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A Systems Engineering Approach to A Technology Planning System For Companies Seeking To Operate In Configure-To-Order Markets

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Abstract: Technology Planning is critical for businesses in the Configure-To-Order market that want to establish themselves, gain traction, and thrive in the marketplace. Planning on a generational horizon ensures market satisfaction. The technology planning process must translate the brand strategy into the technology development process. This work explores a previously unrecognized system that ties business strategy to technology development efforts, revealing a missing interface between them. Using a Systems Engineering Framework, a repeatable process from brand strategy through feature development and product deployment is proposed for Configure-to-Order Markets, better meeting customer needs and increasing the technology's value.

Keywords: technology planning; technology roadmapping; technology development; business strategy; configure-to-order; adaptive management; systemic optimization

1. Introduction

Every industry is comprised of the following generalized styles of products that are provided to the market by companies: Engineer-To-Order, Configure-To-Order, and Make-To-Stock [1,2]. Engineer-To-Order (ETO) systems are developed for a customer desiring uncompromised performance to meet their exacting needs. These systems are costly and take considerable time to develop to ensure every need is met and the product can perform under the desired working conditions. Configure-To-Order (CTO) products are developed from a catalog of modules that enable combinations to fit many customers' desired needs. Make-To-Stock (MTS) products are developed from a well-defined set of needs from a large customer pool. The resulting product has no customization options for the customer. As the world is becoming a global marketplace, Engineer-To-Order (ETO) markets are shrinking as these companies see pressure from CTO and MTS markets [3,4]. ETO companies have a vastly different technology planning horizon as compared to CTO and MTS companies. Technology planning and development for ETO companies are driven and paid for by customers during their specific product development activities. For example, if a customer needed a custom heating system for a residential home due to more than average concrete usage within a house, the home designer would only invest resources for the creative solution to achieve appropriate heating profiles after achieving billable hours to research and design the solution. With ETO companies lack of foresight on future technology developments, competitors in CTO and MTS segments making investments in key technologies to achieve performance or scale is drawing away crucial customers seeking reduced financial burden for development efforts. The ETO market customers seek benefits such as reduced system cost and reduced deployment schedule from the CTO marketplace. While the CTO marketplace can provide the desired cost and schedule reductions, the customers must typically accept reduced system performance. To drive the cost and schedule reductions, CTO vendors drive more rigorous technology planning campaigns and create strategic partnerships to provide a broader spectrum of technologies that serve a wider market or markets. This creates a suite of technologies to suit the performance, cost, and schedule of a myriad of

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customers. The nature of large product variability drives the need for extensive investigation in customer needs to draw accurate conclusions of future performance needs. Selective technology development cycles are then focused on future market trends. CTO companies can develop flaws in their product configurations by failing to translate business strategy into technology planning effectively. A systems engineering approach was applied to the Configure-to-Order planning cycle to assess the process that companies execute. The identification of a gap of sufficient processes to translate between Business Strategy and Technology Planning is explored as a source of instability within the overall system.

2. Materials and Methods

2.1. Configure-to-Order Technology Planning Cycle

The value proposition of CTO companies is to capture an ever-growing share of the market by providing the largest set of combinations of technologies or features that bring the greatest value to the customer. To capture this value proposition, CTO companies need an effective process that can link business strategy to the technology planning process. This process would yield sets of technologies or features to augment currently deployed systems in the marketplace. This full process is illustrated in **Figure 1**.

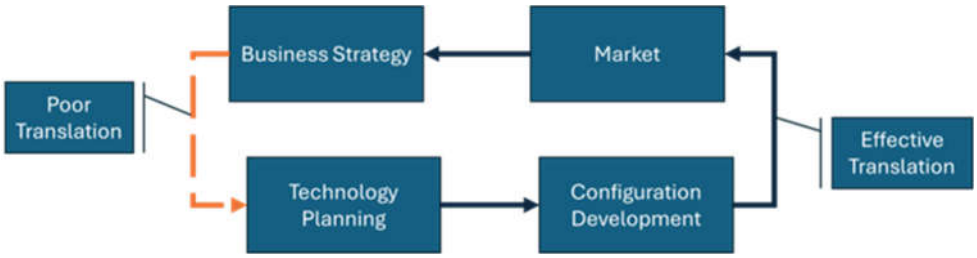

Figure 1. Configure-to-Order Planning Cycle.

Without an effective process for successful generational technology planning and delivery cycles, companies are left to their haphazard methods to perceive business needs and translate those into technologies for deployment into the market. CTO companies often have an ineffective transition of strategic goals of the business to the generational technology development cycle along with a means to validate the business value of the technologies designed in the generational cycles. The needs of the business are blocked at a critical interface where the strategy is translated to the teams who develop the technology or features. This disconnect brings technologies to market with inconsistent customer value, shrinking the precious resources needed for technologies that can add significant customer value. This gap will be explored in order to bridge the business strategy system and the technology development system operating as two discontinuous systems instead of one.

2.2. Business Strategy

The markets served by companies exist along a spectrum from the high-end, custom solutions serving very intricate needs, to one-size fits all solutions [5,6]. The solution space that a manufacturer exists in is based on the products produced for their consumers. As the solution space moves from custom and one-off solutions into more economic production scales, market classes emerge. The market classes represent segmentation with respect to products available in the marketplace and can be referenced back to Jean-Noel Kapferer's work in the management of luxury brands [5]. Segmentation provides the opportunity for companies to distinguish themselves in the methods of product architecture and product management philosophies to meet the needs of varying customer bases searching for varying degrees of cost, availability and system performance. Companies vary parameters of product architecture and management approaches to achieve commercial viability and market share [7].

The Corporate Brand Strategy cements the company's awareness of the needs of the customer that they are trying to attract. For example, the Corporate Brand Strategy for Rolls Royce Motor Cars

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selects a completely different market space than that of the Toyota Motor Corporation. For Rolls Royce, their Values are "Our strive for perfection guides us. Rolls-Royce is an everlasting expression of the exceptional, where everything we do reflects our persistence and commitment towards the remarkable. Uncover what drives us."[8]. While the Toyota Motor Corporation's vision is "Creating mobility for all. In a diverse and uncertain world, Toyota strives to raise the quality and availability of mobility. We wish to create new possibilities for all humankind and support a sustainable relationship with our planet."[9]. These two companies are attacking different market segments based on the values that they seek to bring to their customers. Rolls Royce, targets more affluent clientele by appealing to the unique, remarkable, and unmistakable elegance that their cars produce. Conversely, the Toyota Motor Corporation seeks to provide the availability of the automobile to the masses by producing an affordable quality product and creating sustainable products that minimize their impact on the environment. By identifying the traits that the company would like the customer to relate to the product, the selection of a market segment becomes apparent. With the selection of market segment, it then becomes possible to select the best approach to managing the creating of the products by selecting appropriate product architecture and product management strategies to deliver the values, the customer desires [7,10].With the corporate brand strategy, the company sets high level goals to set the strategic landscape. These goals are often targeting product segments for increases in sales or other top line metrics. Brand strategy fails to capture capabilities as a means to drive the strategic intent of the company. Technology development teams can often be led astray while trying to develop technologies to meet the metrics of a brand strategy.

2.3. Technology Planning

The concept of technology roadmapping began its academic surge in 2004 with the release of an article by Robert Phaal at the University of Cambridge [11,12]. The article by Robert Phall is the foundation with which modern schools of thought in technology roadmapping were developed [11]. Technology Roadmapping has been well documented and is a method to collect potential customer feedback, distill perceived needs, develop sets of products, and deploy the products into the market [12–16]. Technology roadmapping has been enhanced by industry to achieve the combination of strategic direction and technology development to achieve success in the deployment of products into the market [17,18]. A market to technology roadmap process can be viewed in **Figure 2**. The technology roadmap example in **Figure 2** identifies time progressing across the horizontal axis and the decomposition of market events to enabling technologies on the vertical axis. When implementing standard development of a technology roadmap, the decomposition of the ties between market, capabilities, and technologies must be understood [12,19]. Companies must first gather market data to begin the process. The market data represents the opportunity to see trends and assess the future market needs of products and features. With the market well understood, technology teams review the forecasted products and features needed to meet future market release timelines and create measures of effectiveness (MOEs). These MOEs are performance, aesthetic, or other requirements that a product can perform to meet the needs of a customer. The MOEs can then highlight deficiencies in current product offerings, thus providing a heading toward what products would be beneficial to develop and produce. The company must then agree to the desired performance level needed by the products and begin identifying resources needed to complete the respective technology projects.

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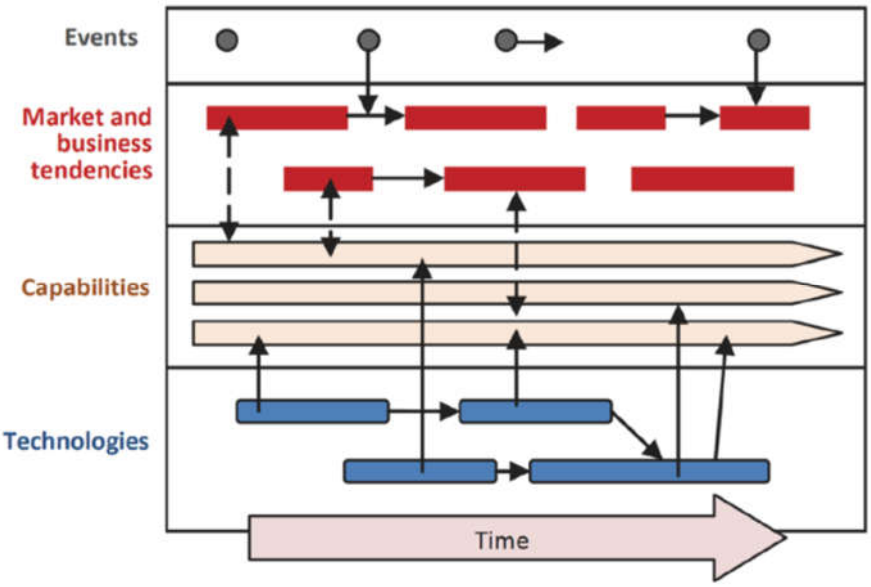

Figure 2. Market to Technology Roadmap [15].

2.4. Configuration Development

From the technologies from distilled from market needs, the technologies can be executed. The technology developments while interacting at the capability level of the technology roadmap, each development is completed as a separate system under development. With each technology to be developed, the resources needed to complete evolutionary and revolutionary jumps can be vastly different. The systems engineering process is heavily leveraged to achieve success when defining the requirements of the technology and capability levels of the technology roadmap.

2.5. Market

Deployment of products into the marketspace is measured principally by its sales to understand if the product has successfully met the needs of the end user. However, technology adoption, absorption, and diffusion are also key metrics in determining where in the sales cycle a product may be for a given market. These metrics also provide context to continued expansion, stagnation, or decline in a given market leading to a more confident investment of resources for emerging markets and less for degrading markets.

The adoption of technology into a market space is the rate at which the technology is being absorbed and accepted by the customers of the market. One of the most famous adoption rate curves can be viewed in **Figure 3**, it most noticeably resembles a bell curve with standard deviations marked out. The book *Crossing The Chasm* by Geoffrey Moore talks through the difficult transition of technology in the adoption process and why so many technologies fail to gain adoption and die in the "chasm" before reaching full market diffusion [21]. The "chasm" is represented by the metaphorical gap as shown in **Figure 3** that exists between the "Early Adopters" and the "Early Majority" phases of the product adoption [21]. This "chasm" exists due to the difficulty of gaining enough traction on a product to transition from the "Early Adopters" to the "Early Majority" phase. Moore goes on in his book to explain the generalized difficulties with engaging the "Early Majority" and the extent necessary to drive adoption throughout all phases of the product adoption timeline.

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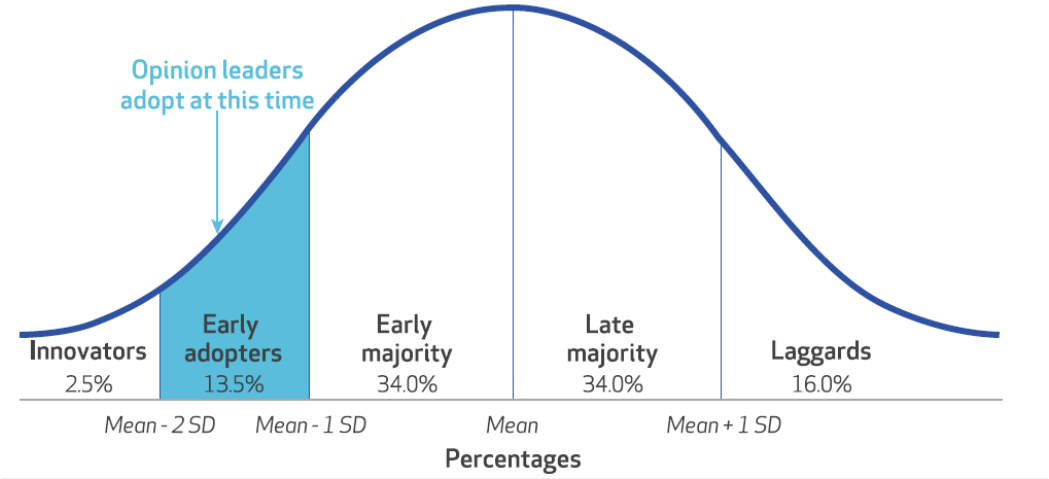

Figure 3. Distribution of adopter innovativeness [22,23].

The technology adoption distribution curve has important connection to the Kano model shown in **Figure 4**. As a technology becomes available as a delight in the Kano model, if the technology does not gain significant acceptance by the market segment to "cross the chasm" the technology could fail to move to the standard technology area of the Kano model. Failure to move to standard technology would signal an unsuccessful crossing of the chasm and the inability of the technology to have gained enough traction in the market segment to drive the continued desire of that technology. These two methods of understanding technology and its reach into the industry is an important basis for the implementation of successful technology roadmapping and development campaigns. The unsuccessful adoption of a roadmapped technology could result with numerous market, profit, and brand effects.

Technology often enters the marketplace in high end products when the barrier to the creation of that technology is less focused on cost and more focused on the improvement of performance of the product. As the technology matures, manufacturing and supply chain processes improve to drive the cost of the technology down, lower tier submarkets can now enable the technology in their products and provide their customers an enhanced experience. The process described is known as technology dissemination or technology diffusion. As the technology enters the lower tier submarkets, the focus of the technology shifts to becoming a cost-effective technology at scale to gain or maintain market share. The Kano Model shown in **Figure 4**, is graphical in nature.

The technology for a particular market segment would be plotted on the graph in relation to customer satisfaction and technology achievement. The Kano Model has three segmented levels that describe the novelty rating of the function or feature, "Delight", "Standard" and "Must Have". When a technology is first introduced into a market segment that a customer did not anticipate or have anticipation of needing, the technology sits in the delight range of the graph. The technology of the delight range provides the customer with a higher intrinsic value for the product that is in use. Within the "standard" range of the Kano Model the technologies of this range have been

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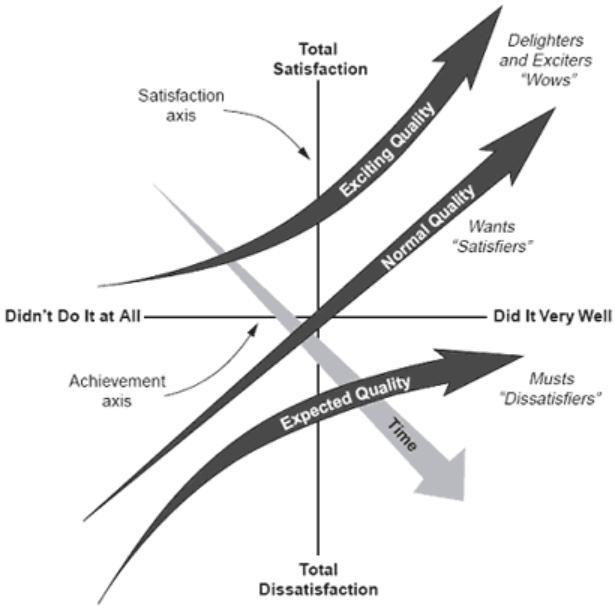

Figure 4. Kano Model [24].

downgraded from a novel technology to something that has become a standard feature in the product sphere. These technologies no longer provide significant increased appeal to the product but still drive customers to desire these increased capabilities for their added comfort. Lastly, in the "must have" range the technology has become so ubiquitous that the technology provides no delight to the customer and is thought to be mandatory to convince a customer to purchase a product.

3. Results

3.1. Technology Planning and Systems Engineering

Technology planning is a process executed by companies of all sizes and in various markets [16,17]. Companies will perform activities as part of their business strategy and technology development process as a means create a holistic technology planning system [14,16,17]. If the CTO planning system was imaged to be a system of systems (**Figure 1**), and the four stages within are systems on their own, the interface between the business strategy stage and the technology planning stage is weak and often ineffective. The CTO planning system has improperly defined translation between business needs as a system output of one stage and as the to the input of the technology planning system stage. The Systems Engineering Framework is used as a guide to manage interface requirements in terms of the required data to pass between these two systems with the CTO planning system. Revising **Figure 1** in a linear graphic instead of a cyclical graphic, presents **Figure 5**, Configure-to-Order Technology Planning System. Also, in **Figure 5**, the gap in the process of translating requirements to the next phase can be seen.

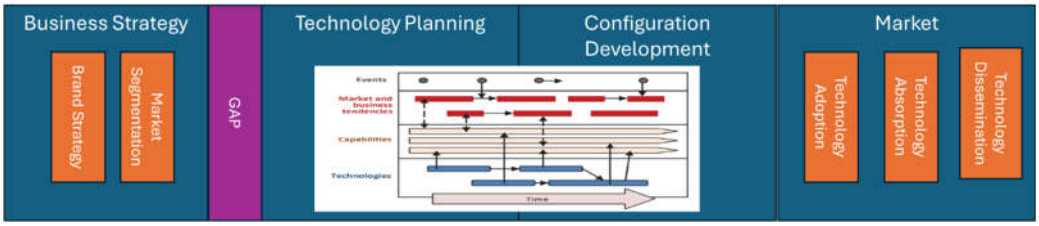

Figure 5. Configure-to-Order (CTO) Technology Planning System.

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3.1.1. Market-Product Architecture

A product architecture is a crucial component in product development [25]. Product architecture creates the framework which characterizes a systems functional attributes based on the components used to complete that function. Integrated architecture styles enable success in ETO products as the system under development can achieve the highest performance capable. Modular architectural styles when used in CTO products can provide benefits such as reduction in product development cost and manufacturing costs, thus reducing development times compared to the ETO counterparts [7,25–28].

Market-Product Architecture (MPA) is a methodology to deliver a consolidated enterprise level product line architecture guidance, reducing unrelated technology development spread to enable higher market effectiveness. MPA first absorbs the information obtained from the business strategy system. The nature of the brand strategy should be consistent from year to year. However, the market segmentation information can change quickly and therefore requires careful consideration on which market segments are the most valuable to the enterprise. The access of this data concludes the inputs needed to complete the market side of the Market-Product Architecture methodology. Next, existing enterprise product data, which is not a part of the business strategy system, it is an output of a previous years product deployment campaign. The product data is then assessed against the enterprise's brand strategy and the market segmentation data to determine the needed architecture of products within a market segment. With the assessment of each product, recommendations can be leveraged to direct the future technology planning system to provide more modular or integrated products. The assessment reveals the need to review technical details for certain products as an input to the technology planning system. This data can reveal projected movements within the market identifying trends that could be counter to the notional direction of the enterprise's technology planning from the previous year. The assessment also reveals that certain technologies, if managed better as enterprise level interchangeable modules, multiple products could integrate the technologies leading to a more optimized deployment of products into multiple adjacent market segments. By providing these crucial details with the technology planning teams, the teams can more quickly narrow in on how to effectively manage technologies to enable more narrow or widespread use across numerous enterprise products. Market-Product Architecture gives enterprises clarity as to what architectures their products are and can pivot to provide greater value to the customer by adjusting the architecture of CTO products.

An example of the Market-Product Architecture methodology is as follows for a power tool company. The power tool company is heavily focused on the battery-operated, sawing market. The company's brand strategy is to have uncompromising quality, boasting that they have the longest lasting tools on the market. The company could perform a market segment study that shows there are 3 main segments within the battery-operated, sawing market: small diameter (< 7 ¼") circular sawing , large diameter (> 7 ¼") circular sawing, reciprocating sawing and shearing. The outcome of the market segments shows that small diameter circular sawing is receding as reciprocating sawing is growing dramatically, large diameter circular sawing is staying constant and shearing is projected to slowly grow over the next year. The outcome of a MPA assessment could yield that in reciprocating sawing, the product is very integrated with only one product and that to capture additional market share, the addition of another product centered around the armature could yield profitable results even with a compressed development cycle. The MPA assessment could also show that the small circular sawing products, which there are currently three options should have the least modular product discontinued to preserve resources.

The MPA methodology short circuits the ability of the technology planning system to gain valuable insights and focus on developing core technologies. By following the Market-Product Architecture process, critical research and go-to-market dollars were saved by not investing in technologies that do not provide additional value to the customer and the enterprise. The Market-Product Architecture process provides a clear and concise interface to translate the desired outputs of the business strategy system to the inputs of the technology planning system.

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3.2. CTO Technology Planning as A Systems Engineering Process

The CTO technology planning system follows the natural flow of the Systems Engineering process and the Systems Engineering Vee Model [29,30]. The process of architecture and conops flows into systems and subsystems trades and decomposition [31,32]. From there detailed design and subsystem test plays an integral role in the physical manifestation of the technology. This leads to system level test and validation are processed before deployment into end user environments. The technology planning system emulates these phases in perfect harmony as the system in operations, in this case, is the technology planning and deployment system. A visualization of the technology planning system can be viewed in **Figure 6** overlayed on a conceptual Systems Engineering Vee Model. The business strategy and Market-Product Architecture play into traditional system architecture and conops. The development of the corporate strategy relates to the conops, and the Market-Product Architecture drives the implementation strategy for how the products will be deployed in the marketplace. The technology planning system and configuration development system encompasses the traditional detailed subsystem design and test phases as physical and soft technologies materialize. The market adoption, absorption, and dissemination system are analogous to the systems test phase as the technology must be fielded to validate its capability.

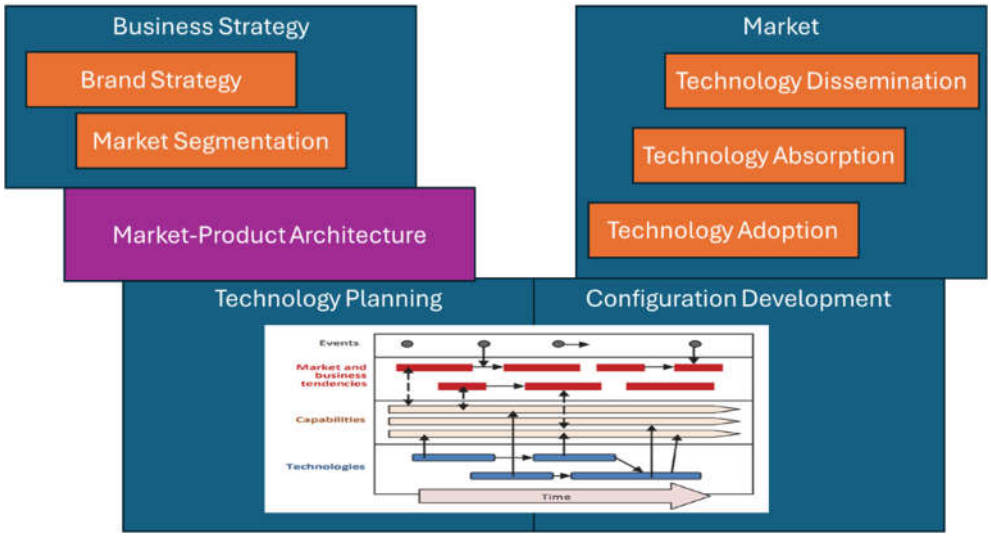

Figure 6. CTO Technology Planning System in Systems Engineering Vee Model Orientation.

The CTO technology planning system is meant to drive generational technology development, coordinated with business decisions. As each CTO technology planning system cycle ends another is ramping up to continue pushing the development of technology further as shown in **Figure 7**. This generational approach also provides the opportunity for companies to reassess their strategic direction. If the strategic direction shifts, the MPA methodology must realign, driving new concepts in the development of technologies for the line of business the company is adjusting to.

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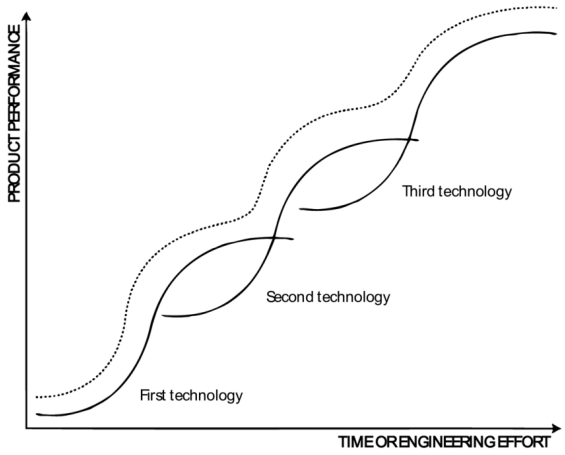

Figure 7. Technology Generational Chart [33].

4. Discussion

The criticality of technology planning is imperative for companies that compete in configure-to-order markets. Technology planning has been identified to assess, develop, and deploy strategic technologies into the marketplace. While many companies perform these activities, the haphazard approach to their completion leaves opportunity for improvement. The improvement this work proposes is the design of a system that better integrates two discontinuous systems into one. The interface defined provides the opportunity for business strategy systems and technology development systems to synthesize and pass information downstream with the ability to validate the results. The use of the Systems Engineering Framework was critical to the identification of the gap that existed in the holistic system. The CTO technology planning system now closes the loop on technology planning, tying technical developments back to business principles to ensure the technology developed fits the company's core market deployment needs.

Future work would be the continued definition Market-Product Architecture and its integration into CTO technology planning system. Extensions of this work could be to investigate how the CTO technology planning system could explore how to integrate better product line thinking into MPA activities. Another possible extension could be to add an automated assessment to MPA to generate product permutations that meet market segment needs that could be profitably produced with little investment.

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