational elements understanding where common opportunities reside. This provided insight that allowed me to analyze the relationship between opportunities so we could prioritize the opportunities within themes. This allows the dependencies of the opportunities based on engineering and agronomics within the themes to be understood so we don't implement a theme before the enable elements are in place for the subsequent theme within the sugar production system. Let's refer to Figure 58 again; the theme of technology is made up of 5 enabling technologies (Automation, Autonomy, Artificial intelligence, virtual reality, and machine learning) that need to be in place to allow the theme of logistics to be realized. Logistics now must develop the enabling elements (In-field logistics, Highway logistics, Orchestrated Logistics, and Temporal logistics) to be complete to enable job optimization. Once Job Optimization is in place, it enables us to produce sugar but to maximize dextrose level and maintain commodity health; we are dependent on our ability to manage compaction and plant spacing through mechanization (note: mechanization due to sugar cane being a perennial plant hadn't been considered before in the strategy) which enable residue, nutrient, pest, and weed management.

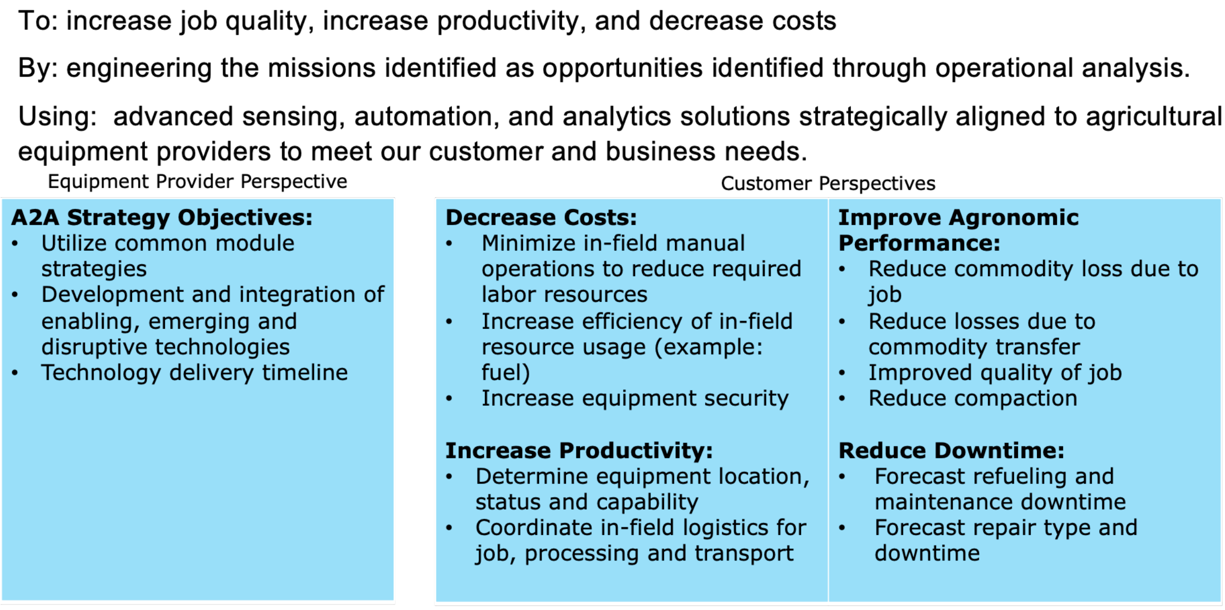
5.5 Mission Engineering – Automation and Autonomy

Now that I have defined our mission themes, we can develop our problem statements, technologies, characteristics, and metrics. The mission problem statement is starting point in understanding the socio-technical and technological context in which the potential problems or opportunities reside. The purpose of the mission is to understand the market opportunity, analyze the solution space, and initiate the life cycle of a potential solution that could address or take advantage of an opportunity.

The problem statement is made up of three key elements, and sometimes an optional fourth element is added when appropriate:

- *1st, the problem is clearly and concisely stated with enough background to authenticate its importance. It clearly articulates the value needed.*
- *2nd, the method of solving the problem is stated as the action needed in a solution-specific function or operation.*
- *3rd, the principal value is delivered to the primary stakeholder.*
- *4th, it is Optional, although we must live with a governing constraint.*

This is often articulated as a System Problem Statement (SPS) ref. MITsdm and Caltech SEM in a To, by, using, while. It is most often in the form of to, by, and using. In Figure 58, we identified four mission themes. Within the thesis, we addressed the mission theme of technology, specifically automation and autonomy. The mission statement and the principal value are delivered to the enterprise, and the customers are shown in Figure 59. The information presented in Figure 59 started in 2017/2018 as an assessment of the technology and the state of different industries in general to agriculture the writer. It was updated in 2020 and 2022, respectively. A complete list of the references review can be found in Chapter 7.



To: increase job quality, increase productivity, and decrease costs

By: engineering the missions identified as opportunities identified through operational analysis.

Using: advanced sensing, automation, and analytics solutions strategically aligned to agricultural equipment providers to meet our customer and business needs.

Equipment Provider Perspective

A2A Strategy Objectives:
- Utilize common module strategies
- Development and integration of enabling, emerging and disruptive technologies
- Technology delivery timeline

Customer Perspectives

Decrease Costs:
- Minimize in-field manual operations to reduce required labor resources
- Increase efficiency of in-field resource usage (example: fuel)
- Increase equipment security

Increase Productivity:
- Determine equipment location, status and capability
- Coordinate in-field logistics for job, processing and transport

Improve Agronomic Performance:
- Reduce commodity loss due to job
- Reduce losses due to commodity transfer
- Improved quality of job
- Reduce compaction

Reduce Downtime:
- Forecast refueling and maintenance downtime
- Forecast repair type and downtime

Figure 59 - Mission Problem Statement Automation to Autonomy, Sugar Cane

We also need to understand, analyze, and articulate the existing gaps within our enterprise to our industrial ecosystem compared to another enterprise within a similar ecosystem utilizing the same or similar technologies. This is sometimes referred to as a gap analysis shown in Figure 60. The information shown in Figure 60 came from an assessment started in 2017/2018 by the author to evaluate the levels of automation and autonomy and the expected progression. It was updated in 2020 and 2022, respectively.

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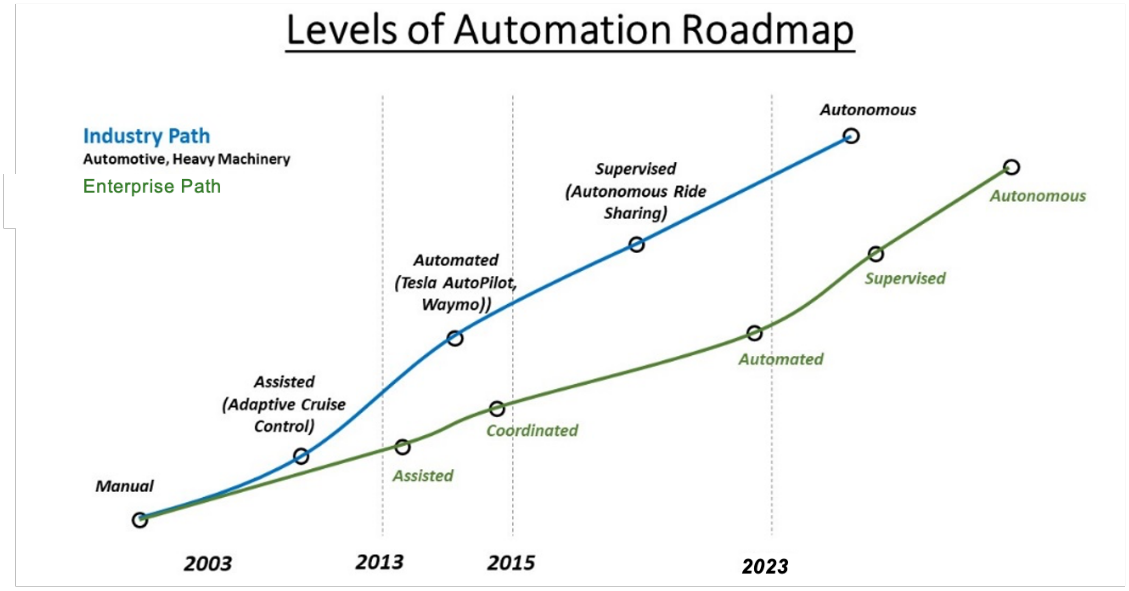
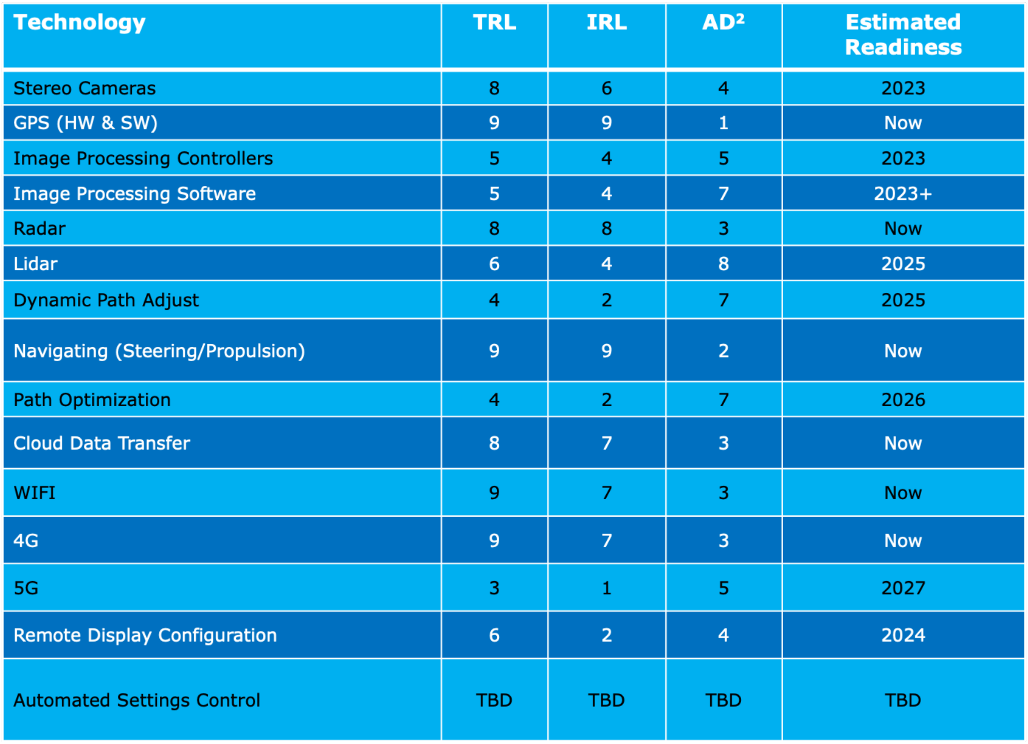


Figure 60 - Automation and Autonomy Progression

At this point, the necessary technology must be identified through the exploration of relevant and innovative research. We then complete a technology assessment determining our technology readiness level (TRL) and integration readiness level (IRL) based on the NASA system engineering handbook (Shea, 2017). We also utilized the Advancement Degree of Difficulty (AD^2), which systematically deals with aspects beyond TRL (Shea, 2017), as shown in Figure 61. The information shown in Figure 61 comes from an assessment of TRL, IRL, and AD^2 started in 2017/2018 by the author as an evaluation of the state of automation and autonomy and the expected progression and was updated in 2020 and 2022 respectively.



Technology	TRL	IRL	AD^2	Estimated Readiness
Stereo Cameras	8	6	4	2023
GPS (HW & SW)	9	9	1	Now
Image Processing Controllers	5	4	5	2023
Image Processing Software	5	4	7	2023+
Radar	8	8	3	Now
Lidar	6	4	8	2025
Dynamic Path Adjust	4	2	7	2025
Navigating (Steering/Propulsion)	9	9	2	Now
Path Optimization	4	2	7	2026
Cloud Data Transfer	8	7	3	Now
WIFI	9	7	3	Now
4G	9	7	3	Now
5G	3	1	5	2027
Remote Display Configuration	6	2	4	2024
Automated Settings Control	TBD	TBD	TBD	TBD

Figure 61 - Automation and Autonomy - Technology Assessment

We want to develop our concepts to further develop within the mission theme of technology, automation, and autonomy. To do this, we first need to understand the progression of the technology and, through our research, find that SAE had defined the levels of automation to autonomy (Search for 'automation levels ' - SAE International, no date). From this understanding, we can develop a general concept for this mission theme of technology automation and autonomy figure 62 & 63. This was completed by taking the technology table Figure 61 and automation roadmap Figure 60 and defining the enabling technologies that become a technology package based on the progression needed to become fully autonomous. For example, we need certain technologies at level 1 to enable level 2 and so on, as shown in Figure 62. From this, we took the technologies from Figure 61 and asked what technologies are needed for obstacle detection; I found that we need radar, GPS, stereo cameras, image processing software, and hardware to deliver this functionality. Based on this and our TRL, IRL, and AD^2, we understand *the development time and can come up with a timeline for the different levels of automation and autonomy.*

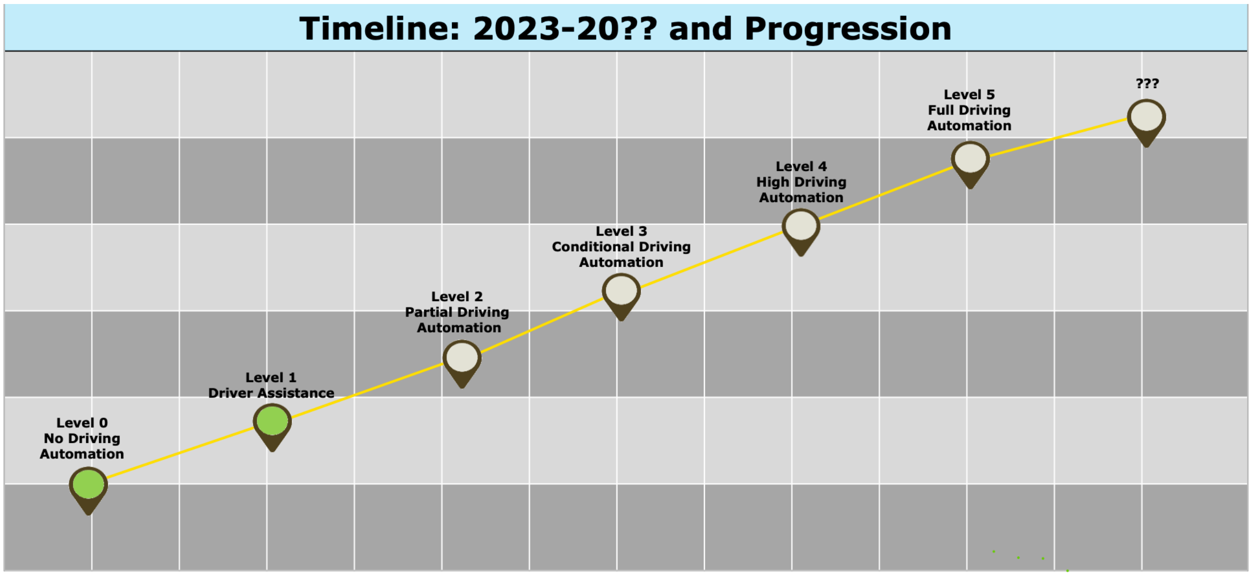


Figure 62 - Automation and Autonomy – Timeline

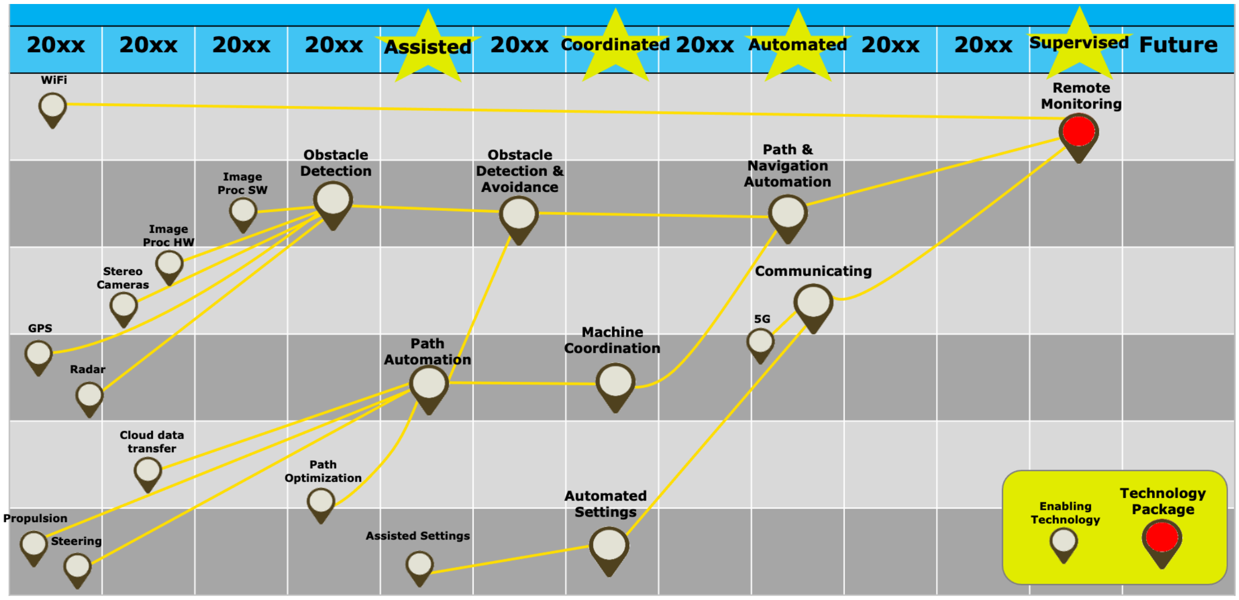


Figure 63 – Concepts with Technology Progression

We have developed a high-level technology roadmap with timelines for the needed technology for the mission themes of technology.

5.6 Mission Engineering – Measure of Success

At this point, through our analysis, we need to characterize the mission to provide the necessary information to develop our mission metrics for our Measure of Success (MOS), Measure of Effectiveness (MOE), and Measure of Performance (MOP). To characterize the mission theme of technology, specifically automation and autonomy, we develop our Concept of Operation (ConOps) and Operational Concepts (OpsCon). The ConOps is developed in the enterprise operational environment refer to Figure 53 and is all operational characteristics, operational elements, and enterprise boundary relationships within which our enterprise operates (see Figure 64). This gives us the steps in sugar production and, from our theme of technology automation and autonomy, the ability to determine where this technology could be applied. Based on my 25 years of experience, I created this as I have been studying sugar production since 2000 and in 2017, was involved in several projects around sugar cane production that provided me with this insight into sugar cane agronomics.

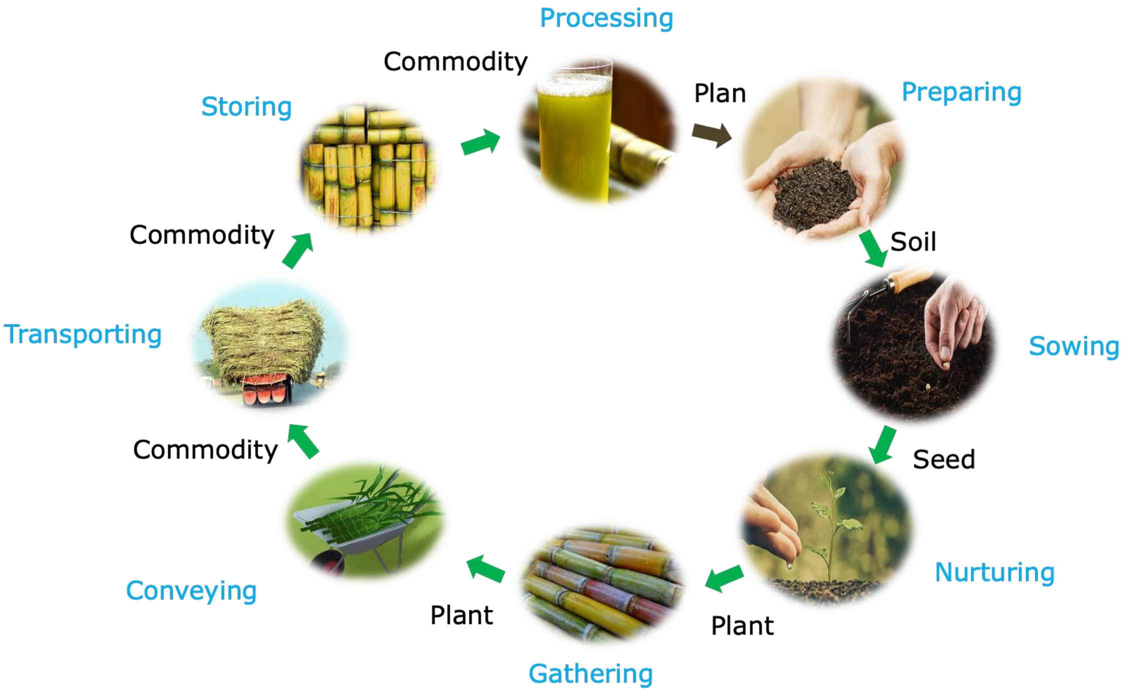


Figure 64 – Automation and Autonomy, Concept of Operation

The development of the OpsCon is the last constituent needed before the development of our MOS, MOE, and MOPs and subsequent development of the enterprise strategy and mission architecture after completing mission engineering with the technology theme as well as logistics, produce sugar, and mechanization refers to figure 58. While this may seem straightforward, our OpsCons need the necessary detail to provide the enterprise strategy development team with the required strategic elements to architect each mission and stitch them together within the mission thread for our operational characteristics of producing sugar cane. We, therefore, will utilize a *framework of get ready, get set, go, get unset, get unready, as well as our go contingencies and emergency contingency.*

In system development, it has often been found that only the execution (go) portion of the OpsCon is provided. Yet, to develop our strategy and mission architecture, this is only one-seventh of the picture. We need to prepare (get ready), plan (get set), execute the mission (go), debrief (get unset), complete (get unready), redundancy (go contingency), and safe operation (emergency contingency) Figure 65 shows an example of the detail needed. While this may seem trivial, it is a key deliverable to the enterprise strategy development team and mission architecture. Based on my experience, engineering, and agronomics, it was found that the most appropriate place to start automation and autonomy are the operational elements shown in Figure 65.

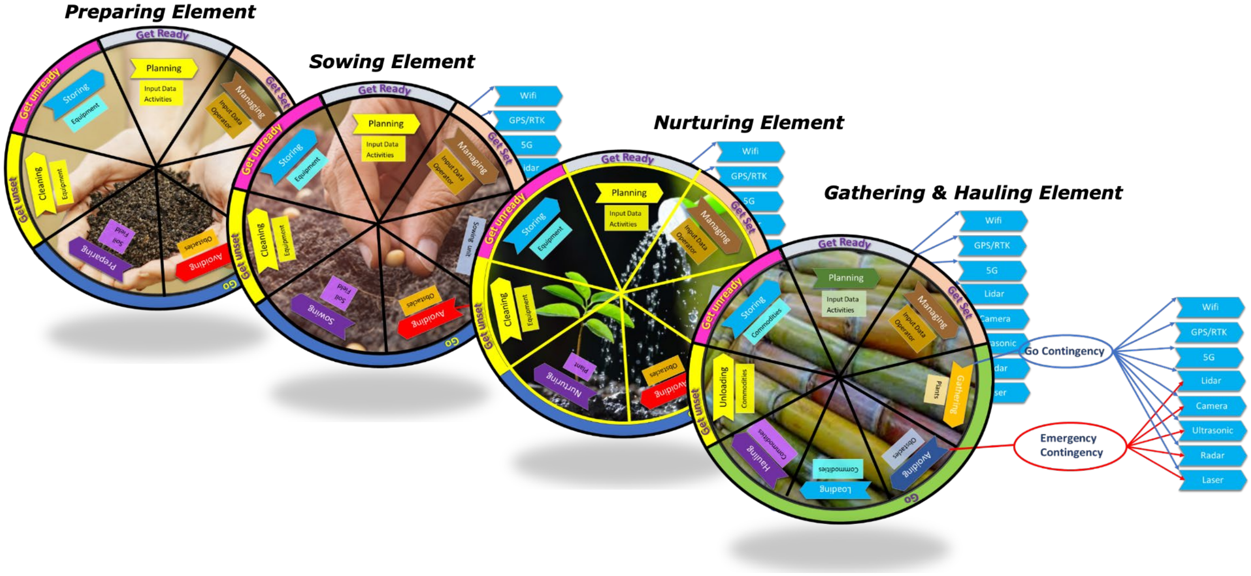


Figure 65 – Automation and Autonomy Operational Concepts

As outlined in our literature review, the DOD Mission Engineering Guide states that analytical documentation uses several similar terms to refer to mission metrics, including Measures of Success, Measures of Suitability, Measure of Utility, Measure of Efficacy, Measures of Effectiveness (MOEs) and Measure of Performance (MOPs). Based on the recommendation with the DOD guide during my literature reviews, I will define our mission development and simplify using MOEs and MOPs as they suggested in the guide. At this point of development, the MOEs and MOPs, see Figure 66

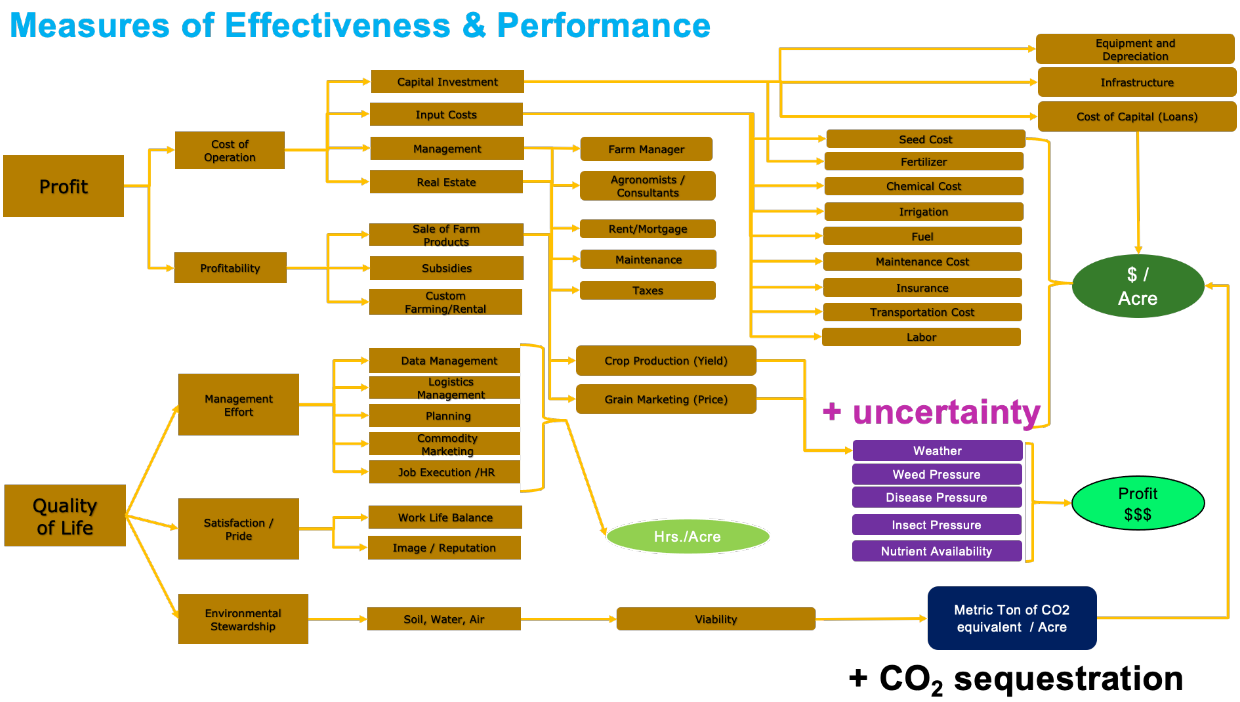


Figure 66 – Measures of Effectiveness & Performance (MOE & MOP)

I have completed the mission definition. Our mission definition for all the themes is now turned over to the strategy development team. The elements to provide as inputs to the strategy development team would be Missions for each theme made up of the following: mission opportunities table, mission problem statement, high-risk mission dependencies map, relationship map within the theme and between the themes, and associated mission threads (interrelationships), ConOps, OpsCons, Technology Roadmaps, technology readiness level, integration readiness level, and advanced degree of difficulty as well as our MOPs and MOEs. Although my research and experiences showed this, the list could expand as these methods are refined through additional pilots. The MOP and MOE were generated based on my experience working in the machinery industry and my understanding of the sugar production system. I also have considered the socioeconomic and sociotechnical projects in sugar production from other projects I worked on. Yet, we still need to complete operational analysis and mission engineering on the other operational depictions. This only allows the strategy development team to develop the strategic plan for sugar. Yet, we know that we must see if there are common opportunities within the other operational depiction (vignettes) in Figure 34, allowing us to develop a holistic strategy for not just sugar. Still, for the enterprise, much of the automation and autonomy applies to all operational depictions. This provides a common opportunity to modularize across platforms and missions, reducing uncertainty and complexity around the agri-food ecosystem within our strategy. It is also the key input to mission architecture.

Mission Architecture (AOL 3) develops the architecture needed for the enterprise to assure alignment between the AOL 0-2. Once the mission architecture is completed, we can begin the work at AOL 4 Technology Roadmapping and, from there, our portfolio AOL 5. The scope of this thesis was limited to AOL 0 Industrial Ecosystem, AOL 1 Operational Analysis, and AOL 2 Mission Engineering; much of this is done using the existing system engineering methods, language, and tools, yet additional research is needed at the AOL 3-7 to complete this work.

As a result of our research and experience working on the sugar cane production examples, the following process map was developed in Figure 67 to further assist the practitioner in applying mission engineering in providing the inputs to the enterprise strategy.

Several other questions that could have been stated at this thesis's outset show promising potential. Based on our initial work within my thesis, technology identification within mission engineering provides a more consistent approach to identifying technology enablers. It enhances our understanding of technology identification and enabling relationships, allowing us to define mission themes more consistently. At the same time, it allows prioritized themes that enable technology to modularize technology packages.

The next chapter will discuss the insights, implications, conclusions, and recommendations.

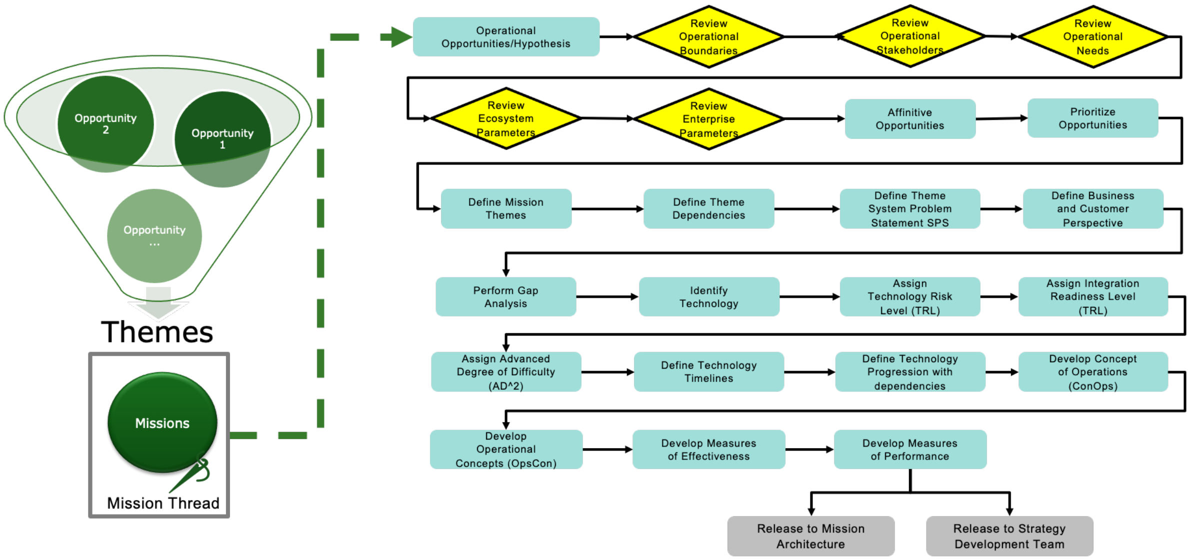


Figure 67 Mission Engineering Process Map

If we take a moment to reflect on the process map allows upfront to assure as we engineer our mission, we have a holistic view versus an independent view of the boundaries, stakeholders, and stakeholder needs, understanding both the enterprise and enterprise operational parameters to ensure the correct affiliation and prioritization of the missions by defining our mission themes and dependencies that allow us to successfully develop a cohesive system problem statement from both the enterprise and customer perspective. This enables us to understand better both the *short-term and long-term technology needs. It helps us to minimize the socioeconomic and technical impacts through the understanding of the technology development timelines and progression based on the dependencies that enable the effect MOE and MOP to be defined to allow the enterprise to measure the performance of the operational analysis and missions developed for the industrial ecosystem they reside as well as the secondary and tertiary relationship to other ecosystems.*

At this point and with our comprehensive understanding, we can create the process map of mission engineering utilizing the perspective of an industrial ecosystem within the context of the operational ontology with our method for operational analysis to provide a more comprehensive assessment identifying the key insights and inputs to the enterprise strategy. Yet, it won't come for free and may require a paradigm shift in our thinking. As a result of the process map, it will be necessary for the enterprise to integrate our process map outputs as key inputs to enterprise strategy. This means that our strategy development methods, processes, and tools would need to incorporate the key outputs from mission engineering into the enterprise strategy. Many enterprise customer acquisition processes must be updated to utilize the framework and structure outlined in previous sections. This would require the enterprise to thoroughly understand the industrial ecosystem(s), operational ontology, and outputs from operational analysis of the customers, markets, and competition, providing quantitative and qualitative market research to mission engineering. This would provide better missions, mission threads, technology assessment, and inputs to the enterprise strategy.

6 Discussion

Let's take a moment to summarize the key artifacts needed to build the framework and structure, starting with the classifications of industrial ecosystems Figure 68, Operational Ontology Figure 69, Operational Analysis Process Map, Figure 70, Mission Engineering Processes Map Figure 71 and how they fit into my framework and structure Figure 72. These are shown again here to assist the reader versus having them page back and forth through this thesis.

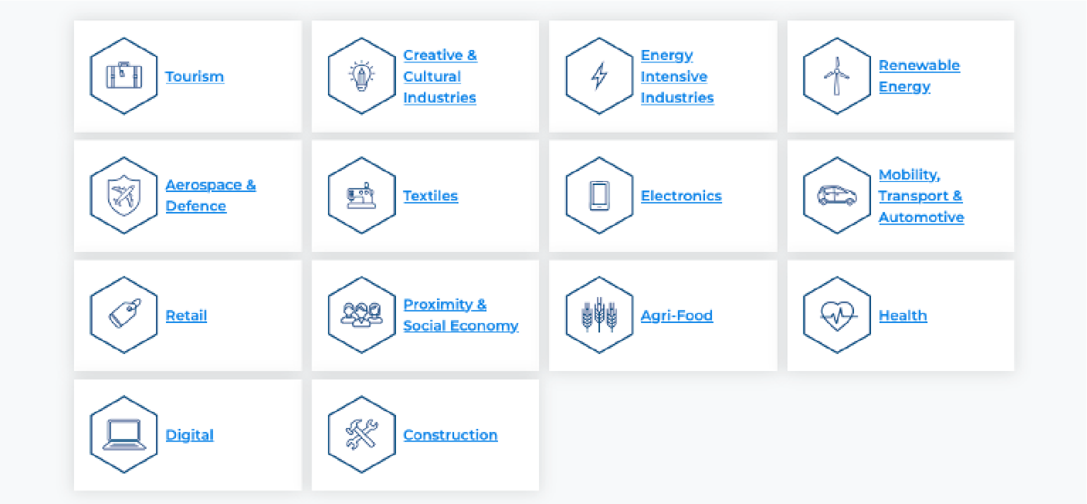


Figure 68 – Industrial Ecosystems Classification (Ref: Industrial Ecosystems/European Cluster Collaboration Platform)

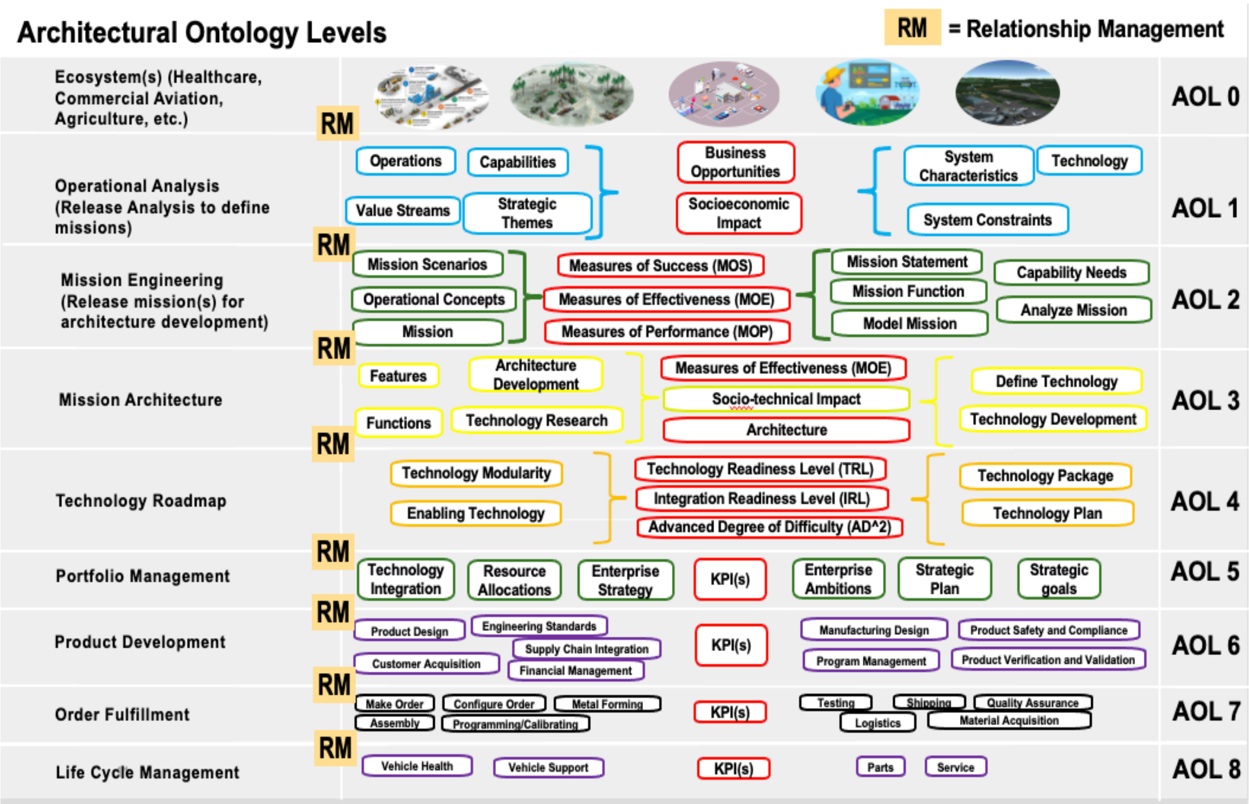


Figure 69 - Summary Architectural Ontology Levels

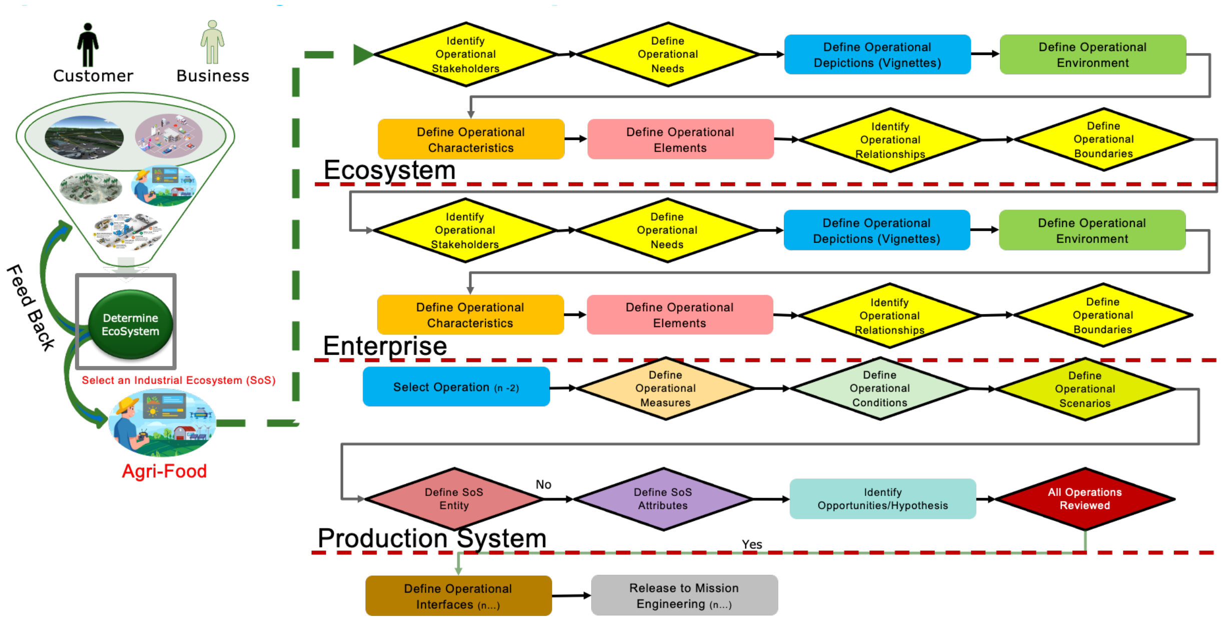


Figure 70 - Operational Analysis Process Map

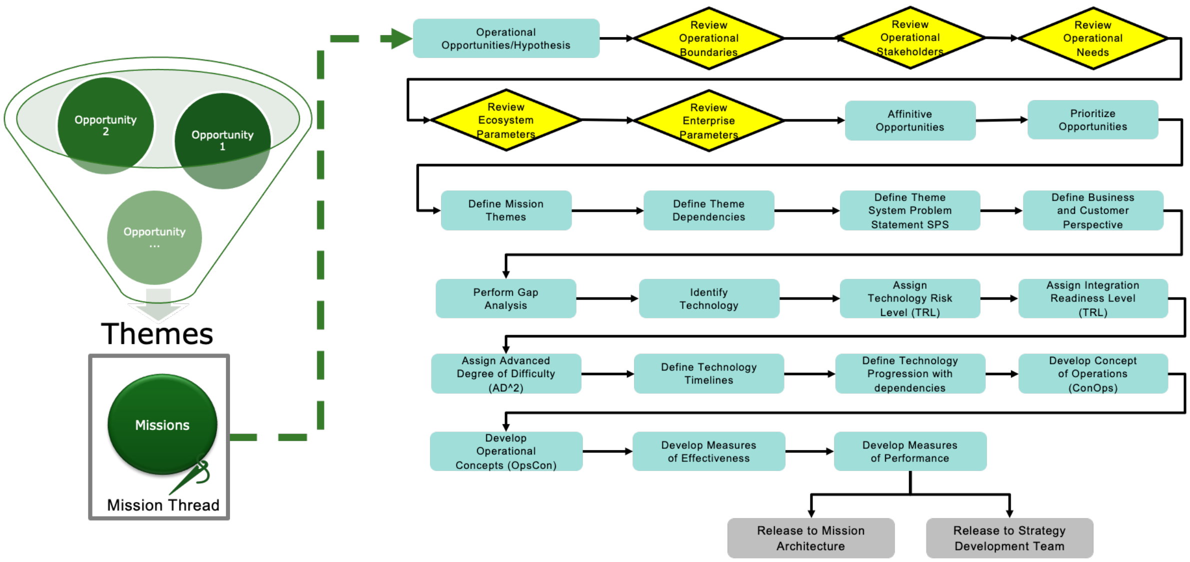


Figure 71 - Mission Engineering Process Map

I will now share this framework and structure and show you how an industrial ecosystem can be considered and still provide enterprises with profits, social benefits, and social responsibility.

Therefore, based on the research and experiences, we intended to provide the framework and structure in the form of the two frameworks, two methods, and metrics used in developing the enterprise strategy, as shown in Figure 72.

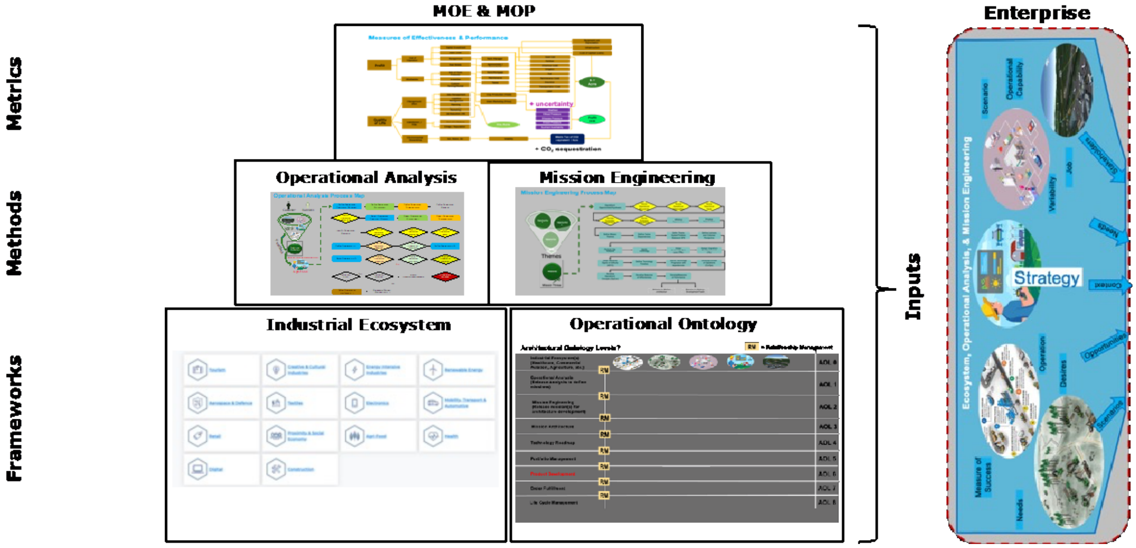


Figure 72 - Framework & Structure

The framework and structure to develop the enterprise strategy are a path to a more holistic method for developing a concise understanding of the opportunities through the operational ontology proposed within this research. The development starts with the operational ontology, identification of the primary industrial ecosystem in which the enterprise resides, and the *relationship to other secondary ecosystems. This allows operational analysis to be completed in a structured fashion providing key inputs to develop our missions through mission engineering while maintaining the key relationship from an enterprise and ecosystem perspective.*

Understanding the architectural ontology levels within any sociotechnical industrial ecosystem demonstrates that we can identify key opportunities as inputs to the overall enterprise strategy. We also can understand and manage the inherent relationships of the architectural ontology at the operational and mission levels within any primary industrial ecosystem(s) as inputs to the enterprise strategy. Applying the operational analysis to any industrial ecosystem will improve the enterprise's ability to develop a more consistent strategy if they are willing to invest the time in the short term for the long-term gains in creating a more consistent strategy. The operational analysis provides sufficient insights into the industrial ecosystem by identifying opportunities that enable us to engineer our missions more effectively within mission engineering.

The framework allows the enterprise to identify technology, provide a more consistent understanding of the key enablers and technology packages, and manage the inherent relationships between the enterprise and the industrial ecosystem(s). Through technology identification and the inherent relationships, one can be more consistent in the missions' development and themes. We can prioritize technology development and modularization of technology packages through these themes.

After applying the framework to the sugar production system, additional research is needed to thoroughly examine the overall operational ontology of the Agri-Food ecosystem and additional industrial ecosystems influenced by the enterprise. To further expand the framework within the operational ontology, operational analysis and mission engineering would need to be examined for all operational depictions (vignettes) associated with the enterprise to provide all necessary inputs for a complete strategy to be developed as key inputs for mission architecture. It is also evident that this framework is adaptable to the academic and industrial realms to bridge the current gaps when developing products, processes, and services and the relationship to the industrial ecosystem(s) they reside in.

We have established that the existing methods, processes, and tools currently used in industry and academia can be effectively used within the framework and structure to provide more comprehensive inputs to the enterprise in strategy development. Also, demonstrated through the sugar production system that by understanding the inherent relationships of the architectural ontology levels (inputs & outputs), while executing operational analysis and mission engineering to an industrial ecosystem(s), patterns emerge that would allow us to consistently apply modeling methods to help manage the operational opportunities and missions more comprehensively. Based on these patterns in conjunction with today's technology, our framework and structures lend themselves well to Model-Based Engineering (MBE), allowing the enterprise to manage strategy within the industrial ecosystem(s) more effectively.

Because of the similar relationships that exist between the architectural ontology levels (inputs and outputs), these frameworks, structures, and patterns will affect Model-Based Engineering (MBE). This approach has implications that enable this field to move from document-centric to model-centric analysis through digitalization.

This work also supports additional research into the overall operational ontology of any industrial ecosystem. The operational ontology decomposition is adaptable to the academic and industrial worlds, further exploring the educational synergies between system design and management.

Keeping this in mind, there is significant follow-on work to continue promoting system design and management in academic and industrial settings. I have just scratched the surface of what we can and should do to assure as technological innovation continues to accelerate, we develop systems in a socially responsible way. Within the 21st century, enterprise migrates from financial responsibility to their shareholders and how they implement technology with a deep understanding of the short and long-term socioeconomic and sociotechnical impacts.

6.1 Implications of the Framework and Structure

This section will explore the implications of our findings in developing the framework and structure (figure 72) as a methodology to provide additional inputs for developing an enterprise strategy. This will be done by proposing the rationale from both a holistic and individual elements view of our framework and structure.

Classical system engineering has been around now since the 1950s. Over the years, it has evolved as a discipline within industry and academia, focusing on products, processes, and services. In 1995 the NASA system engineering handbook was released, with subsequent updates in 2007 and 2020(Shea, 2017). In 1998 the Massachusetts Institute of Technology (MIT) introduced the System Design and Management program (MITsdm). In 2000 the International Council of System Engineering (INCOSE) was established. In 2015 INCOSE released a System Engineering Handbook. Also, in 2015 MITsdm updated its core curriculum. The documents' essence focused on the industrial ecosystem of aerospace & defense and products, processes, and services within a very specific system and its mission.

The implications of my thesis suggest that we have evolved well beyond what is printed in all this literature, and the system engineering methodology, processes, and tools can be applied to provide key inputs into enterprise strategy development.

Initially, we would have to align on the architectural ontology levels (AOL 0 – AOL8) as depicted in Figure 69 as the standard. Since my thesis focuses on providing a higher fidelity of inputs to the enterprise strategy, AOL 0 – 2 would be the initial focus, with subsequent research and proposals for AOL 3-8. We would likely agree that the primary focus of most systems engineering activity has been on AOL 6 product development and associated products, processes, and services. Once the architectural ontology levels have been defined, agreement on the classification of the *industrial ecosystems (AOL 0) would need to be agreed upon. The starting point could be the European Cluster Collaboration Platform (Industrial Ecosystems | European Cluster Collaboration Platform, no date).*

Upon agreement of the architectural ontologies' levels and the classification of industrial ecosystems has been defined, the operational analysis (AOL 1) would be adopted as outlined in Chapter 4, providing the necessary inputs to mission engineering (AOL 2) as outlined in Chapter 5. Upon successful execution of mission engineering (AOL 2), the strategy development team will need to consider this new input. Thus, the strategy development processes and deliverables must be updated, and key systems personnel must be engaged. While the scope of our thesis was to provide more comprehensive inputs to enterprise strategy development, additional research is needed at architectural ontology levels AOL 3 through AOL 8.

This would result in a paradigm shift in the industry and academia and thus have ramifications for the existing literature, potentially resulting in significant updates. Training and education within the system design and management programs would need updates and possibly substantial rewrites. Follow on research is required in both industry and academia to continue this work. Additionally, this would provide greater insight into the enterprise's sociotechnical and socioeconomic impacts on the industrial ecosystem(s), which could provide additional revenue while maintaining leadership around social responsibility.

Although this thesis did not address Model Based Engineering (MBE), the implications of the architectural ontology combined with the elements outlined within my framework patterns developed. Patterns can be modeled; the implications here are vast. Existing methods for modeling products, processes, and services would need to be able to manage the digital assets comprehensively; therefore, further research is needed into the current suite of digitalization technology to determine applicability to this framework.

Ultimately if we meet these challenges, the focus of transformation efforts will shift toward educating those who are resistant to change, this new way of thinking, and applying our system engineering methods based on our architectural ontology proposed within our framework. Through this research and example within this thesis, I believe that to truly embrace our social responsibilities while anticipating technological advancements to meet the needs of tomorrow's generations, it is imperative to move beyond products, processes, and services in industry and academia.

As the framework and structure were developed during our literature reviews, we found that most industry and academic literature was specific to Product Development (AOL 6). Particularly products, processes, and services. Through this understanding and wanting to develop a categorical decomposition of the domains and their properties to effectively provide input to the enterprise strategy from a sociotechnical and socioeconomic perspective of the enterprise as it relates to an industrial ecosystem, we developed the architectural ontology. The architectural ontology levels are shown in Figure 69.

This uncovered that only the Product Development AOL 6 level is being addressed within industry and academia. The scope of this thesis was to understand if operational analysis and mission engineering using existing methods, processes, and tools could provide inputs to an enterprise's strategy development. Yet, to proceed further, an architectural ontology was needed based on our research as a key initial step.

We have defined the method and process using existing system design and management tools for AOL 0 industrial ecosystems, AOL 1 operational analysis, and AOL 2 mission engineering, as well as processes for each that allow the inherent relationships between the levels to be maintained. Additional work is needed from AOL 3-8 to fully utilize this framework and structure within system design and management by applying the same methodology to develop the analytical process to guide the practitioner at the respective levels while maintaining the relationships between the levels of ontology. This will take time through literature reviews and subsequent development to establish and end to end process defining the inputs and outputs of each as well as MOP and MOE. This in turn means that we may need to develop supplemental or new training and educational material so that all industrial ecosystems can benefit from this initial work and subsequent future work. This will take time, yet this step is necessary to allow enterprises to serve their stakeholders better while maintaining a level of social responsibility needed now and in the future.

Although Model Based Engineering (MBE) was out of the scope of this thesis due to time limitations, the implications of the architectural ontology would benefit MBE from such an approach. This architectural ontology could provide a structured method for categorizing MBE artifacts to promote the existing methods for modeling products, processes, and services while managing the digital assets comprehensively; therefore, further research is needed into the current suite of digitalization technology to determine applicability to this framework.

While some might argue that following our framework and structure starting at AOL 0 industrial ecosystem(s) is too complex and of little value for the time, I, on the other hand, believe it to be imperative for an enterprise to understand the industrial ecosystem(s) in which they reside to align the business strategy more comprehensively to meet both their business and customer needs of today as well as tomorrow allowing them to prosper and grow versus wither and die. As we have seen, technology, environmental pressures, and social responsibility are very much at the forefront of the minds of today's generation. This would result in re-engineering many methods, processes, and tools an enterprise customer acquisition process uses today to understand its existing customer base. This implies that whom you think might be a customer today may not be a customer tomorrow or the loss of potential new customers and provide the potential insights into the product as a service within the industrial ecosystem(s), allowing the enterprise to improve stakeholder value added. Yet, the biggest hurdle may be the initial agreement on classifying the industrial ecosystems as elements this encompasses. Then, the industry and the enterprises, large and small, would be better able to align with their respective ecosystem(s) and identify additional opportunities for growth and prosperity. Additional research, understanding, *and education are needed at the industrial ecosystem level to provide key inputs to an enterprise strategy today and in the future.*

6.2 Implications of the Industrial Ecosystems

The industrial ecosystem would also benefit MBE and digital transformation in many aspects, like the operational ontology outlined previously. MBE could provide a structured method for categorizing artifacts to promote the existing methods for modeling products, processes, and services while managing the digital assets comprehensively; therefore, further research is needed into the current suite of digitalization technology to determine applicability to this framework.

6.3 Implications Operational Analysis

In operational analysis, utilizing the existing methods, processes, and tools currently used in industry and academia at the product development level (AOL 6) demonstrates the applicability to developing a more comprehensive understanding of the opportunities through the process developed in Figure 70. This process was only demonstrated during this thesis and would benefit from additional exploration and experimentation in academia and industry. As this approach gains momentum in the application, creating new material and training for academic use would be necessary. The methods contained would need to deliver to the industry practically and pragmatically to further the adoption.

Most enterprises have a core customer acquisition process that comprises strategic regional and product marketing teams and regional tactical marketing and sales teams. Adopting our framework in the "Generate Customer and Business Insights" area would result in changes to many existing processes and tools. In addition, systems architects and engineers would need to be better integrated into the teams to implement and execute the framework and structure. Some companies have documents they generate to promote an understanding of customer needs. Like a Potential Solution Concepts document, these documents only list the problems a customer faces with our framework and structure; they would also need to list the opportunities within a specific ecosystem and define what level of the architectural ontology the opportunity or issues reside at. As the company performs market scans which are based on prioritized global value and chains, job maps, production systems, customer segments for prioritized markets, competitive landscape, as well as policy, regulations, and compliance would need to experience a paradigm shift to allow the market scan to be performed at the industrial ecosystem level to permit the execution of the framework and structure to provide key inputs to the market scan for inclusion in the enterprise strategy. Proposed market opportunities, product opportunities, and non-product opportunities, i.e., product as a service plan, would have to utilize key inputs from my findings.

Other areas impacted would be the development of market opportunities documents needing to cover relationships to other opportunities and specific product opportunities documents. Adopting this framework and structure for operational analysis of an industrial ecosystem within *the operational ontology would result in a more comprehensive understanding of key inputs to any enterprise strategy. This would provide better customer, market, and competitive insights. It would also result in the development of comprehensive plans with prioritized action lists that enhance the long-term strategic plan and provide a deeper understanding of the opportunities and the size of the opportunities. Lastly, it would enable a more entrepreneurial view allowing innovation by utilizing current and future technologies while understanding the sociotechnical and socioeconomic impacts on the enterprise strategy. Lastly, the key elements would be necessary to develop the missions, mission themes, and mission threads, which will be outlined in the next section. MBE could provide a structured method for categorizing elements of operational analysis to promote and manage these digital assets comprehensively; therefore, further research is needed into the current suite of digitalization technology to determine applicability to operational analysis.*

6.4 Implications Mission Engineering

In mission engineering, the effects of this framework and structure are numerous, as seen in our literature review, as much of this work is around the individual and sub-mission(s) within that mission. They outline mission threads as the mission and sub-mission(s). Yet, these missions are related to the industrial ecosystem(s) at AOL 6 (Product Development) of the operational ontology. This limits our ability to provide the necessary inputs to the enterprise strategy and a clear understanding of the inherent relationships between our missions, technologies needed, and sociotechnical and socioeconomic impacts on the industrial ecosystem(s). It also has implications for mission architecture (AOL 3) as mission engineering feeds the prioritized themes, technology, and relationships of the missions as key inputs to the architectural development team. The result of missing inputs to this process would affect the enterprise's ability to provide value to its stakeholders.

This process was only demonstrated during this thesis and would benefit from additional exploration and experimentation in academia and industry. As this approach gains momentum in the application, creating new material and training for academic use would be necessary. The methods contained would need to deliver to the industry practically and pragmatically to further the adoption.

Today mission engineering only provides the foundational inputs to the enterprise strategy by engineering the missions associated with the customer, competitive, and market insights of today in a somewhat short-term view. Our literature review shows that the mission(s) are sometimes engineered without considering the enterprise strategy. Critical opportunities and relationships are missed.

The framework and structure of mission engineering utilizing the perspective of an industrial ecosystem within the context of the operational ontology in conjunction with our method for operational analysis can provide a more comprehensive assessment identifying the key insights and inputs to the enterprise strategy. Yet, it won’t come for free and require a paradigm shift in *our thinking. Following this framework and structure, it would be necessary for the enterprise to integrate operational analysis outputs as key inputs to mission engineering. This means that our strategy development methods, processes, and tools would need to incorporate the key outputs from mission engineering into the enterprise strategy. Many enterprise customer acquisition processes would need to be updated to utilize the framework and structure outlined in previous sections. This would require the enterprise to thoroughly understand the industrial ecosystem(s), operational ontology, and outputs from operational analysis of the customers, markets, and competition, providing quantitative and qualitative market research to mission engineering. This would provide better missions, mission threads, technology assessment, and inputs to the enterprise strategy.*

Existing literature handbooks, textbooks, and guidelines in all industries and academia need revision or rewrites. Additional chapters or new books are required to incorporate the framework and structure outlined within this thesis. This would take considerable time and effort, not just in further research and development but through piloting as the development progresses to ensure this provides value to the enterprise strategy and, ultimately, stakeholder value added in the form of business results. While the implications are vast, we have by no means captured all of them here; with further research, development, and piloting, we can uncover an even more comprehensive operational ontology and shift our system thinking from products, processes, and services to industrial ecosystems for the development of comprehensive enterprise strategy. I would be remiss if I didn't also mention the power of technology and MBE as a potential method to provide a structure for categorizing elements of mission engineering output as inputs to both the enterprise strategy and mission architecture to promote and manage these digital assets comprehensively; therefore, further research is needed into the current suite of digitalization technology to determine applicability to mission engineering.

6.5 Conclusion

In conclusion, this research demonstrated the potential benefits of enterprise strategy development using system engineering principles and practices to provide key inputs in the form of opportunities to the strategy development team. This research concludes by applying our framework and structure in a systematic methodology, providing an opportunity to develop further and adopt the operational ontology to any industrial ecosystem(s) understanding through operational analysis and mission engineering identifying the key opportunities, inherent relationships, technology, and prioritization of these elements as key inputs to the enterprise strategy.

Through the application of the framework, as applied to the example of sugar cane production, the enterprise can unlock entrepreneurial innovation through the understanding of these opportunities. This will enable aligning their engineered mission through mission themes to the business needs. It could also help align the business strategy to the industrial ecosystem(s) while minimizing the socioeconomic impact and maximizing the sociotechnical integration of key technologies. This would help to facilitate the management of critical ecosystem relationships. It *balances the customer and business needs while adding value to the enterprise to grow and prosper, allowing it to unlock economic headroom through an aligned strategy and, in time, with the additional research into the operational ontology, provide the enterprise with a significantly more comprehensive system portfolio versus a product portfolio and technologies. If one asked me to give them a recipe that all enterprises could use to develop in strategy development, that would be very difficult, but tailoring our structure and framework to your enterprise will provide a more comprehensive set of inputs to your strategy development team. Thus, this structure and framework in the form of the operational ontology will continue to grow in use. This thesis only begins to contribute to the initial literature on the subject and the successful application of the structure and framework of the operational ontology applied to an industrial ecosystem utilizing operational analysis and mission engineering processes to provide a complete understanding of the inputs to an enterprise strategy.*

6.6 Limitations

By their very nature, system development, and strategy development have inherent uncertainty. Enterprises often develop a business strategy around the existing products, processes, and services that their success was built on. Enterprises execute their strategy over time, and often, these strategies fall short from both a customer and business perspective due to the dynamics within the industrial ecosystem(s), technology, customer expectations, social responsibilities, complexity, uncertainty, etc., and this continues to accelerate. The dynamic events of the world result in strategies that fail to account for this uncertainty, impact our business results, and leave our customers demanding our systems to do more.

From an academic and industrial perspective, systems engineering focuses on products, processes, and services in training and education. They assume that if we teach and apply it at this level over time, it will be applied or evolve to other areas of an enterprise.

Systems engineering is an evolving discipline that needs to be developed and nurtured over time to continue evolving into the mainstream, like the natural sciences of chemistry, physics, and biology and disciplines like mechanical, industrial, chemical, and electrical engineering. Literature reviews showed very little application of system thinking to enterprise strategy.

In contrast, this thesis made no assumptions. It was intentional to develop the framework and structure to aid system engineering as a discipline and the enterprise in providing better inputs to the enterprise strategy development team.

The limitations of my research and the scope of a master's thesis focused on a single industrial ecosystem to perform operational analysis and mission engineering within the context of our architectural ontology levels. We have developed four key artifacts within this thesis's context: the structure and framework Figure 72, the architectural ontology Figure 69, the operational analysis process map Figure 70, and the mission engineering process map Figure 71. Thus, further research is needed on the operational ontology and additional pilots in strategy development.

Other limitations were around MBE and its applications to the structure and framework. I would be remiss if I didn't also mention the power of technology and MBE as a potential method to provide a structure for categorizing elements of the operational ontology, industrial ecosystems, operational analysis, and mission engineering output as inputs to both the enterprise strategy and mission architecture to promote and manage these digital assets comprehensively; therefore, further research is needed into the current suite of digitalization technology to determine applicability to contents of this thesis.

This research did not cover teamwork. This would require some organizational structure changes to answer the question of the nature of teamwork in this ontology. How might we conduct research through pilots during the development of this framework and structure to uncover and answer critical questions in team dynamics? Are there opportunities within an enterprise to rethink the current organizational structure for our strategy development teams by integrating system engineers, architects, and project management? These are just a few of the questions that need to be answered as we embark on this new understanding of our operational ontology levels and the relationship management between these levels.

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