Meta Systems Engineering Management Plan for a Digital Startup Manufacturing Facility

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Abstract

To thrive in the marketplace, startups need a clear plan to either develop or acquire and integrate a system of systems or a system of interest that solves client problems and generates market excitement, especially in the automotive and aerospace sectors.

The focus is on grasping key concepts like systems engineering, Systems Engineering Management Plan (SEMP), systems of interest, the Vee model, and various frameworks, and then linking these concepts to uncover commonalities and new insights.

This scholarly activity aimed to synthesize two life cycle models (INCOSE and DOT), one digital transformation framework (Deloitte), and one management plan (DOD) to provide insight into creating a management plan for both classified and commercial products. The insights gained will lay a foundation for future enterprise architecture.

Combining the DOD systems engineering management plan, INCOSE and DOT Vee models, and Deloitte's digital transformation model resulted in a meta-model that highlights the roles of engineers, managers, and entrepreneurs throughout each production stage. This meta-model also encourages startup stakeholders to take on two or more of the outlined roles in the systems plan.

The meta-model offers startups a clear roadmap for confidently developing products and services, even amidst fluctuating economic conditions such as budget, time, and resource constraints. The roadmap is applicable across commercial, private, public, and government sectors, and the meta-model also provides systems engineers with guidance on effectively using modeling tools (MBSE) like SysML, Modelica, and Modelio to demonstrate system requirements.

Keywords

Digital Transformation, Manufacturing Startup, MBSE

1. Scope

This journal article exists to create a step-by-step plan on how entrepreneurs can create viable products for customers based on observed market trends while minimizing risk and uncertainty. This scholarly work benefits the reader because the plan for the business endeavor is broken down into life cycle stages from the systems engineer's perspective. In each life cycle stage, actions to achieve digital transformation prescribed by a successful firm is infused with the aid of system engineering management plans published from renowned organizations in the public, private, commercial and government sector. All this takes place at the concept and planning stage of the project.

This article in greater detail presents a clear framework for digital manufacturing startups, focusing on the integration of Systems Engineering and Digital Transformation tools to boost product design and operational efficiency. Drawing from the Department of Defense's systems engineering plan and life cycle models from the Department of Transportation and INCOSE, it advocates for a combined use of the Vee model and Deloitte's digital transformation approach. The article addresses ethical considerations and industry standards, offering a practical, structured method for startups to navigate digital challenges, foster innovation, and achieve sustainable success. Potential obstacles like software interoperability and resource limitations are acknowledged, it also underscores the importance of continuous improvement.

2. Introduction

Digital startups are newly established companies that use digital technologies to innovate and deliver products or services [1]. These startups can thrive by integrating Systems Engineering tools alongside Digital Transformation to enhance operational and technical processes, enabling effective competition in a dynamic market [2].

In manufacturing startups, Product Design is crucial in the technical process. Selecting the right tools, like Systems Modeling Language (SysML) or Modelica, can streamline workflows and enhance automation across manufacturing systems, offering strategic benefits. However, transitioning design conceptualization to realization poses challenges.

This study proposes a structured implementation approach to ensure the effective adoption of people, plants, property, and equipment within a startup environment, integrating principles of Systems Engineering. By adhering to set life cycle stages, digital manufacturing startups can navigate the complexities of integrating advanced digital tools, driving innovation, enhancing efficiency, and achieving substantial market success.

"Digital transformation" merges "digital"—referring to data creation, storage, and processing through electronic technology—with "transformation," which signifies significant changes in a system's form or function. In organizational terms, digital transformation involves innovating business models, enhancing customer experiences, optimizing processes, adopting new technologies, and meeting social responsibilities [3].

For digital manufacturing startups, embracing digital transformation is crucial to maintaining competitiveness. Integrating technologies like CAD, CAM, CAE, and SysML can profoundly enhance product design process. In Aerospace and Manufacturing industries, establishing connections on systems engineering modeling platform stands out for integrating all software needed in the value creation of a cloud-based environment. This platform supports real-time collaboration and seamless access to simulation and manufacturing requirement and specifications across distributed teams. Choosing such an integrated software solution reduces costs for digital startups by consolidating multiple functionalities into a unified platform.

The process of "digital transformation" typically progresses through several key phases: Planning, Implementation, Growth, Maturity, and Optimization. These stages offer a structured framework for organizations to harness digital technologies effectively, aiming to boost operational efficiency and secure strategic advantages. Each phase builds upon the previous one, guiding organizations through the complexities of digital change.

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2.1 Literature Review

Prior research was examined to discover a comprehensive body of knowledge that can be used to ensure the successful digital transformation of a manufacturing startup. The Systems engineering management plan created by the Department of Defense (DOD) plan was chosen. The chosen life cycle model is the combination of Department of Defense (DOT) & INCOSE Vee model. Finally, Deloitte's framework was used to infuse digital transformation (DT).

The systems engineering management plan is defined as a technical management plan that combines systems engineering effort together [4]. During the research leading to this paper's writing, it was discovered that many organizations have system engineering management plans tailored to their business model. Noteworthy examples of such plans include the Department of Defense (DOD), NASA, and Spirit's system engineering management plan.

The system engineering management plan for the National Aeronautics and Space Administration [5] is first broken down into two stages; they are the formulation stage and implementation stage. The formulation stage consists of Concept studies (pre-phase A), Concept & development (Phase A), preliminary design & technology completion (Phase B). The implementation stage consists of final design & fabrication (Phase C), System Assembly Integration &Test Launch (Phase D), Operation and Sustainment (Phase E) and Close out (Phase F). Furthermore, the formulation and implementation stage are separated by an approval process.

The systems engineering developed and used by the US department of transportation [6]. A systematic method for the creation and administration of transportation systems is described in the Department of Transportation's Systems Engineering Plan (SEP). It places a strong emphasis on the lifespan perspective, making sure that every stage—from creation to disposal—is methodically handled. Stakeholder involvement, requirements specification, risk management, and validation procedures are some of the important components of the strategy. It seeks to guarantee system safety and dependability while lowering expenses and improving project efficiency. To continually enhance system engineering procedures, the SEP also incorporates best practices and lessons discovered.

The Systems Engineering Plan used by the US Department of Defense is divided into six phases: "User Needs, Material, Solution, Analysis," Technology Development, Engineering and Manufacturing Development, Production and Deployment, and Support and Operation (including retirement) [4]. These phases are categorized into three main groups: Pre-Systems Acquisition (Phase A), Systems Acquisition (Phase B), and Sustainment (Phase C). It is important to emphasize that User Needs and technical opportunities must be addressed before Phase A [4].

In systems engineering, there are different life cycle models that can be used to ensure that a project is conceptualized and successfully realized. Examples of such models include the Waterfall model, V-model, and Agile Model. The life cycle model contains about six characteristics; these characteristics are Concept, Development, Production, Utilization, Support and Retirement [4]. Moreover, between these characteristics are decision gates where the current risks are evaluated, accepted, or rejected before progressing to the next stage.

The systems engineering waterfall model is a linear and sequential approach to software development and project management. It consists of distinct phases: requirements analysis, system design, implementation, integration, testing, deployment, and maintenance. Each phase must be completed before moving on to the next, ensuring a structured progression from start to finish. This model is best suited for projects with well-understood requirements and low levels of uncertainty. While it provides clear milestones and documentation, it is often criticized for its inflexibility and difficulty in accommodating changes once the process is underway [7].

The systems engineering agile model integrates the principles of agility into systems engineering to enhance flexibility and responsiveness to change. This model emphasizes iterative development, where small, functional increments are delivered frequently, allowing for continuous feedback and adjustments throughout the project lifecycle. Collaboration between cross-functional teams and stakeholders is crucial, promoting communication and knowledge sharing. Agile systems engineering prioritizes customer satisfaction by adapting to evolving requirements and incorporating their feedback. It also focuses on delivering high-quality systems through regular testing and refinement. This model is effective in managing complex, dynamic projects where traditional approaches may fall short due to their rigidity [8], [9], [10].

In this article the vee model will be our choice model used to establish a system management plan that grants its startup the ability to produce value for its customers while making progress on its digital transformation journey.

The Vee model emphasizes a sequential design process with a distinct focus on verification and validation at each stage. It starts with the definition of requirements and progresses down the left side of the "V" with system design and subsystem design. At the bottom of the "V," the components are developed and integrated. As the process moves up the right side of the "V," verification and validation are performed at each level, ensuring that each component and the overall system meet the initial requirements [11]. The model's structured approach facilitates clear milestones and deliverables, enhancing project management and reducing risks [12].

In the pursuit of wealth creation by a digital startup, a framework is required to ensure that there is consistency and repeatability to developing products and services that meet known and unknown customer needs in core, adjacent and new markets. The framework that was imbibed was Deloitte's framework. This framework was selected because Deloitte is a key player in the transformation for manufacturers and the consolidation of their enterprise resource planning (ERP) systems if desired.

Deloitte’s comprises of three broad phases: getting your focus right, getting the right concept and finally getting the business to scale [13]. For a transformation to be successful; innovation, human centered design, digital technology, overall leadership, and risk management must be interwoven using creativity, strategy, connection, and an adaptable approach [13].

The action steps of the framework put forward by Deloitte are broken down in the Imagine, phase, deliver phase and the run phase.

The imagine phase is focused on drawing inputs from market trends, disruptors, and customer needs. These inputs are processed by aligning a portfolio of ideas and actions to blaze a path to success powered by ambition. This phase has three sub-categories; sense, aspire and decide. Here the opportunities are sensed from economic inputs. In the aspire the data sensed is used to foster initiative and desire, this desire is defined through an ambition statement. The “decide” phase is initiated by presenting future value which would cause the customer to act and build momentum to achieve the defined ambition [13].

The focus of this phase of Deloitte's framework is to feel and acquire a deep understanding of what the customer needs and how they behave to design a solution for them. A prototype or a minimal viable offering of the solution is created through design, testing and learning. This phase has three sub-categories; In the deepen phase a mile is walked in the customers shoes to feel their needs, drivers, concerns and motivations. Next is to weave customer insight, engineering, and business metrics to create a well-rounded concept that can be tested in the marketplace. Finally, the build and/or prove stages are where iterative learning, building and concurrent minimal viable offerings (MVO’s) are taken to the market to reduce innovation risk.

In the final phase of Deloitte’s framework, the success of minimal viable offerings is improved upon to mature the solution, improve its operational pillars to support lasting success. In this phase the successful project is delivered to the customer and scaled through production and delivery teams. Within this phase are three sub-phases; In the launch phase, the MVO is refined with feedback from the marketplace to ensure that the business launches successfully, and outcomes are monitored. In the scale phase, the data created by the new release are collected and interpreted as the solution matures. In the Operate subphase, the product is studied, and its operational features improved to support lasting success.

3. Methodology

The overview of this process involves creating and linking requirements pertaining to the property, equipment, enterprise resource planning systems (ERP) and Material requirement planning systems (MRP) to cater to the demands of the customer. The systems engineering tools that can be used to show case this plan in a model format can be SysML, Modelica, and Modelio.

This endeavor is focused on creating a synthesis of the department of Defense systems engineering management plan, INCOSE Vee model, Department of transportation vee model, Deloitte's framework, and a digital transformation plan. The goal is to identify common trends, similarities and overlaps to create a meta plan. Tools that can be used to model this artifact are SysML, Modelio, or Modelica.

There are no participants in this research article as this paper is an overview of multiple plans synthesized together.

There are no physical materials associated with this research as it is a synthesis of multiple plans, nevertheless the artifact produced can represent both physical and cyber systems.

The procedure for this study involved a systematical synthesis of choice plans and frameworks. Afterwards an idea of a cyber-physical manufacturing plant is passed through the framework to create an overview (model) which integrates trained people, plant, property, equipment, and software (ERP & MRP Systems) to produce a market worthy product that creates value.

The Inputs for the project are gotten from extracting hypothetical qualitative data from the process, plant, property, and equipment that enable the value creation activities at the Gemba of a startup firm.

The focus is on creating a synthesis of multiple life cycle models, management plans and frameworks to create an artifact that eliminates ambiguity, and inaccuracies from an organization specifications and requirements.

To ensure the validity of this systems engineering digital transformation startup research and its successful implementation at the product design level, attention must be paid to certain systems to create the positive emergence to foster the startup's success. The ethical considerations explored include User Centric Design, Ethical AI, and Automation.

In industry today, most of the product development is primarily driven by the need to reduce costs and improve quality [14]. When using systems engineering methodologies to create product design plans for a digital manufacturing startup, the goal must be to provide value that meets and exceeds the needs of the end user by creating solutions that saves the customer time, resources, and energy. All these must be accomplished while remaining profitable with sufficient cashflow. Also, the product must comply with standards set by industry, government, systems, and population influenced by the solution.

In the creation of a digital startup, especially startups that research, design, and manufacture products, it is vital to factor in standards and all professional ethics that regulate business activity. Standards like the AS 9100, ISO 9001 and TS16496 are referenced by the startup firm to plan for quality products.

The main limitation in this paper's research and authorship is that not all factors may be accounted for when the Systems Engineering Management Plan (SEMP) was infused with digital transformation. Nevertheless, the artifact created has a continuous improvement future. In implementation of said plan, factors such as inadequate interoperability of software, inadequate resources and production/utilization philosophies of workers may become obstacles to the system's functionality.

It is vital to highlight that the input (product idea) is subject to change, but the plan created that links plants, equipment, and software is sufficient and open to improvement.

4. Results

Life Cycle Stages	Sytems Engineering Management Plan - DOD	Vee Model - INCOSE	Vee Model - DOT	Digital Transformation Framework - Generic	Digital Transformation Framework - Deloitte
Conceptualization	User Needs	System Development	Feasibility Study	**Planning**	**IMAGINE**
	Technology		Concept Exploration		Sense
	Opportunity		Concept of Operation		Aspire
	Resources		System Requirements		Decide
Development	Technology Development	Upper level system development	High Level Design	**Implementation**	**DELIVER**
	Engineering Development	Lower Level system element development	Detailed Design		Deepen
					Design
					Build/Prove
Production	Production	Upper level system element realization	Software Development	**Growth**	**RUN**
		Lower Level system element realization	Hardware Development		Launch
			Field Installation		Scale
					Operate
Utilization	Deployment	Solution/system realization	Unit/Device Testing	**Mature**	**(Feedback)**
			Subsystem Verification		Operate
			System Verification and Deployment		
			System Validation		
			Operations		
Support	Operation		Maintenance	**Optimize**	**(Upgrades)**
	Support		Changes and Upgrades		(Support)
	Disposal				
Retirement			Retirement/Replacement		**(Retirement)**
					(Salvage)

Figure 1: comparison of DOD systems engineering management plan, DOT & INCOSE life cycle model, Deloitte's framework, and Digital transformation infusion

Sytems Engineering Management Plan - DOD	Framework - Deloitte
Life Cycle Model - Vee Model (DOT & INCOSE)	
Conceptualization	**Imagine | Planning**
Feasibilty study	Sense
Concept of Operations	Aspire
Systems Requirement	Decide
User needs, Technology, Resources	
Development	**Deliver | Implementation**
System Development	Deepen
Upper Level System element development (High-Level Design)	Design
Lower level system element development (Detailed Design)	Build/Prove
Production	**Run | Growth**
Lower level system element realization	Launch
Upper level system element realization	Scale
Solution/system realization	Operate
Unit /Device Testing	
Subsystem Verification & Deployment	
System Validation	
Utilization	**Mature | (Feedback)**
Operations	Operate
Support	**Optimize | (Upgrades)**
Maintenance	(Support)
Changes and Upgrades	
Retirement	**(Retirement)**
Retirement/Replacement	(Salvage)

Figure 2: Compression of DOD systems engineering management plan, DOT & INCOSE life cycle model, Deloitte's framework, and Digital transformation infusion

	MANAGER	ENGINEER	ENTREPRENUER
Concept	*SEMP-DOD*	*LCM - DOT & INCOSE*	*DT - DELOITTE*
	Resources & Needs	Feasibility Study	Sense
	Material, Solution, Analysis	Concept of Operations	Aspire
		Systems Requirement	Decide
Development	*SEMP-DOD*	*LCM - DOT & INCOSE*	*DT - DELOITTE*
	Technology Development	Systems Development	Deepen
		High Level Design	Design
		Detailed Design	Build (MVO)
Production	*SEMP-DOD*	*LCM - DOT & INCOSE*	*DT - DELOITTE*
	Engineering Development	Upper-level realization	Launch
	Manufacturing Development	Lower-level realization	Scale
	Production	Verification	
		Validation	
		Testing	
Utilization	*SEMP-DOD*	*LCM - DOT & INCOSE*	*DT - DELOITTE*
	Deployment	Operations	Operation
Support	*SEMP-DOD*	*LCM - DOT & INCOSE*	*DT - DELOITTE*
	Sustainment	Maintenance	(Support)
		Changes and Upgrades	
Retirement	*SEMP-DOD*	*LCM - DOT & INCOSE*	*DT - DELOITTE*
	Disposal	Retirement	(Salvage)
		Replacement	

Figure 3: Emergence of roles and perspectives from the synthesis model

After the synthesis of the model shown in [Fig.1] the DOD systems engineering management plan, the INCOSE vee model, DOT Vee model and the Deloitte framework; two interesting trends emerge. The first trend is an overlap in the project's Conceptualization, Development, production, and utilization phase across all the first four frameworks. The second involves an overlap in the Support and retirement phases across the first three frameworks.

In the first group in [Fig 1], we see the connection and collection of the Feasibility study, concept of operations, systems, sense, aspire, decide. This group highlights the steps taken to identify the customer's needs, create a high-level solution that aligns with the individual's requirements to produce a plan to capitalize on the opportunity identified, to prompt action. Furthermore, we infuse digital transformation planning at this level.

The Second group as illustrated in [Fig 1] highlights a connection between system development, Upper-level systems element development (High Level Design), Lower-level systems element development (Detailed Design), Deepen, Design, and build stages. The trend shows that after the high-level design has been generated, from there the lower-level design is then created. From Deloitte's perspective we see that the concept is studied further, then a design is created, and a minimal value offering (MVO) is produced to cement the viability of the design in the eyes of the customer. The production of a minimal viable offering can be a working prototype or a digital simulation with real life inputs to prove the economic viability of the deliverable. Also, it is at this level that planning for digital transformation of the product is continued.

The Third group in [Fig 1] shows the connection between the production and run stages. At this stage we see a link between lower-level system element realization, upper-level system element realization, system validation, subsystem verification and deployment, Launch, and scale. During the production phase of the products' life cycle, the digital transformation should be implemented concurrently.

The Fourth group is captured under the utilization as depicted in [Fig.1]. The only trend found here is operation or the operate stage where the system of interest (SoI) is used to create value for the marketplace. Surprisingly, two phases of the digital transformation “Growth” and “Mature” are executed here [Fig.2]. This is so because it is in the utilization of the product and its digital systems that growth and maturity takes place.

At the fifth and sixth group illustrated in [Fig.1] we have support and retirement which have common categories between the DOD systems engineering management plan, INCOSE Vee model, and the DOT vee model. At this stage, it was observed that Deloitte framework has no steps to execute the support and retirement lifecycle stage. To address this knowledge gap, successful entrepreneurs were interviewed to find out what their actions at these stages would be. Their summarized input was that they would support the product by restarting the three phases of the transformation model [Fig. 2]. At the retirement stage, the product can be sold to obtain the salvage value instead of spending monetary resources to dispose of the product [Fig.2].

5. Conclusion

The synthesis model unlocks a new insight. That is the emergence of the engineers, managers and entrepreneurs' perspective captured in [Fig.3] when it comes to planning and executing the life cycle of stages of a manufacturing plant or any product in the commercial, government, private and public sector. For a startup to be successful, these perspectives must continually work together to achieve the sole objective of creating value for the customer at the right time, quality, and price. The processes that can be used to align these perspectives are the consent-based decision process, and the integrative decision process. In the consent-based decision process, a structured approach is followed where decisions are made without objections. This approach focuses on addressing objections so that decisions are deemed good or safe enough to carry out in the real time [18]. The integrative decision-making (IDM) or Holacracy refers to the approach in decision making whereby a person presents a proposal with oversight of a neutral facilitator to address a problem while the rest of the team prescribes improvements upon the presented proposal in the case of objections. The iteration of the proposal leads to the discovery of a better solution that satisfies the organization's needs [19].

6. Discussion

During this academic endeavor, we faced challenges associated with common biases such as framing, representativeness and availability. When judgment and decision-making are influenced by the way information is presented, this is known as framing bias. Even when the results are the same, this bias may cause people to choose differently depending on whether a situation is presented in terms of gains or losses. Experiments conducted by [15] illustrated this effect, revealing that individuals are more likely to take risks when presented in a negative light than when presented in a favorable one. In domains where the way information is presented can have a big impact on behavior, such public policy, marketing, and healthcare, it's important to understand framing bias. For instance, stressing a medical procedure's survival rate as opposed to its death rate may increase acceptability of the therapy.

Representative bias, also known as the representativeness heuristic, is the phenomenon where people assess an event's likelihood not from mathematical probability but rather from how well it fits their preexisting experiences or prejudices. Reasoning mistakes like ignoring base rates or falling for conjunction fallacies can result from this tendency. This was demonstrated in situations where people disregarded statistical data in favor of typical features by [16]. Due to anecdotal parallels, people may overestimate the chance of an event in a variety of disciplines, including finance and legal judgments.

Availability bias is the tendency for people to judge an event's likelihood based more on the ease with which they can recall examples than on the actual frequency of the event. This heuristic causes more remembered or recent events—like spectacular or emotional incidents—to be overestimated in probability. People frequently use this mental shortcut, according to [17], which can distort perceptions and decision-making in contexts such as risk assessment and media consumption. For example, even though plane crashes are uncommon, people may overestimate the risk of flying after learning about one.

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